



DEVELOPMENT OF A RELATIVE POTENCY FACTOR (RPF) APPROACH FOR POLYCYCLIC AROMATIC HYDROCARBON (PAH) MIXTURES

**In Support of Summary Information on the
Integrated Risk Information System (IRIS)**

February 2010

NOTICE

This document is an **External Review draft**. This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by EPA. It does not represent and should not be construed to represent any Agency determination or policy. It is being circulated for review of its technical accuracy and science policy implications.

U.S. Environmental Protection Agency
Washington, DC

DISCLAIMER

This document is a preliminary draft for review purposes only. This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by EPA. It does not represent and should not be construed to represent any Agency determination or policy. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency's (U.S. EPA's) Integrated Risk Information System (IRIS) Program is releasing for scientific review a relative potency factor (RPF) approach for polycyclic aromatic hydrocarbon (PAH) mixtures as one approach for assessing cancer risk from exposure to PAH mixtures. The RPF analysis under review is not a reassessment of individual PAH carcinogenicity, but rather provides a cancer risk estimate for PAH mixtures by summing doses of component PAHs after scaling the doses (with RPFs) relative to the potency of an index PAH (i.e., benzo[a]pyrene). The cancer risk is then estimated using the dose-response curve for the index PAH. RPFs for seven individual PAHs were developed in the U.S. EPA (1993) *Provisional Guidance for Quantitative Risk Assessment of PAHs (Provisional Guidance)* and are utilized extensively within U.S. EPA program offices and other regulatory agencies. The RPF analysis provided in the current report includes more recent data and an analysis of both tumorigenicity and genotoxicity data for PAHs.

The Supplemental Guidance for Conducting Health Risk Assessment of Chemical Mixtures (U.S. EPA, 2000) indicates that approaches based on whole mixtures are preferred to component approaches, such as the RPF approach. Risk assessment approaches based on toxicity evaluations of whole mixtures inherently address specific interactions among PAHs and account for the toxicity of unidentified components of PAH mixtures. They also do not require assumptions regarding the toxicity of individual components (e.g., dose additivity or response additivity). While whole mixture assessment is preferred, there are challenges associated with using these approaches. There are very few toxicity data available for whole PAH mixtures and, in most cases, chemical analyses of the composition of mixtures are limited. In addition, PAH-containing mixtures tend to be very complex; the composition of these mixtures appears to vary across sources releasing these mixtures to the environment and in various environmental media in which they occur. For these reasons, a whole mixtures approach may not always be practicable for risk assessment purposes. This report provides recommendations for development of the RPF approach for PAH mixtures health risk assessment and includes:

- (1) A rationale for recommending an RPF approach (Chapter 2);
- (2) A summary of previous approaches for developing the RPF approach for PAHs (Chapter 3);
- (3) An evaluation of the carcinogenicity of individual PAHs (Chapter 4);
- (4) Methods for dose-response assessment and individual study RPF calculation (Chapter 5);
- (5) Selection of PAHs for inclusion in the RPF approach (Chapter 6);

- (6) Derivation of RPFs for selected PAHs (Chapter 7); and
- (7) Characterization of strengths, weaknesses, and uncertainties associated with the RPF approach to PAH cancer risk assessment (Chapter 8).

The RPF approach involves two key assumptions related to the application of a dose-additivity model: (1) a similar toxicological action of PAH components in the mixture; and (2) interactions among PAH mixture components do not occur at low levels of exposure typically encountered in the environment. Mechanistic studies indicate that the mutagenic and tumor-initiating activity of carcinogenic PAHs requires metabolic activation to reactive intermediates (e.g., dihydrodiol epoxides, quinones, radical cations), which covalently modify deoxyribonucleic acid (DNA) targets resulting in mutation, and that tumor promotion and progression phases may involve parent compound binding to the Ah receptor (AhR) and subsequent alterations of gene expression or a cell proliferation response to metabolite cytotoxicity (see Section 2.4, Similarities in Mode of Carcinogenic Action for PAHs, and Figure 2-3, Overview of the proposed key events in the mode of action for PAH carcinogenicity). As such, there is evidence that an assumption of a similar toxicological action is reasonable; however, the carcinogenic process for individual PAHs is likely related to some unique combination of multiple molecular events resulting from the formation of several reactive species. The second assumption of no interactions at low levels of exposure is also reasonable, but cannot be conclusively demonstrated in experimental systems (see Section 2.8, Dose Additivity of PAHs in Combined Exposures). Use of the RPF approach assumes that doses of component chemicals that act in a similar manner can be added together, after scaling the potencies relative to the index chemical. The assumptions of toxicological similarity and no interaction effects at low environmental exposure levels that are inherent in the dose-additivity model are generally supported by the experimental data for PAHs (see Sections 2.4 and 2.7).

Several approaches have been used previously for the determination of RPFs for PAHs (see Chapter 3). In the published literature, RPF values were proposed in at least one analysis for a total of 27 PAHs (see Table 3-1). Because these approaches generally relied on similar bioassay data and modeling methods, the resulting RPF values are considered comparable for most PAHs across analyses.

There is a large PAH database on carcinogenicity in animal bioassays, genotoxicity in various test systems, and bioactivation to tumorigenic and/or genotoxic metabolic intermediates. The RPF analysis presented here includes only unsubstituted PAHs with three or more fused aromatic rings containing only carbon and hydrogen atoms, because these are the most widely studied members of the PAH chemical class. The study types that were considered most useful for RPF derivation were rodent carcinogenicity bioassays (all routes) in which one or more PAH was tested at the same time as benzo[a]pyrene. In addition, in vivo and in vitro data for cancer-related endpoints in which one or more PAH and benzo[a]pyrene was tested simultaneously were

obtained, including studies on the formation of DNA adducts, mutagenicity, chromosomal aberrations, sister chromatid exchange frequency, aneuploidy, DNA damage/repair/recombination, unscheduled DNA synthesis, and cell transformation. Although it would be possible to calculate RPFs from studies where a PAH and benzo[a]pyrene were tested by the same laboratory using the same test system but at different times, this approach was not considered because it could introduce differences in the dose-response information that are unrelated to the chemical (e.g., variability associated with laboratory environment conditions, animal handling, food supply, etc.). Thus, studies in which benzo[a]pyrene was not tested simultaneously with another PAH were not considered in the RPF calculations.

Studies of AhR binding/activation were not considered for use in deriving RPFs because there does not appear to be a clear relationship between affinity for the AhR and carcinogenic potency. For example, highly mutagenic fjord-region PAHs are potent carcinogens despite exhibiting lower AhR affinity (reviewed by Bostrom et al., 2002). Likewise, some PAHs that strongly activate the AhR, such as benzo[k]fluoranthene (Machala et al., 2001), are only weakly carcinogenic. In addition, some studies have demonstrated the formation of DNA adducts in the liver of AhR knock-out mice following intraperitoneal or oral exposure to benzo[a]pyrene (Sagredo et al., 2006; Uno et al., 2006; Kondraganti et al., 2003), indicating that Ah responsiveness is not strictly required for metabolic activation and genotoxicity. These findings suggest that there may be alternative (i.e., non-AhR-mediated) mechanisms of benzo[a]pyrene activation in the mouse liver, and that AhR affinity would not be a good predictor of carcinogenic potency. Also, several studies indicate that AhR-mediated CYP1A1 induction potency does not correlate well with carcinogenic potency. These studies compared CYP1A1 induction potency for several PAHs using assays to measure ethoxyresorufin O-deethylase (EROD) activity, CYP1A1 protein, and messenger ribonucleic acid (mRNA) levels, or chemical-activated luciferase reporter gene expression (Bosveld et al., 2002; Machala et al., 2001; Bols et al., 1999; Till et al., 1999; Willett et al., 1997).

Several study types were excluded from the database because they did not provide carcinogenicity or cancer-related endpoint information for individual PAHs. These include biomarker studies measuring DNA adducts in humans, studies of PAH metabolism, and studies of PAH mixtures. Although these studies contain important information on human exposure to PAH mixtures and the mode of action for PAH toxicity, they generally do not contain dose-response information that would be useful for calculation of RPF estimates.

A database of primary literature relevant to the RPF approach for PAHs was developed by performing a comprehensive review of the scientific literature dating from the 1950s through 2009 on the carcinogenicity and genotoxicity of PAHs. The search identified over 900 individual publications for a target list of 74 PAHs (see Table 2-1) that have been identified in environmental media or for which toxicological data are available. Review of these publications

resulted in the identification of more than 600 papers that included carcinogenicity or cancer-related endpoint data on at least one PAH and benzo[a]pyrene tested at the same time.

References in the PAH database were sorted into the following major categories: cancer bioassays, in vivo studies of cancer-related endpoints, and in vitro studies of cancer-related endpoints. These categories were further sorted by route (for bioassays) or by endpoint (for cancer-related endpoints). Each study was reviewed, and critical study details were extracted into tables for each individual endpoint (see Chapter 4). The tables also include an initial determination of whether the data from each study meet selection criteria for use in the RPF analysis. Studies with data on selected PAHs and benzo[a]pyrene were considered for RPF determination, even if a particular PAH has not been classified by U.S. EPA or International Agency for Research on Cancer (IARC) as a carcinogen. Studies were included in the analysis if the following selection criteria were met:

- Benzo[a]pyrene was tested simultaneously with another PAH;
- A statistically increased incidence of tumors was observed with benzo[a]pyrene administration, compared with control incidence;
- Benzo[a]pyrene produced a statistically significant change in a cancer-related endpoint finding;
- Quantitative results were presented;
- The carcinogenic response observed in either the benzo[a]pyrene- or other PAH-treated animals at the lowest dose level was not saturated (i.e., tumor incidence at the lowest dose was <90%), with the exception of tumor multiplicity findings; and
- There were no study quality concerns or potential confounding factors that precluded use (e.g., no concurrent control, different vehicles, strains, etc. were used for the tested PAH and benzo[a]pyrene; use of cocarcinogenic vehicle; PAHs of questionable purity; unexplained mortality in treated or control animals).

If the above criteria were met, studies were selected for use in the analysis regardless of whether positive or nonpositive results were reported. Studies with positive findings were used for calculation of RPFs. Studies with nonpositive findings were used in a weight of evidence evaluation to select PAHs for inclusion in the RPF approach (see Section 6.1).

Dose-response data were extracted from studies with positive findings that met selection criteria. For studies that reported results graphically, individual data points were extracted using digitizing software. In all, over 300 data sets were extracted, reflecting dose-response data from at least one study for 51 of the 74 PAHs included in the analysis. All of the extracted data are presented in Appendix C of this report.

While tumor multiplicity data from tumor bioassays are not generally used to estimate *cancer potency*, these data were included in the dose-response assessment in order to determine whether they could serve as a reliable measure of *relative cancer potency*. Several bioassays reported data on both tumor incidence and tumor number, providing information that was later used to compare relative potencies estimated from these two endpoints. Statistical analyses were performed on tumor bioassay data to determine whether the tumor incidence or multiplicity observed at a particular dose represented a statistically significant increase over controls. If statistical analyses were not described in the original report, incidence data were analyzed using Fisher's exact test and the Cochran-Armitage trend test. Positive findings were indicated by a significant ($p < 0.05$) difference for at least one dose group by comparison to control (in Fisher's exact or an equivalent test) or a significant dose-response trend (Cochran-Armitage or equivalent) for multidose studies. For tumor bioassay data reported as tumor count, a t-test was conducted (when variance data were available) to determine whether the count was significantly different from control ($p < 0.05$). The results of the statistical analyses are shown with the dose-response data in Appendix C. Statistical analyses of the cancer-related endpoint data were not conducted; the study author's conclusions as to response (positive or nonpositive) was used.

Chapter 5 describes the methods used for both the dose-response assessment and the RPF calculation in detail. The general equation for estimating an RPF was the ratio of the slope of the dose-response curve for the subject PAH to the slope of the dose-response curve for benzo[a]pyrene. For bioassay data, tumor incidences were modeled using the multistage model within the U.S. EPA Benchmark Dose (BMD) Software (Version 1.3.2). For cancer-related endpoint data in quantal form, this model was also used; for continuous data (either tumor multiplicity or cancer-related endpoint data), the simplest continuous model (linear) within the software was applied. Whenever the data allowed, benchmark response (BMR) values of 10% for quantal data and 1 standard deviation (SD) from the control value for continuous data were used to calculate the slope by linear extrapolation to the origin for consistency across data sets. Alternative BMR values were used in select instances, as described in Section 5.3. For data sets that included only a single dose, or those for which no model fit was achieved with the selected models, a point estimate RPF¹ was calculated. As Table G-2 indicates, final RPFs for five compounds (benz[a]anthracene, benz[b,c]aceanthrylene, benz[j]aceanthrylene, dibenzo[a,h]pyrene, and naphtho[2,3-e]pyrene) are based exclusively on point estimates; the remaining 19 PAHs had at least one dataset that could be modeled (see Appendix G).

The RPFs calculated from individual studies for each PAH were used in a weight of evidence evaluation to select PAHs for inclusion in the RPF approach (see Chapter 6) and in the derivation of a final RPF for each compound (Chapter 7). The selection of PAHs to be included

¹For the purpose of this report, the term "point estimate RPF" is used to describe an RPF calculated from a single point on the dose-response curve for both the PAH of interest and benzo[a]pyrene. This term distinguishes the RPF from one calculated using a BMD modeling result from multidose data.

in the RPF approach began with an evaluation of whether the available data were adequate to assess the carcinogenicity of each compound. At least one RPF value was calculated for each of 51 PAHs. For 16 of these compounds, only a single RPF value derived from an in vitro cancer-related endpoint (primarily mutagenicity assays) was available (see Table 6-1). Due to the limited data available for these 16 compounds, no further evaluation of these PAHs was conducted, and they were not selected for inclusion in the RPF approach.

For the remaining 35 PAHs, a weight of evidence evaluation (see Figure 6-1) was conducted to assess the evidence that each PAH could induce a carcinogenic response. For the purposes of this analysis, PAHs were assumed to be carcinogenic due to toxicological similarity to the indicator compound, benzo[a]pyrene. The weight of evidence approach was developed to determine whether the available information for each PAH was adequate for inclusion in the RPF approach. If the data were not considered adequate, then the PAH was excluded. In vivo tumor bioassays that included benzo[a]pyrene were given the greatest weight in assessing the carcinogenicity of a given PAH; data from other bioassays and cancer-related endpoint studies were used to supplement the weight of evidence when the bioassay data that included benzo[a]pyrene were conflicting or nonpositive. Structural alerts for PAH carcinogenicity or mutagenicity (as defined in Section 2.5 as the presence of a classic bay or fjord region in a PAH containing at least four benzene rings) were noted in the evaluation for each PAH, but were not used explicitly in the weight of evidence evaluation.

The weight of evidence evaluation (Chapter 6) indicated that the available data were adequate to determine that 24 of the 35 PAHs were carcinogenic, that 3 PAHs (anthracene, phenanthrene, and pyrene) were not carcinogenic, and that data were inadequate to evaluate the carcinogenicity for 8 PAHs. The eight PAHs with inadequate data were excluded from the RPF approach. For the three PAHs for which there were sufficient data to conclude that they were not carcinogenic (i.e., robust nonpositive tumor bioassay data and cancer-related endpoint data), a final RPF of zero was recommended. While there is little quantitative difference between selecting a final RPF of zero for a given PAH and excluding that PAH from the RPF approach, this is an important distinction for uncertainty analysis. There is substantial uncertainty in the risk associated with PAHs that are excluded from the RPF approach due to inadequate data; these compounds could be of low or high potency. However, for PAHs with an RPF of zero, there is evidence to suggest that these compounds are not carcinogenic, and the uncertainty associated with the cancer risk for these compounds is markedly reduced.

For each of the remaining 24 compounds, a final nonzero RPF was derived. A number of options were considered for deriving an RPF from among the numerous values calculated for each individual PAH. These options included: prioritizing bioassay RPFs from different exposure routes based on environmentally relevant routes; prioritizing bioassay RPFs based on target organs considered relevant to human susceptibility to PAH carcinogenesis; prioritizing RPFs based on quality of the underlying study; prioritizing cancer-related endpoints by their

correlation with bioassay potency (i.e., ability to predict bioassay potency); and aggregating RPFs across all bioassays, across all cancer-related endpoints, or across all endpoints. In the end, it was concluded that the available data did not provide a clear scientific basis for prioritizing RPFs except for a preference for bioassay data over cancer-related endpoints. As a consequence, final RPFs were derived from bioassay data for any PAH that had at least one RPF based on a bioassay.

For each carcinogenic PAH with bioassay data, the average RPF was calculated from bioassays with positive results. For those PAHs that did not have an estimated RPF based on a bioassay, but for which the weight of evidence evaluation indicated a carcinogenic response (e.g., dibenz[a,c]anthracene), the final RPF was calculated from all cancer-related endpoint studies with positive results. In both cases, nonpositive results were not included in the calculation. The final RPF for each PAH was reported to one significant figure. The range of RPF values was also reported. Presenting the RPFs in this manner provides an average and maximum estimate for each PAH that has data from multiple studies.

Several options were considered for the determination of final RPFs (e.g., arithmetic mean, geometric mean, weighted average, maximum, or order of magnitude estimates). The arithmetic mean and range were chosen as a simple approach to describing the calculated RPF values available for each PAH. Other estimates were not considered appropriate due to the limited number of RPF values calculated for most PAHs and the variability in the RPF estimates. Most PAHs (18/24, 73%) had ≤ 3 calculated RPF values and the range of RPF values was greater than an order of magnitude for several compounds (7/24 PAHs). The variability in RPF estimates is likely due to differences in study design parameters (e.g., route, species/strain, exposure duration, exposure during sensitive time periods, initiation versus promotion and complete carcinogenesis protocols, tumor incidence versus multiplicity reporting) and dose-response methods (modeled versus point estimates). Calculation of a weighted average was not possible because there is no clear scientific rationale for choosing among study types or tumor data outcomes. Providing order of magnitude estimates, as has been previously done for estimating RPFs for PAHs, was not considered to be superior to calculating simple means. Including the range in the estimated RPFs was considered to be informative to the user for characterizing uncertainty.

Once a final RPF was derived for a given PAH, the resulting value was assigned a relative confidence rating of *high*, *medium*, or *low confidence*. The relative confidence rating characterized the nature of the database upon which the final RPF was based. Confidence rankings were based on the robustness of the database. For final RPFs based on tumor bioassay data, confidence ratings considered both the available tumor bioassays and the availability of supporting data for cancer-related endpoints. The most important factors that were considered included the availability of in vivo data and whether multiple exposure routes were represented. Other database characteristics that were considered included the availability of more than one in

vivo study, and whether effects were evident in more than one sex or species. *Very low relative confidence* was reserved for final RPFs based on cancer-related endpoint data only (e.g., dibenz[a,c]anthracene). An RPF of zero was only applied if the data implied *high* or *medium relative confidence*.

Table 1 shows the average RPFs based on tumor bioassay data with their associated range and relative confidence ratings, and an overview of the tumor bioassay database (total number of studies, exposure routes tested, species tested, and sexes tested) for each PAH. Table 2 shows the average RPF for dibenz[a,c]anthracene, the only RPF based on cancer-related endpoint data, with its associated range, relative confidence rating, and an overview of the database for this compound.

Table 1. PAHs with final RPFs based on tumor bioassay data

PAH	Average RPF	Range of RPFs	Relative confidence	Number of datasets	Exposure routes tested	Species tested	Sexes tested
Anthanthrene	0.4	0.2–0.5	Medium	2	Dermal, lung implantation	Mouse, rat	Female
Anthracene	0	0	Medium ^a	1 (nonpositive)	Dermal	Mouse	Female
Benz[a]anthracene	0.2	0.02–0.4	Medium	3	Dermal, intraperitoneal	Mouse	Female, male
Benz[b,c]aceanthrylene, 11H-	0.05	0.05	Low	1	Dermal	Mouse	Female
Benzo[b]fluoranthene	0.8	0.1–2	High	5	Dermal, intraperitoneal, lung implantation	Mouse, rat	Female, male
Benzo[c]fluorene	20	1–50	Medium	2	Oral, intraperitoneal	Mouse	Female
Benz[e]aceanthrylene	0.8	0.6–0.9	Low	2	Dermal	Mouse	Female, male
Benzo[g,h,i]perylene	0.009	0.009	Low	1	Lung implantation	Rat	Female
Benz[j]aceanthrylene	60	60	Low	1	Intraperitoneal	Mouse	Male
Benzo[j]fluoranthene	0.3	0.01–1	High	5	Dermal, intraperitoneal, lung implantation	Mouse, rat	Female, male
Benzo[k]fluoranthene	0.03	0.03–0.03	Medium	2	Dermal, lung implantation	Mouse, rat	Female
Benz[l]aceanthrylene	5	4–7	Low	2	Dermal	Mouse	Female, male
Chrysene	0.1	0.04–0.2	High	7	Dermal, intraperitoneal, lung implantation	Mouse, rat	Female, male
Cyclopenta[c,d]pyrene	0.4	0.07–1	Medium	5	Dermal, intraperitoneal	Mouse	Female, male
Cyclopenta[d,e,f]chrysene, 4H-	0.3	0.2–0.5	Low	2	Dermal	Mouse	Female
Dibenzo[a,e]fluoranthene	0.9	0.7–1	Low	2	Dermal	Mouse	Female
Dibenzo[a,e]pyrene	0.4	0.3–0.4	Low	2	Dermal	Mouse	Female
Dibenz[a,h]anthracene	10	1–40	High	3	Dermal, intraperitoneal, lung implantation	Mouse, rat	Female, male
Dibenzo[a,h]pyrene	0.9	0.9	Low	1	Dermal	Mouse	Female
Dibenzo[a,i]pyrene	0.6	0.5–0.7	Low	2	Dermal	Mouse	Female
Dibenzo[a,l]pyrene	30	10–40	Medium	3	Dermal, intraperitoneal	Mouse	Female, male
Fluoranthene	0.08	0.009–0.2	Low	5	Intraperitoneal	Mouse	Female, male
Indeno[1,2,3-c,d]pyrene	0.07	0.07	Low	1	Lung implantation	Rat	Female
Naphtho[2,3-e]pyrene	0.3	0.3	Low	1	Dermal	Mouse	Female
Phenanthrene	0	0	High	3 (nonpositive)	Dermal, intraperitoneal, lung implantation	Mouse, rat	Female, male
Pyrene	0	0	Medium	7 (nonpositive)	Dermal, intraperitoneal	Mouse	Female, male

^aReflects availability of data from anthracene exposure via another exposure route in a study that did not include benzo[a]pyrene.

Table 2. PAHs with final RPFs based on cancer-related endpoint data (no tumor bioassay data available)

PAH	Average RPF	Range of RPFs	Relative confidence	Types of studies	Multiple dose studies
Dibenz[a,c]anthracene	4	0.04–50	Very low	Total = 14 studies One in vivo DNA adduct Six in vitro bacterial mutagenicity One in vitro mammalian mutagenicity One in vitro morphological/malignant transformation Three in vitro DNA damage Two in vitro DNA adducts	Total = 6 studies Four in vitro bacterial mutagenicity One in vitro DNA damage One in vitro DNA adduct

The cancer risk for a PAH mixture of concern is determined by multiplying the benzo[a]pyrene equivalent dose or concentration by the benzo[a]pyrene cancer toxicity value (e.g., oral slope factor). Benzo[a]pyrene equivalents are calculated by multiplying the concentration (or dose) of a particular PAH component in the mixture by its RPF. The proposed RPF approach considers each of the bioassay types used for RPF derivation to be equivalent for the purpose of determining relative potency to benzo[a]pyrene.

According to the *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens* (U.S. EPA, 2005b), benzo[a]pyrene is carcinogenic by a mutagenic mode of action. A common mutagenic mode of action for other carcinogenic PAHs is hypothesized based on information available for the indicator chemical, benzo[a]pyrene (U.S. EPA, 2005b). When assessing PAH cancer risks for lifestages under 16 years of age, or for lifetime exposures that include early-life exposures, the RPF values should be applied with specific exposure information to the benzo[a]pyrene cancer risk estimates including adjustment for early-life susceptibility, through the application of age-dependent adjustment factors (ADAFs).

A description of uncertainties and limitations is crucial to interpretation of the RPF approach for PAH mixtures risk assessment (see Chapter 8). Many of the general uncertainties related to chemical-specific risk assessment are also applicable to the proposed RPF approach for PAHs (e.g., appropriateness of animal models, low-dose and interspecies extrapolation, variability within the human population). Use of a component-based approach for mixtures risk assessment leads to additional uncertainties related to adequate characterization of the mixture and the potential interactions that may occur between individual components within the mixture (i.e., PAHs and other chemicals). The RPF approach is limited by the small number of PAHs for which there are analytical chemistry and toxicology data, and thus may result in underestimation of actual cancer risks from complex PAH mixtures. There are uncertainties and limitations related to the size and nature of the PAH database, the human relevance of animal data,

assumptions regarding mode of action and dose additivity, and cross-route extrapolation. Specific uncertainties that are related to dose-response assessment (i.e., calculation of RPFs) and the selection of single RPF values for each PAH are also discussed in Chapter 8.

In summary, the current analysis represents a significant improvement upon the previous component-based approaches for PAH mixtures risk assessment. One of the most important improvements is the consideration of data from a comprehensive review of the scientific literature dating from the 1950s through 2008 on the carcinogenicity and genotoxicity of PAHs. The search identified over 900 individual publications for a target list of 74 PAHs that have been identified in environmental media and for which toxicological data are available. Review of these publications resulted in the identification of more than 600 papers that included carcinogenicity or cancer-related endpoint data on at least one PAH and benzo[a]pyrene tested at the same time. Dose-response data were extracted, and RPFs from individual studies were calculated from over 300 data sets representing 51 individual PAHs. For 35 compounds, a weight of evidence evaluation was conducted to select PAHs for inclusion in the RPF approach; data were inadequate to conduct such an evaluation for the remaining 16 compounds. A final RPF was derived for each PAH based on tumor bioassay data (if available) or cancer-related endpoint data (if no tumor bioassay RPFs were available). Final RPFs were derived for 27 PAHs, significantly increasing the number of PAHs that can be addressed through this approach. Each RPF was assigned a relative confidence rating reflecting the nature of the tumor bioassay or cancer-related endpoint database that was used to derive the final RPF for that PAH.

CONTENTS

LIST OF TABLES	xvii
LIST OF FIGURES.....	xxi
LIST OF ABBREVIATIONS AND ACRONYMS.....	xxiv
AUTHORS, CONTRIBUTORS, AND REVIEWERS.....	xxvi
1. BACKGROUND FOR THE DEVELOPMENT OF RELATIVE POTENCY FACTOR APPROACH FOR PAH MIXTURES HEALTH ASSESSMENT	1
2. RATIONALE FOR RECOMMENDING AN RPF APPROACH	2
2.1. PAHs AS A CHEMICAL CLASS	4
2.2. THE TOXICOLOGICAL DATABASE FOR PAHs	20
2.3. BENZO[A]PYRENE AS AN INDEX CHEMICAL	21
2.4. SIMILARITIES IN MODE OF CARCINOGENIC ACTION FOR PAHs	23
2.5. STRUCTURAL ALERTS FOR PAH CARCINOGENESIS.....	34
2.6. SIMILARITIES IN RELATIVE POTENCY ACROSS ENDPOINTS	35
2.7. SIMILARITIES IN RELATIVE POTENCY ESTIMATES ACROSS SPECIES AND EXPOSURE ROUTES	37
2.8. DOSE ADDITIVITY OF PAHs IN COMBINED EXPOSURES	38
3. DISCUSSION OF PREVIOUSLY PUBLISHED RPF APPROACHES	44
3.1. PREVIOUS EFFORTS TO VALIDATE THE RPF APPROACH.....	52
4. EVALUATION OF THE CARCINOGENICITY OF INDIVIDUAL PAHs.....	55
4.1. DATABASE OF STUDIES ON PAH CARCINOGENICITY AND CANCER- RELATED ENDPOINTS.....	55
4.2. STUDIES IN HUMANS	57
4.3. STUDIES IN ANIMALS	57
4.3.1. In Vivo Cancer Bioassays in Animals	86
4.3.1.1. Dermal Exposure	86
4.3.1.2. Intraperitoneal Exposure.....	89
4.3.1.3. Subcutaneous Injection Exposure.....	90
4.3.1.4. Oral Exposure	91
4.3.1.5. Other Routes	92
4.3.2. In Vivo Studies of Cancer-Related Endpoints.....	93
4.3.2.1. DNA Adducts.....	93
4.3.2.2. Clastogenicity or Sister Chromatid Exchange Frequency	95
4.3.2.3. In Vivo Mutagenicity	96
4.3.3. In Vitro Studies of Cancer-Related Endpoints.....	97
4.3.3.1. Bacterial Mutagenicity.....	97
4.3.3.2. Mammalian Mutagenicity.....	98
4.3.3.3. Morphological/Malignant Cell Transformation.....	99
4.3.3.4. DNA Adducts.....	100
4.3.3.5. DNA Damage/Repair.....	101
4.3.3.6. Clastogenicity or Sister Chromatid Exchange Frequency	102
4.4. SUMMARY OF INFORMATION AVAILABLE TO DEVELOP RPFs FOR INDIVIDUAL PAHs.....	103

5. METHODS FOR DOSE-RESPONSE ASSESSMENT AND RPF CALCULATION	104
5.1. CHOICE OF DOSE-RESPONSE DATA	104
5.1.1. Dose-Response Data for Tumor Bioassays.....	104
5.1.2. Dose-Response Data for Cancer-Related Endpoint Studies	105
5.2. OVERALL FORM OF RPF ESTIMATE	106
5.3. RPF CALCULATION FOR MULTIDOSE DATASETS	106
5.4. RPF CALCULATION FOR SINGLE DOSE DATASETS.....	108
5.5. DOSE CONVERSION FOR RPF CALCULATION.....	109
5.6. SPECIAL CONSIDERATIONS FOR RPF CALCULATION USING TUMOR BIOASSAY DATA.....	110
5.7. SPECIAL CONSIDERATIONS FOR RPF CALCULATION USING CANCER- RELATED ENDPOINT DATA.....	111
6. SELECTION OF PAHs FOR INCLUSION IN RELATIVE POTENCY APPROACH.....	113
6.1. METHOD FOR SELECTING PAHs FOR INCLUSION IN RELATIVE POTENCY APPROACH.....	114
6.2. WEIGHT OF EVIDENCE EVALUATION FOR 35 INDIVIDUAL PAHs	117
7. DERIVATION OF FINAL RPFs FOR SELECTED PAHs	190
7.1. METHODS FOR DERIVING FINAL RPFs	190
7.2. CONFIDENCE RATINGS FOR FINAL RPFs	194
7.3. APPLICATION OF RPFs FOR ASSESSING CANCER RISKS FROM EXPOSURE TO PAH MIXTURES	196
7.4. SUSCEPTIBILITY FROM EARLY LIFE EXPOSURE TO CARCINOGENS	196
8. UNCERTAINTIES AND LIMITATIONS ASSOCIATED WITH THE RPF APPROACH	198
8.1. DOSE-RESPONSE ASSESSMENT FOR INDIVIDUAL PAHs.....	199
8.2. SELECTION OF PAHs FOR INCLUSION IN RPF APPROACH.....	201
8.3. DERIVATION OF A FINAL RPF FOR EACH PAH.....	203
8.4. USE OF ANIMAL DATA TO PREDICT HUMAN CANCER RISK FOR PAHs.....	208
8.5. ASSUMPTIONS OF A COMMON MODE OF ACTION AND DOSE ADDITIVITY	210
8.6. EXTRAPOLATION OF RPFs ACROSS EXPOSURE ROUTES	211
9. REFERENCES	218
APPENDIX A. SECONDARY SOURCES REVIEWED FOR IDENTIFICATION OF PRIMARY LITERATURE	A-1
APPENDIX B. BIBLIOGRAPHY OF STUDIES WITHOUT BENZO[A]PYRENE AS A REFERENCE COMPOUND	B-1
B.1. BIBLIOGRAPHY OF BIOASSAYS WITHOUT BENZO[A]PYRENE	B-4
B.2. BIBLIOGRAPHY OF STUDIES ON CANCER-RELATED ENDPOINTS WITHOUT BENZO[A]PYRENE	B-10
APPENDIX C. DOSE-RESPONSE DATA FOR POTENCY CALCULATIONS	C-1

APPENDIX D. BENCHMARK DOSE MODELING OUTPUTS..... D-1

 D.1. DERMAL BIOASSAYS D-1

 D.2. INTRAPERITONEAL BIOASSAYS D-43

 D.3. LUNG IMPLANTATION BIOASSAYS..... D-82

 D.5. BACTERIAL MUTAGENICITY D-117

 D.6. MAMMALIAN MUTAGENICITY D-126

 D.7. MALIGNANT TRANSFORMATION D-154

 D.8. IN VITRO DNA DAMAGE D-186

APPENDIX E. CALCULATION OF RPFsE-1

APPENDIX F. EXAMPLE CALCULATION OF RPF DETECTION LIMITF-1

APPENDIX G: EVALUATION OF ALTERNATIVES FOR RANKING RPFs..... G-1

 G.1. OPTIONS FOR RANKING TUMOR BIOASSAY RPFs G-1

 G.2. RANKING NONBIOASSAY DATA G-7

LIST OF TABLES

1. PAHs with final RPFs based on tumor bioassay data.....	xi
2. PAHs with final RPFs based on cancer-related endpoint data (no tumor bioassay data available).....	xii
2-1. PAHs evaluated in the RPF analysis	5
2-2. Studies of binary mixtures of PAHs and tumorigenicity.....	40
3-1. Comparison among various relative potency estimates for PAHs from the published literature and regulatory agencies (1984–2004).....	45
4-1. Study summaries: dermal bioassays of benzo[a]pyrene and at least one other PAH.....	59
4-2. Study summaries: intraperitoneal bioassays of benzo[a]pyrene and at least one other PAH	63
4-3. Study summaries: subcutaneous bioassays of benzo[a]pyrene and at least one other PAH	65
4-4. Study summaries: oral bioassays of benzo[a]pyrene and at least one other PAH.....	66
4-5. Study summaries: other route bioassays of benzo[a]pyrene and at least one other PAH	67
4-6. Study summaries: in vivo DNA adducts with benzo[a]pyrene and at least one other PAH	68
4-7. Study summaries: in vivo clastogenicity or sister chromatid exchange with benzo[a]pyrene and at least one other PAH	70
4-8. Study summaries: in vivo mutagenicity with benzo[a]pyrene and at least one other PAH	72
4-9. Study summaries: in vitro bacterial mutagenicity with benzo[a]pyrene and at least one other PAH.....	73
4-10. Study summaries: in vitro mammalian mutagenicity assays with benzo[a]pyrene and at least one other PAH.....	76
4-11. Study summaries: in vitro morphological/malignant cell transformation with benzo[a]pyrene and at least one other PAH	79
4-12. Study summaries: in vitro DNA adducts with benzo[a]pyrene and at least one other PAH.....	81

4-13. Study summaries: in vitro DNA damage, repair, or synthesis with benzo[a]pyrene and at least one other PAH.....	82
4-14. Study summaries: in vitro clastogenicity or sister chromatid exchange with benzo[a]pyrene and at least one other PAH.....	84
5-1. Comparison between molar and mass-based RPF.....	110
6-1. PAHs with only one RPF from a single in vitro cancer-related endpoint study and excluded from RPF approach.....	113
6-2. Results of weight of evidence evaluation for 27 PAHs selected for inclusion in the RPF approach.....	118
7-1. Final RPFs based on tumor bioassay data.....	193
7-2. Final RPFs based on cancer-related endpoint data (no tumor bioassay data available).....	194
7-3. Relative confidence ratings for RPFs.....	195
7-4. Sample calculation of estimated cancer risk for benz[a]anthracene with the application of ADAFs.....	197
8-1. Results of simple linear regression of log-transformed average tumor bioassay RPF versus log average genotoxicity RPF.....	206
8-2. PAHs with RPFs of varying relative confidence.....	207
8-3. Comparisons among average tumor bioassay RPF values by exposure route and target organ.....	213
B-1. Bioassays with and without benzo[a]pyrene by PAH.....	B-2
C-1. Dermal bioassays: dose-response information for incidence data.....	C-2
C-2. Dermal bioassays: dose-response information for tumor multiplicity.....	C-8
C-3. Intraperitoneal bioassays: dose-response information for incidence data.....	C-13
C-4. Intraperitoneal bioassays: dose-response information for tumor multiplicity.....	C-23
C-5. Lung implantation bioassays: dose-response information for incidence data.....	C-27
C-6. Oral bioassays: dose-response information for incidence data.....	C-31
C-7. Oral bioassays: dose-response information for tumor multiplicity.....	C-31
C-8. In vitro bacterial mutagenicity: data use.....	C-32

C-9. In vitro bacterial mutagenicity: dose-response data.....	C-35
C-10. In vitro mammalian mutagenicity: data use.....	C-53
C-11. In vitro mammalian mutagenicity: dose-response data	C-56
C-12. In vitro malignant/morphological cell transformation: data use.....	C-64
C-13. In vitro malignant/morphological cell transformation: dose-response data	C-66
C-14. In vitro DNA adducts: data use.....	C-74
C-15. In vitro DNA adducts: dose-response data	C-75
C-16. In vitro DNA damage: data use	C-78
C-17. In vitro DNA damage: dose-response data	C-79
C-18. In vitro clastogenicity: data use	C-84
C-19. In vitro clastogenicity: dose-response data.....	C-85
C-20. In vivo DNA adducts: data use	C-86
C-21. In vivo DNA adducts: dose-response data.....	C-87
C-22. In vivo clastogenicity: data use.....	C-95
C-23. In vivo clastogenicity: dose-response data	C-96
E-1. Dermal bioassays: RPF calculations for incidence data	E-2
E-2. Dermal bioassays: RPF calculations for multiplicity data	E-5
E-3. Intraperitoneal bioassays: RPF calculations for incidence data.....	E-6
E-4. Intraperitoneal bioassays: RPF calculations for multiplicity data.....	E-8
E-5. Lung implantation bioassays: RPF calculations (incidence data).....	E-9
E-6. Oral bioassays: RPF calculations (incidence and multiplicity data).....	E-10
E-7. In vivo DNA adducts: RPF calculations	E-11
E-8. In vivo clastogenicity or sister chromatid exchange: RPF calculation	E-14
E-9. In vitro bacterial mutagenicity: RPF calculations.....	E-16
E-10. In vitro mammalian mutagenicity: RPF calculations.....	E-22

E-11. In vitro morphological/malignant transformation: RPF calculation	E-25
E-12. In vitro DNA adducts: RPF calculations.....	E-27
E-13. In vitro DNA damage: RPF calculations	E-29
E-14. In vitro clastogenicity or sister chromatid exchange: RPF calculations	E-31
F-1. Example data for calculation of RPF detection limit	F-1
G-1. Comparisons among average nonzero tumor bioassay-based RPF values by exposure route.....	G-3
G-2. Comparisons among average nonzero tumor bioassay-based RPF values by calculation method.....	G-6
G-3. Results of simple linear regression of log–transformed average genotoxicity RPF versus log average tumor bioassay RPF	G-8

LIST OF FIGURES

1		
2		
3		
4	2-1. Structural features of PAHs.....	20
5		
6	2-2. Metabolic pathways for benzo[a]pyrene	24
7		
8	2-3. Overview of the proposed key events in the mode of action for PAH carcinogenicity	26
9		
10	2-4. Structures of the four stereoisomeric adduct moieties, <i>anti</i> -[BaP]- <i>N</i> ² -dG, derived from	
11	the <i>trans</i> - or <i>cis</i> - covalent binding of (+)- <i>anti</i> -BaP diol epoxide or (-)- <i>anti</i> -BaP diol	
12	epoxide to dG residues in DNA.....	27
13		
14	2-5. Depurinating adducts of benzo[a]pyrene formed by one-electron oxidation	28
15		
16	2-6. Spectrum of DNA adducts anticipated with PAH o-quinones	29
17		
18	2-7. Interaction of PAHs with the AhR – regulation of genes related to induction of	
19	metabolism and cell differentiation and proliferation	31
20		
21	6-1. Weight of evidence analysis of for selection of PAHs to be included in the RPF	
22	approach	115
23		
24	6-2. 2,3-Acepyrene (ACEP) RPFs.....	120
25		
26	6-3. Anthanthrene (AA) RPFs	122
27		
28	6-4. Anthracene (AC) RPFs.....	124
29		
30	6-5. Benz[a]anthracene (BaA) RPFs.....	126
31		
32	6-6. 11H-Benz[b,c]aceanthrylene (BbcAC) RPFs.....	128
33		
34	6-7. Benzo[b]fluoranthene (BbF) RPFs.....	130
35		
36	6-8. 11H-Benzo[b]fluorene (BbFE) RPFs	132
37		
38	6-9. Benzo[c]fluorene (BcFE) RPFs.....	134
39		
40	6-10. Benz[e]aceanthrylene (BeAC) RPFs	136
41		
42	6-11. Benzo[e]pyrene (BeP) RPFs.....	138
43		
44	6-12. Benzo[g,h,i]fluoranthene (BghiF) RPFs.....	140
45		
46	6-13. Benzo[g,h,i]perylene (BghiP) RPFs	142
47		
48	6-14. Benz[j]aceanthrylene (BjAC) RPFs	144
49		

1	6-15. Benzo[j]fluoranthene (BjF) RPFs.....	146
2		
3	6-16. Benzo[k]fluoranthene (BkF) RPFs.....	148
4		
5	6-17. Benz[l]aceanthrylene (BlAC) RPFs	150
6		
7	6-18. Chrysene (CH) RPFs	152
8		
9	6-19. Coronene (CO) RPFs.....	154
10		
11	6-20. Cyclopenta[c,d]pyrene (CPcdP) RPFs	156
12		
13	6-21. Cyclopenta[d,e,f]chrysene (CPdefC) RPFs	158
14		
15	6-22. Dibenz[a,c]anthracene (DBacA) RPFs.....	160
16		
17	6-23. Dibenzo[a,e]fluoranthene (DBaeF) RPFs.....	162
18		
19	6-24. Dibenzo[a,e]pyrene (DBaeP) RPFs	164
20		
21	6-25. Dibenz[a,h]anthracene (DBahA) RPFs	166
22		
23	6-26. Dibenzo[a,h]pyrene (DBahP) RPFs	168
24		
25	6-27. Dibenzo[a,i]pyrene (DbaiP) RPFs	170
26		
27	6-28. Dibenzo[a,l]pyrene (DBalP) RPFs	173
28		
29	6-29. Fluoranthene (FA) RPFs.....	175
30		
31	6-30. Fluorene (FE) RPFs	177
32		
33	6-31. Indeno[1,2,3-c,d]pyrene (IP) RPFs.....	179
34		
35	6-32. Naphtho[2,3-e]pyrene (N23eP) RPFs.....	181
36		
37	6-33. Perylene (Pery) RPFs.....	183
38		
39	6-34. Phenanthrene (PH) RPFs	185
40		
41	6-35. Pyrene (Pyr) RPFs	187
42		
43	6-36. Triphenylene (Tphen) RPFs	189
44		
45	8-1. Correlation between incidence and multiplicity RPFs	204
46		
47	G-1. Average bioassay RPF versus average in vivo DNA adduct RPF.....	G-9
48		
49	G-2. Average bioassay RPF versus average in vivo nonbioassay RPF	G-10

1
2 G-3. Average bioassay RPF versus average nonbioassay RPF G-11
3
4 G-4. Average bioassay RPF versus average in vitro nonbioassay RPF..... G-12
5
6

LIST OF ABBREVIATIONS AND ACRONYMS*

1		
2		
3		
4	ADAF	age-dependent adjustment factor
5	AEL	acceptable exposure level
6	Ah	aryl hydrocarbon
7	AhR	Ah receptor
8	ATSDR	Agency for Toxic Substances and Disease Registry
9	AUC	area under the curve
10	BMD	benchmark dose
11	BMR	benchmark response
12	CASRN	Chemical Abstract Service Registry Number
13	CCRIS	Chemical Carcinogenesis Research Information System
14	CHO	Chinese hamster ovary
15	CYP	cytochrome P450
16	dG	deoxyguanosine
17	DMSO	dimethyl sulfoxide
18	DNA	deoxyribonucleic acid
19	DSSTOX	Distributed Structure-Searchable Toxicity
20	EOPP	estimated order of potential potency
21	EROD	ethoxyresorufin O-deethylase
22	HPRT	hypoxanthine-guanine phosphoribosyl transferase gene
23	IARC	International Agency for Research on Cancer
24	IRIS	Integrated Risk Information System
25	MGP	manufactured gas plant
26	MN-PCE	micronucleated polychromatic erythrocyte
27	mRNA	messenger ribonucleic acid
28	MVK	Moolgavkar-Venson-Knudsen two-stage model
29	NTP	National Toxicology Program
30	OEHHA	Office of Environmental Health Hazard Assessment, California EPA
31	PAC	polycyclic aromatic compound
32	PAH	polycyclic aromatic hydrocarbon
33	PCB	polychlorinated biphenyl
34	PCR	polymerase chain reaction
35	PEF	potency equivalency factor
36	QSAR	quantitative structure activity relationship
37	RNA	ribonucleic acid
38	RPF	relative potency factor
39	RTD	relative tumor dose
40	SD	standard deviation
41	TK	thymidine kinase locus
42	TIDAL	time-integrated DNA adduct level
43	TEF	toxicity equivalency factor
44	TK	thymidine kinase
45	TPA	12-O-tetra-decanoylphorbol-13-acetate
46	TSCATS	Toxic Substances Control Act Test Submissions

1 **U.S. EPA** U.S. Environmental Protection Agency
2 **WHO** World Health Organization

3

4 * Abbreviations for PAH chemical names are provided in Table 2-1.

5

1 Jamie Strong, Ph.D.
2 National Center for Environmental Assessment, IRIS Program
3 Office of Research and Development
4 U.S. Environmental Protection Agency
5 Washington, DC
6

7 Linda Teuschler, Ph.D.
8 National Center for Environmental Assessment
9 Office of Research and Development
10 U.S. Environmental Protection Agency
11 Cincinnati, OH
12

13 Stephen Nesnow, Ph.D.
14 Environmental Carcinogenesis Division
15 National Health and Environmental Effects Research Laboratory
16 Office of Research and Development
17 Research Triangle Park, NC
18

19 Chao Chen, Ph.D.
20 National Center for Environmental Assessment
21 Office of Research and Development
22 Washington, DC
23

24 Heather Carlson-Lynch, S.M.
25 Syracuse Research Corporation, Inc.
26 Syracuse, NY
27

28 Julie Stickney, Ph.D., DABT
29 Syracuse Research Corporation, Inc.
30 Syracuse, NY
31

32 Peter R. McClure, Ph.D., DABT
33 Syracuse Research Corporation, Inc.
34 Syracuse, NY
35

36 Amber Bacom
37 Syracuse Research Corporation, Inc.
38 Syracuse, NY
39
40

1 **1. BACKGROUND FOR THE DEVELOPMENT OF A RELATIVE POTENCY**
2 **FACTOR APPROACH FOR PAH MIXTURES HEALTH ASSESSMENT**

3
4 This analysis focuses on the relative potency factor (RPF) approach that is based on
5 component PAHs in PAH mixtures. U.S. EPA held a peer consultation workshop to outline some
6 of the important issues related to approaches for PAH mixtures risk assessment. These issues are
7 discussed in *Peer Consultation Workshop on Approaches to Polycyclic Aromatic Hydrocarbon*
8 *(PAH) Health Assessment* (U.S. EPA, 2002) and the accompanying discussion document. Health
9 assessments for 15 unsubstituted, nonheterocyclic polycyclic aromatic hydrocarbons (PAHs)
10 with three or more rings are currently entered on EPA’s IRIS database. Benzo[a]pyrene is the
11 only PAH for which there are robust animal dose-response data for the oral, dermal, and
12 inhalation routes.

13 In 1993, U.S. EPA published the *Provisional Guidance for Quantitative Risk Assessment*
14 *of PAHs (Provisional Guidance)*. The *Provisional Guidance* recommended estimated orders of
15 potential potency (EOPP) for individual PAHs that could be used in a component-based
16 approach to PAH mixtures risk assessment. The *Provisional Guidance* recommended EOPPs for
17 seven PAHs categorized as Group B2 (probable human carcinogens) under the 1986 U.S. EPA
18 Cancer Guidelines: benzo[a]pyrene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluor-
19 anthene, chrysene, dibenz[a,h]anthracene, and indeno[1,2,3-c,d]pyrene (U.S. EPA, 1993). The
20 current analysis extends the 1993 *Provisional Guidance* and provides recommendations for
21 further development of this approach to PAH mixtures risk assessment. The assessment includes
22 the following:

- 23
24 (1) A rationale for recommending an order of potency, or RPF, approach;
25
26 (2) A summary of previous approaches for developing the RPF approach for PAHs;
27
28 (3) Identification of individual carcinogenic PAHs that could be included in the RPF
29 approach;
30
31 (4) Identification of potential index chemicals;
32
33 (5) Presentation of the available literature for in vivo carcinogenicity and both in vivo and in
34 vitro cancer-related endpoint assays for individual PAHs;
35
36 (6) Development of a recommendation for the RPF approach for PAH mixtures; and
37
38 (7) Characterization of strengths, weaknesses, and uncertainties associated with the
39 recommended approaches.
40
41
42

1 **2. RATIONALE FOR RECOMMENDING AN RPF APPROACH**
2
3

4 PAHs are a concern as human health hazards, because many PAHs are demonstrated
5 tumorigenic agents in animal bioassays and are active in in vivo or in vitro tests for genotoxicity
6 or deoxyribonucleic acid (DNA) damage. PAHs do not occur in the environment as isolated
7 entities; they primarily occur in complex mixtures generated from the combustion or pyrolysis of
8 substances containing carbon and hydrogen. Several complex mixtures of PAHs have been
9 classified as possibly carcinogenic, probably carcinogenic, or carcinogenic to humans (Straif et
10 al., 2005; U.S. EPA, 2002; Bostrom et al., 2002; WHO, 1998; ATSDR, 1995; IARC, 1985,
11 1984a, b, 1983).

12 In accordance with U.S. EPA (2000, 1986) guidance for health risk assessment of
13 chemical mixtures, assessment of the cancer risk from long-term human exposure to a particular
14 PAH mixture would best be conducted with quantitative information on the dose-response
15 relationship for cancer from chronic exposure to the mixture of concern. When data for the
16 mixture of concern are not available, U.S. EPA (2000, 1986) guidance recommends using
17 toxicity data on a “sufficiently similar” mixture. However, quantitative cancer dose-response
18 information exists only for a few complex mixtures generated from the combustion or pyrolysis
19 of organic matter; for example, tobacco smoke, coke oven emissions, and emissions from roofing
20 tar pots (see Bostrom et al., 2002; Albert et al., 1983). U.S. EPA’s IRIS database currently
21 includes assessments for only three PAH-containing mixtures: coke oven emissions, creosote,
22 and diesel emissions. The availability of oral carcinogenicity bioassays of manufactured gas
23 plant (MGP) residue (Weyand et al., 1995) and coal tar preparations (Culp et al., 1998; Gaylor et
24 al., 1998) has expanded the PAH mixture cancer database.

25 Component-based approaches, involving an analysis of the toxicity of components of the
26 mixture, are recommended when appropriate toxicity data on a complex mixture of concern, or
27 on a “sufficiently similar” mixture, are unavailable (U.S. EPA, 2000, 1986). Component-based
28 approaches involving dose addition (such as the RPF approach) are recommended when
29 components in the mixture are judged to act in a toxicologically similar manner. In the RPF
30 approach, doses of component chemicals that act in a toxicologically similar manner are added
31 together, after scaling the doses relative to the potency of an index chemical (U.S. EPA, 2000,
32 1986). Then, using the dose-response curve of the index chemical, the response to the total
33 equivalent dose in the mixture is estimated. The index compound is typically the best-studied
34 member of the class with the largest body of available data describing exposure and health
35 effects. The index chemical should have a quantitative dose-response assessment of acceptable
36 scientific quality and must have (or be expected to have) similar toxic effects to the rest of the
37 members of the class.

1 For exposure situations in which dose-response data for the PAH mixture or a sufficiently
2 similar mixture are not available (e.g., the source of the PAH contamination may be mixed or
3 unknown), there are at least three practical advantages of an RPF approach that uses
4 benzo[a]pyrene as the index PAH:

- 5
- 6 (1) Benzo[a]pyrene is routinely assayed and detected in environmental media contaminated
7 with PAH mixtures;
- 8
- 9 (2) Benzo[a]pyrene is the only PAH for which robust cancer dose-response data involving
10 chronic exposures are available; and
- 11
- 12 (3) There is a large database of studies in which the potency of benzo[a]pyrene is compared
13 with the potency of other PAHs in various assays.
- 14

15 The database includes animal tumorigenicity² assays involving dermal or parenteral
16 administration, and in vivo and in vitro assays of cancer-related endpoints (e.g., various
17 genotoxic endpoints). Thus, RPFs for a number of PAHs can be derived.

18 The RPF approach involves two key assumptions related to the application of a dose-
19 additivity model: (1) the assumption of similar toxicological action; and (2) the assumption that
20 interactions among PAH mixture components do not occur at low levels of exposure typically
21 encountered in the environment.

22 Mechanistic studies indicate that the mutagenic and tumor-initiating activity of most
23 carcinogenic PAHs requires metabolic activation to reactive intermediates (e.g., stereospecific
24 dihydrodiol epoxides). For several PAHs (e.g., benzo[a]pyrene, dibenz[a,h]anthracene,
25 dibenzo[a,l]pyrene), there is evidence that DNA damage associated with metabolism can lead to
26 mutations in cancer-related genes. Tumor promotion and progression by PAHs may involve
27 parent compound binding to the aryl hydrocarbon (Ah) receptor and subsequent alterations of
28 gene expression, as well as by cell proliferation in response to cytotoxic effects from metabolites
29 (see Section 2.4, Similarities in Mode of Carcinogenic Action for PAHs). As such, there is
30 evidence that an assumption of similar toxicological action is reasonable; however, the
31 carcinogenic process for individual PAHs is likely to be related to some unique combination of
32 multiple molecular events resulting from the formation of several reactive species. The second
33 assumption of no interactions at low levels of exposure is also reasonable, but has not been
34 conclusively demonstrated in experimental systems (see Section 2.8, Dose Additivity of PAHs in
35 Combined Exposures).

36 Key limitations to the RPF approach, relative to whole mixture approaches, are:
37 (1) RPFs have been derived for a limited number of PAHs; and (2) cancer risks from non-PAH
38 components, unidentified PAHs, and heterocyclic and substituted PAHs in PAH mixtures are not

²Throughout this report, the term “tumorigenicity” is used to describe the production of either benign or malignant tumors.

1 estimated. The first of these limitations is being addressed, to the degree allowable by available
2 data, by the derivation of RPFs for numerous PAHs as discussed in Chapters 4 through 7 of this
3 report. If non-PAH carcinogenic components are identified and quantified in the complex
4 mixture of concern and appropriate dose-response data are available, the second limitation can be
5 addressed by adding the cancer risk from PAH components estimated by the RPF approach to
6 cancer risks estimated for the non-PAH carcinogenic components of the mixture. Previous
7 efforts to validate the RPF approach using data for PAH mixtures are discussed in Section 3.1.
8 These validation efforts compared the cancer risk of a PAH mixture measured experimentally
9 with the cancer risk that was predicted using the RPF method but were limited by the small
10 number of compounds for which RPFs and analytical data were available (Muller et al., 1997;
11 McClure, 1996; Goldstein et al., 1994; Clement Associates, 1990, 1988; Krewski et al., 1989).
12 Validation of the updated approach presented here would be of value, either using previous data
13 on PAH mixtures (human and animal) or using new data collected with the main purpose of
14 evaluating the validity of the approach.

16 **2.1. PAHs AS A CHEMICAL CLASS**

17 The PAH chemical class has been variously defined to include organic compounds
18 containing either two or more, or three or more, fused rings made up of carbon and hydrogen
19 atoms (i.e., unsubstituted parent PAHs and their alkyl-substituted derivatives) (WHO, 1998).
20 Most PAHs are high-melting, high-boiling point, lipophilic compounds, predominately generated
21 from the incomplete combustion or pyrolysis of organic matter. The PAH chemical class
22 includes alkylated PAHs (e.g., 1,4-dimethylphenanthrene and 5-methylchrysene), but not
23 heterocyclic compounds containing N, S, or O or PAHs substituted with N-, S-, or O-containing
24 groups; these are included in a larger chemical class, often referred to as polycyclic aromatic
25 compounds (PACs) (WHO, 1998). The number of chemicals that comprise the PAHs class is
26 unknown; however, there are thought to be hundreds of individual PAHs present as components
27 of complex mixtures (WHO, 1998). The analysis presented here is limited in focus to include
28 only unsubstituted PAHs with three or more fused aromatic rings containing only carbon and
29 hydrogen atoms, because these are the most widely studied members of the PAH chemical class.
30 Naphthalene is a widely studied two-ring PAH compound; however, a separate toxicological
31 review and carcinogenicity assessment is being developed by the IRIS Program for this
32 compound and it is not included in this RPF approach. The list of PAH compounds that were
33 considered for inclusion in this analysis is presented in Table 2-1 along with the Chemical
34 Abstracts Service Registry Numbers (CASRN) and the abbreviations that are utilized in tables
35 throughout the report.

Table 2-1. PAHs evaluated in the RPF analysis

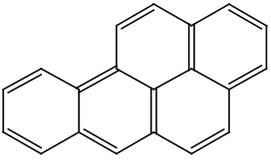
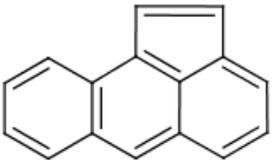
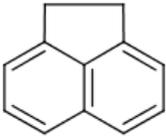
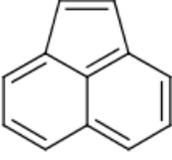
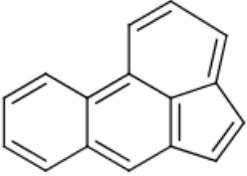
PAH (common synonyms)	CASRN	Abbreviation	Structure	Molecular weight (g/mol)
Benzo[a]pyrene	50-32-8	BaP		252.31
Aceanthrylene	202-03-09	ACEA		202.26
Acenaphthene	83-32-9	AN		154.21
Acenaphthylene	208-96-8	ANL		152.20
Acephenanthrylene	201-06-9	APA		202.26

Table 2-1. PAHs evaluated in the RPF analysis

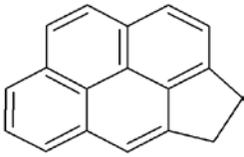
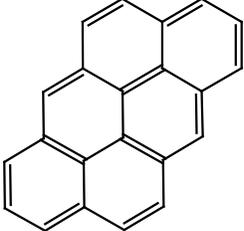
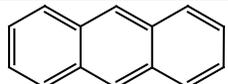
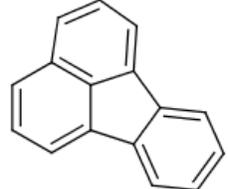
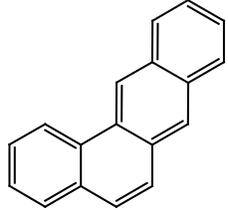
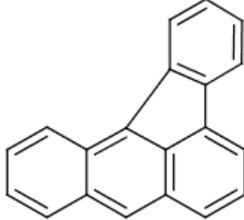
PAH (common synonyms)	CASRN	Abbreviation	Structure	Molecular weight (g/mol)
Accepyrene, 2,3-	25732-74-5	ACEP		228.29
Anthanthrene	191-26-4	AA		276.34
Anthracene	120-12-7	AC		178.23
Benzacenaphthylene	76774-50-0	BAN		202.26
Benz[a]anthracene	56-55-3	BaA		228.29
Benzo[a]fluoranthene	203-33-8	BaF		252.32

Table 2-1. PAHs evaluated in the RPF analysis

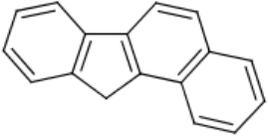
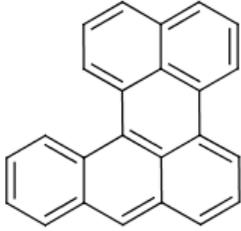
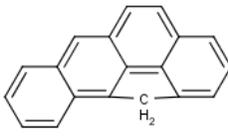
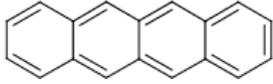
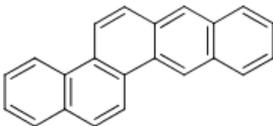
PAH (common synonyms)	CASRN	Abbreviation	Structure	Molecular weight (g/mol)
Benzo[a]fluorene	238-84-6	BaFE		216.28
Benzo[a]perylene	191-85-5	BaPery		302.38
Benz[b,c]aceanthrylene, 11H-	202-94-8	BbcAC		240.30
Benz[b]anthracene (naphthacene)	92-24-0	BbA		228.29
Benzo[b]chrysene	214-17-5	BbC		278.35

Table 2-1. PAHs evaluated in the RPF analysis

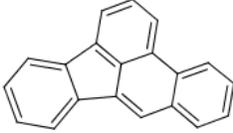
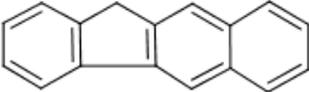
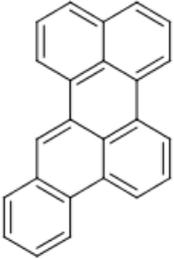
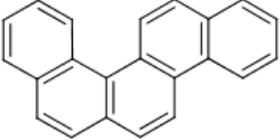
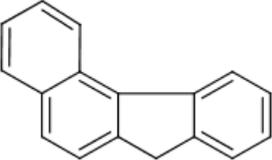
PAH (common synonyms)	CASRN	Abbreviation	Structure	Molecular weight (g/mol)
Benzo[b]fluoranthene	205-99-2	BbF		252.32
Benzo[b]fluorene, 11H	243-17-4	BbFE		216.28
Benzo[b]perylene	197-70-6	BbPery		302.38
Benzo[c]chrysene	194-69-4	BcC		278.35
Benzo[c]fluorene	205-12-9	BcFE		216.28

Table 2-1. PAHs evaluated in the RPF analysis

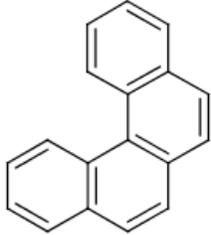
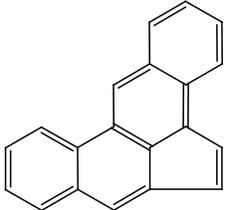
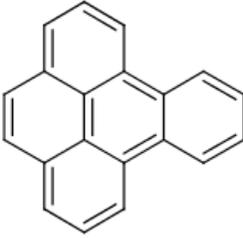
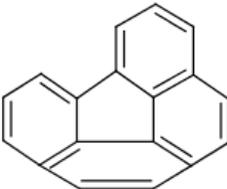
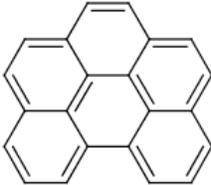
PAH (common synonyms)	CASRN	Abbreviation	Structure	Molecular weight (g/mol)
Benzo[c]phenanthrene	195-19-7	BcPH		228.29
Benz[e]aceanthrylene	199-54-2	BeAC		252.32
Benzo[e]pyrene	192-97-2	BeP		252.32
Benzo[g,h,i]fluoranthene	203-12-3	BghiF		226.28
Benzo[g,h,i]perylene	191-24-2	BghiP		276.34

Table 2-1. PAHs evaluated in the RPF analysis

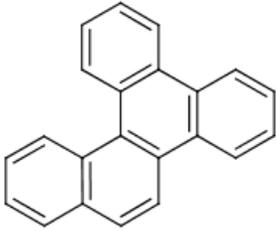
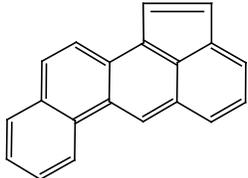
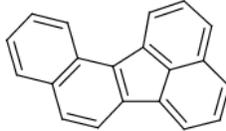
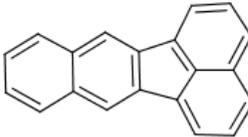
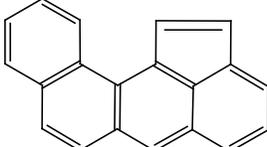
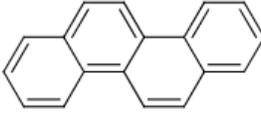
PAH (common synonyms)	CASRN	Abbreviation	Structure	Molecular weight (g/mol)
Benzo[g]chrysene	196-78-1	BgC		278.35
Benz[j]aceanthrylene	202-33-5	BjAC		252.32
Benzo[j]fluoranthene	205-82-3	BjF		252.32
Benzo[k]fluoranthene	207-08-9	BkF		252.32
Benz[l]aceanthrylene	211-91-6	BlAC		252.32
Benzophenanthrene	65777-08-4	BPH		228.29

Table 2-1. PAHs evaluated in the RPF analysis

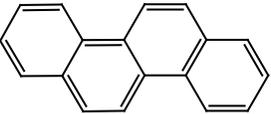
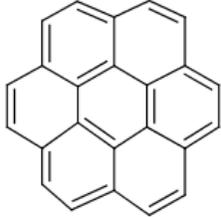
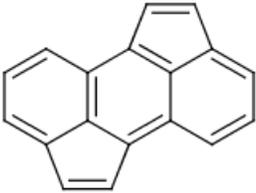
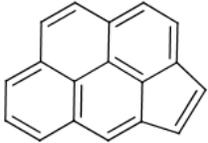
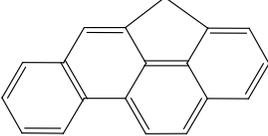
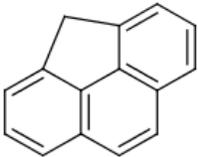
PAH (common synonyms)	CASRN	Abbreviation	Structure	Molecular weight (g/mol)
Chrysene	218-01-9	CH		228.29
Coronene	191-07-1	CO		300.36
Cyclopent[<i>h,i</i>]aceanthrylene	131581-33-4	CPhiACEA		226.28
Cyclopenta[<i>c,d</i>]pyrene	27208-37-3	CPcdP		226.28
Cyclopenta[<i>d,e,f</i>]chrysene, 4H-	202-98-2	CPdefC		240.30
Cyclopenta[<i>d,e,f</i>]phenanthrene	203-64-5	CPdefPH		190.24

Table 2-1. PAHs evaluated in the RPF analysis

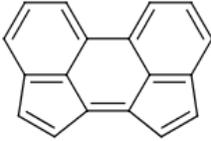
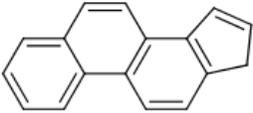
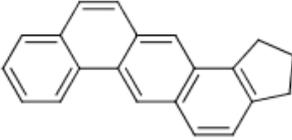
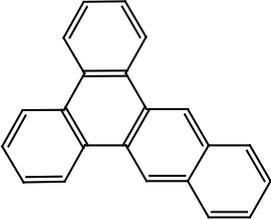
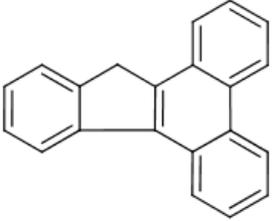
PAH (common synonyms)	CASRN	Abbreviation	Structure	Molecular weight (g/mol)
Cyclopenta[h,i]acephenanthrylene	114959-37-4	CPhiAPA		226.28
Cyclopentaphenanthrene	219-08-9	CPPH		216.28
Cyclopenteno-1,2-benzanthracene, 5,6-	7099-43-6	CPBA		268.36
Dibenz[a,c]anthracene (benzotriphenylene)	215-58-7	DBacA		278.35
Dibenzo[a,c]fluorene, 13H-	201-65-0	DBacFE		266.34

Table 2-1. PAHs evaluated in the RPF analysis

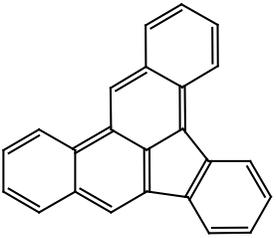
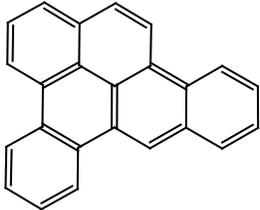
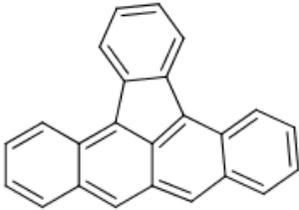
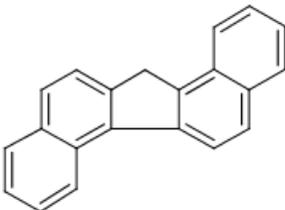
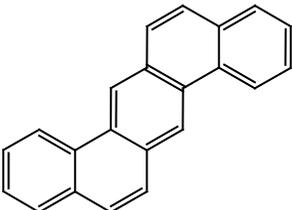
PAH (common synonyms)	CASRN	Abbreviation	Structure	Molecular weight (g/mol)
Dibenzo[a,e]fluoranthene	5385-75-1	DBaef		302.38
Dibenzo[a,e]pyrene	192-65-4	DBaep		302.38
Dibenzo[a,f]fluoranthene (indeno[1,2,3-fg]naphthacene)	203-11-2	DBafF		302.38
Dibenzo[a,g]fluorene, 13H-	207-83-0	DBagFE		266.34
Dibenz[a,h]anthracene	53-70-3	DBahA		278.35

Table 2-1. PAHs evaluated in the RPF analysis

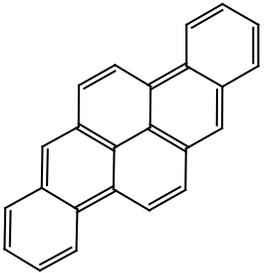
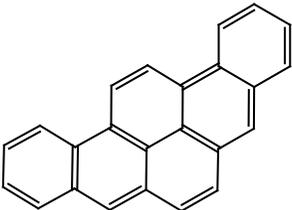
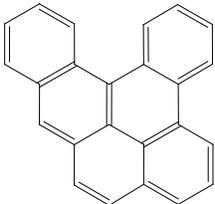
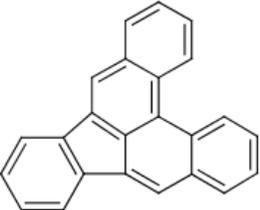
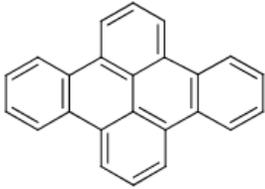
PAH (common synonyms)	CASRN	Abbreviation	Structure	Molecular weight (g/mol)
Dibenzo[a,h]pyrene	189-64-0	DBaHP		302.38
Dibenzo[a,i]pyrene	189-55-9	DBaIP		302.38
Dibenzo[a,l]pyrene	191-30-0	DBaLP		302.38
Dibenzo[b,e]fluoranthene	2997-45-7	DBbeF		302.38
Dibenzo[e,l]pyrene (dibenzo[fg,op]naphthacene)	192-51-8	DBelP		302.38

Table 2-1. PAHs evaluated in the RPF analysis

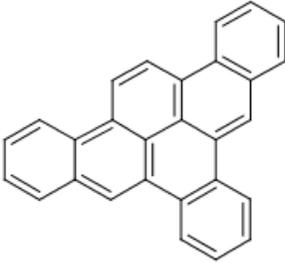
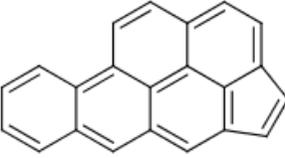
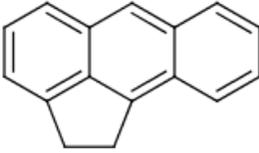
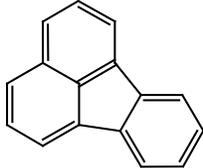
PAH (common synonyms)	CASRN	Abbreviation	Structure	Molecular weight (g/mol)
Dibenzo[h,rst]pentaphene	192-47-2	DBhrstPent		352.43
Dibenz[j,mno]acephenanthrylene	153043-82-4	DBjmnoAPH		276.34
Dibenz[k,mno]acephenanthrylene	153043-81-3	DBkmnoAPH		276.34
Dihydroaceanthrylene, 1,2-	641-48-5	DACEA		204.27
Fluoranthene	206-44-0	FA		202.26

Table 2-1. PAHs evaluated in the RPF analysis

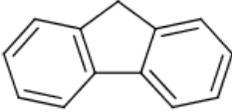
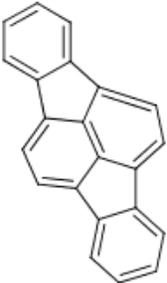
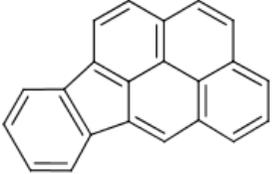
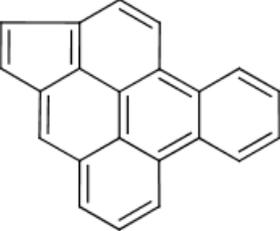
PAH (common synonyms)	CASRN	Abbreviation	Structure	Molecular weight (g/mol)
Fluorene	86-73-7	FE		166.22
Indeno[1,2,3-c,d]fluoranthene	193-43-1	IF		276.34
Indeno[1,2,3-c,d]pyrene	193-39-5	IP		276.34
Naphth[1,2,3-mno]acephenanthrylene	113779-16-1	N123mnoAPH		276.34

Table 2-1. PAHs evaluated in the RPF analysis

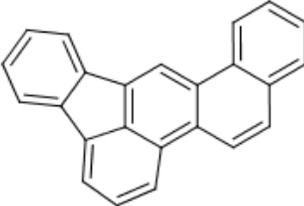
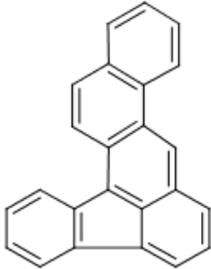
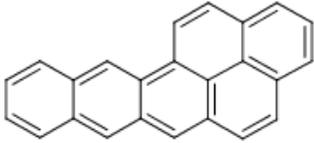
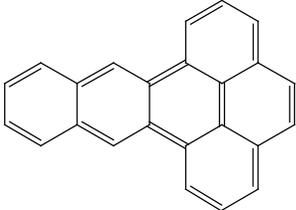
PAH (common synonyms)	CASRN	Abbreviation	Structure	Molecular weight (g/mol)
Naphtho[1,2-b]fluoranthene	111189-32-3	N12bF		302.38
Naphtho[2,1-a]fluoranthene	203-20-3	N21aF		302.38
Naphtho[2,3-a]pyrene (naphtho[2,1,8-qr]naphthacene)	196-42-9	N23aP		302.38
Naphtho[2,3-e]pyrene (dibenzo[de,qr]naphthacene)	193-09-9	N23eP		302.38

Table 2-1. PAHs evaluated in the RPF analysis

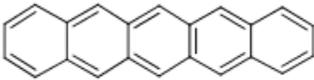
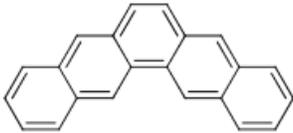
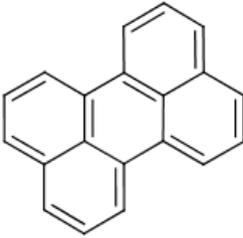
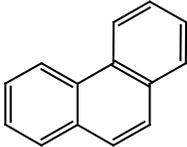
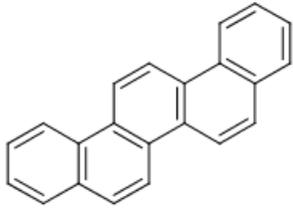
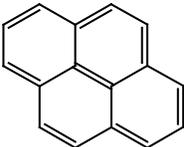
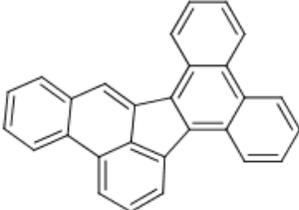
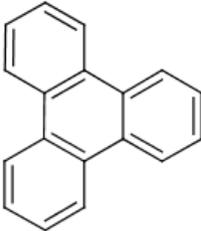
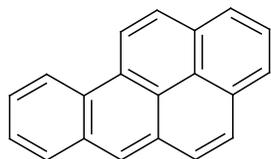
PAH (common synonyms)	CASRN	Abbreviation	Structure	Molecular weight (g/mol)
Pentacene	135-48-8	PCE		278.35
Pentaphene (dibenzphenanthrene, 2,3:6,7-)	222-93-5	Pent		278.35
Perylene	198-55-0	Pery		252.32
Phenanthrene	85-01-8	PH		178.23
Picene	213-46-7	Pic		278.35

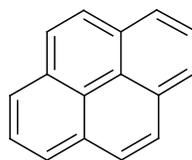
Table 2-1. PAHs evaluated in the RPF analysis

PAH (common synonyms)	CASRN	Abbreviation	Structure	Molecular weight (g/mol)
Pyrene	129-00-0	Pyr		202.26
Tribenzofluoranthene 3,4-10,11-12,13-	13579-05-0	TBF		352.43
Triphenylene	217-59-4	Tphen		228.29

1
2 Unsubstituted PAHs have been further classified into alternant and nonalternant
3 compounds. Alternant PAHs are those compounds composed solely of fused benzene rings,
4 while nonalternant PAHs contain both benzene and five carbon rings. Among alternant PAHs,
5 important structural features related to enhanced mutagenicity and carcinogenicity include the
6 presence of at least four rings (Bostrom et al., 2002). Common structural features of PAH
7 compounds are illustrated in Figure 2-1.

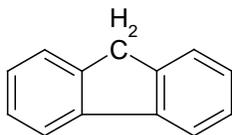


Benzo[a]pyrene

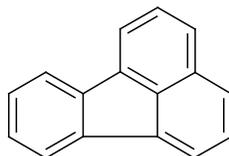


Pyrene

Examples of Alternant PAHs

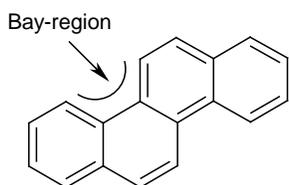


Fluorene

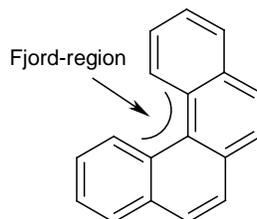


Fluoranthene

Examples of Nonalternant PAHs



Chrysene



Benzo[c]phenanthrene

Bay-region and Fjord-regions of PAHs

1
2 **Figure 2-1. Structural features of PAHs.**
3

4 **2.2. THE TOXICOLOGICAL DATABASE FOR PAHs**

5 Over the last 30- to 50-years, a large PAH database has been generated including studies
6 of carcinogenicity in animal bioassays, genotoxicity in various test systems, and metabolism
7 (bioactivation) to tumorigenic and/or genotoxic intermediates. Carcinogenicity and genotoxicity
8 data are sufficient to classify a number of individual PAHs as possibly carcinogenic to humans
9 (WHO, 1998; U.S. EPA, 1993; IARC, 1989, 1986, 1985, 1984a, b, 1983). Other PAHs have
10 been tested for tumorigenicity and/or genotoxicity, but either nonpositive or equivocal results
11 were obtained; for many PAHs, positive results were only observed in genotoxicity assays (e.g.,
12 pyrene). Many studies have been performed to provide further understanding about the
13 carcinogenic mode of action of PAHs (see Bostrom et al., 2002; WHO, 1998; ATSDR, 1995).
14 Therefore, the PAH database contains studies that evaluate:
15

- 1 • Metabolism to reactive intermediates;
- 2 • Characterization of PAH-DNA adducts;
- 3 • Mutagenicity of PAHs in bacterial and mammalian cells;
- 4 • Mutation spectra in identified oncogene and tumor suppressor genes;
- 5 • Clastogenic effects;
- 6 • Cell transformation; and
- 7 • Initiation and promotion of carcinogenicity (complete carcinogenesis).

8
9 A limitation to the database is the lack of data from long-term oral or inhalation cancer
10 studies for most individual PAH compounds. The only PAH for which there are robust animal
11 dose-response data is benzo[a]pyrene (Kroese et al., 2001; Culp et al., 1998, 1996a, b; Thyssen
12 et al., 1981, 1980; Rigdon et al., 1969; Rigdon and Neal, 1969, 1966; Neal and Rigdon, 1967).
13 Furthermore, most of the toxicological data available for PAHs relate to cancer or genotoxicity.
14 Available information on the systemic, noncarcinogenic effects of PAHs is limited, although
15 immunological, neurotoxic, and developmental effects have been noted in animal studies and
16 some human studies (for earlier reviews, see WHO, 1998; ATSDR, 1995). As a result, the
17 relative potency methodology described here is applied only to cancer risk assessment for PAHs.

18 19 **2.3. BENZO[A]PYRENE AS AN INDEX CHEMICAL**

20 Because long-term animal studies are not available for many individual PAHs, it is
21 necessary to choose an appropriate index chemical for comparison of relative carcinogenic
22 potency. The index compound is typically the best-studied member of the class, with the largest
23 body of available data describing exposure and health effects. The index chemical should have a
24 quantitative dose-response assessment of acceptable scientific quality and must have (or be
25 expected to have) similar toxic effects to the rest of the members of the class.

26 Although the PAH composition of complex mixtures varies, benzo[a]pyrene is
27 considered to be present in significant amounts in certain occupational environments and urban
28 settings (WHO, 1998; Petry et al., 1996; ATSDR, 1995). Benzo[a]pyrene is one of the most
29 potent of the carcinogenic PAHs and has, therefore, been proposed to contribute significantly to
30 the carcinogenicity of a PAH mixture, even when present in low concentrations (Petry et al.,
31 1996). Benzo[a]pyrene is also the best-studied PAH compound, with carcinogenicity bioassay
32 data available for several routes of exposure and a considerable number of studies on
33 carcinogenic mode of action. Benzo[a]pyrene has been characterized as reasonably anticipated
34 to be a human carcinogen (NTP, 2005) or carcinogenic to humans (Straif, 2005).

35 The laboratory animal database for benzo[a]pyrene is robust. Benzo[a]pyrene has been
36 shown to induce tumors at the site of administration and at distal sites in numerous studies.
37 Dose-response data for tumors are available for the oral, inhalation, and dermal routes of
38 administration in multiple species. There are methodological limitations associated with the

1 inhalation data (Thyssen et al., 1981), although positive findings in intratracheal instillation
2 studies support the observed positive response. Dermal exposure studies with several strains of
3 mice also provide data on dose-related tumor incidences (Albert et al., 1991; Warshawsky and
4 Barkley, 1987; Habs et al., 1984, 1980; Nesnow et al., 1983; Wynder et al., 1957).

5 The animal carcinogenicity database for benzo[a]pyrene includes several well-conducted
6 oral cancer bioassays. Kroese et al. (2001) conducted a well-designed gavage study of
7 benzo[a]pyrene carcinogenicity and found that benzo[a]pyrene induced tumors at multiple sites
8 in rats of both sexes, specifically in the liver, forestomach, auditory canal, and oral cavity. In
9 another well-conducted study, using Ah-responsive B6C3F₁ female mice exposed to
10 benzo[a]pyrene in the diet (Beland and Culp, 1998; Culp et al., 1998), only portal-of-entry
11 tumors were found, including papillomas and/or carcinomas of the forestomach, esophagus,
12 tongue, and larynx. Earlier, a number of related studies were conducted to evaluate the
13 carcinogenicity of benzo[a]pyrene in feed in Ah-responsive white Swiss mice (Rigdon and Neal,
14 1969, 1966; Neal and Rigdon, 1967). These studies were not conducted using standard, modern
15 toxicological methods and have several limitations, including inconsistent dosing protocols;
16 varying ages of the animals; use of benzene as a solvent; small numbers of animals; and
17 evaluation of only a limited number of tissues. These studies do, however, provide useful dose-
18 response information on benzo[a]pyrene carcinogenicity. Following oral administration via
19 feeding of benzo[a]pyrene, site-of-contact tumors (both papillomas and carcinomas) were
20 induced in the forestomach, esophagus, and larynx of mice (Culp et al., 1998; Neal and Rigdon,
21 1967) and rats (Brune et al., 1981). The results following inhalation, dermal, or oral exposure
22 are further supported by numerous mechanistic studies or assays using infant mice, susceptible
23 transgenic strains, or Ah-receptor knockout mice.

24 Benzo[a]pyrene is a complete carcinogen and likely acts by initiating tumors through
25 direct DNA damage as well as by promoting tumor growth. Benzo[a]pyrene has been shown to
26 be mutagenic in multiple assay systems. Several modes of carcinogenic action are possible.
27 These include:

- 28
29 (1) Alteration of pathways regulating cell proliferation and survival (Tannheimer et al.,
30 1998);
- 31
32 (2) Inhibition of intracellular communication (Sharovskaia et al., 2003; Blaha et al.,
33 2002; Rummel et al., 1999);
- 34
35 (3) Altered intracellular Ca²⁺ signaling (Tannheimer et al., 1998);
- 36
37 (4) Modulation of cell survival, cell proliferation, and altered growth via generation of
38 oxidative stress and activation of oxidant stress signaling (Burdick et al., 2003; Miller
39 and Ramos, 2001);
- 40
41 (5) Altered apoptosis processes (Chen et al., 2003);

- 1
2 (6) Dysregulation of normal circulating hormone levels or activity affecting
3 tumorigenesis in reproductive tissues (Safe and Wormke, 2003; Archibong et al.,
4 2002) or the central nervous system (Dasgupta and Lahiri, 1992);
5
6 (7) Disruption of cell cycle kinetics in breast cancer cells (Jeffy et al., 2002, 2000); and
7
8 (8) Disruption of DNA repair through alteration of ribonucleic acid (RNA) polymerase
9 activity (Shah and Bhattacharya, 1989).
10

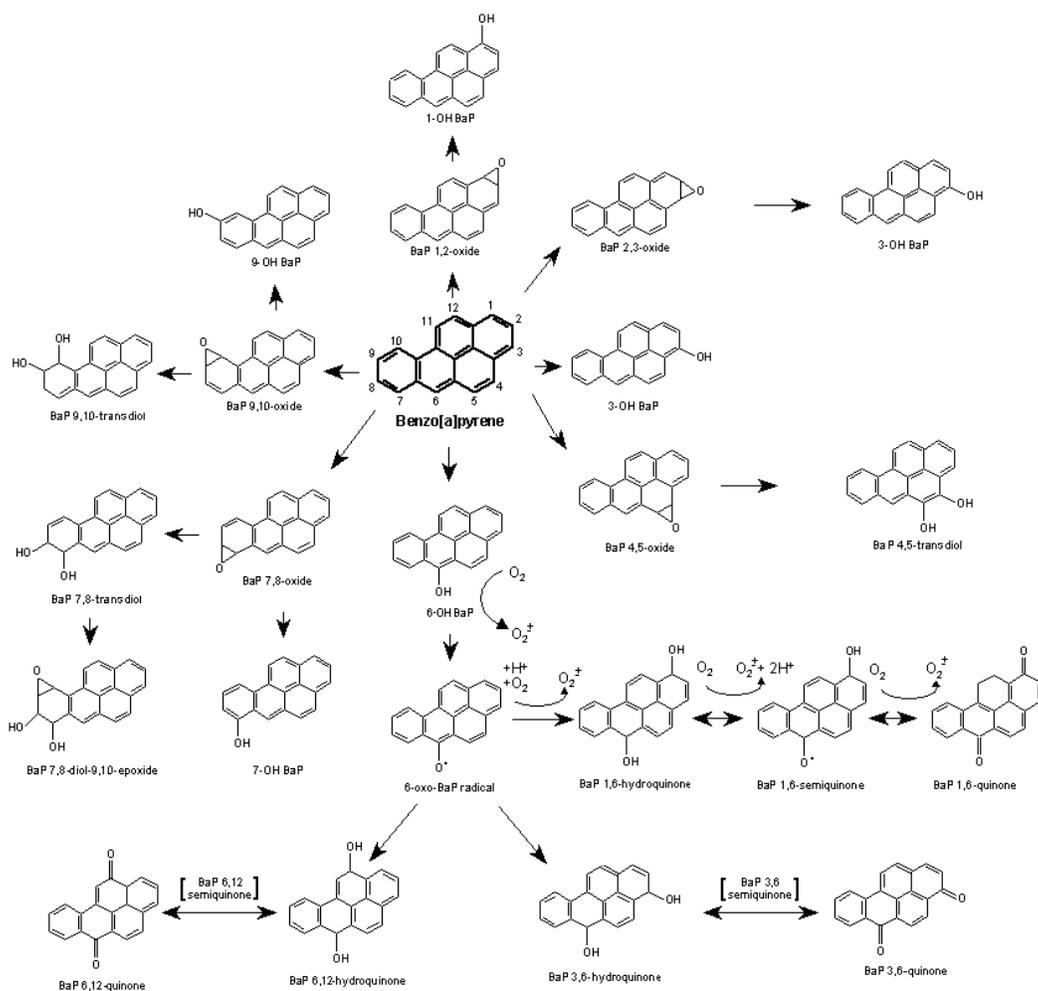
11 Oral (dietary) carcinogenicity bioassays are available that compare MGP residue
12 (Weyand et al., 1995) or coal tar preparations (Culp et al., 1998; Gaylor et al., 1998) with
13 benzo[a]pyrene. In both cases, there were significant differences in the target organ distribution
14 of tumors between benzo[a]pyrene and complex mixtures of PAHs. Following dietary
15 administration, benzo[a]pyrene-induced tumors were observed primarily at the point of contact
16 (i.e., the forestomach), while MGP residue and coal tar produced tumors in the lung, liver,
17 forestomach, skin, and other organs. Tissue-specific differences in metabolic activation and
18 DNA binding of PAHs may contribute to the observed differences in target organ sensitivity
19 (Weyand and Wu, 1995; Culp and Beland, 1994). However, a dietary study in A/J mice
20 (Weyand et al., 2004) showed that benzo[a]pyrene could induce significant increases in the
21 incidences of lung adenomas and forestomach carcinomas. Further, a gavage study in rats
22 (Kroese et al., 2001) demonstrated that oral exposure to benzo[a]pyrene could induce tumors in
23 the liver and auditory canal; no lung tumors were observed. The latter two studies indicate that,
24 contrary to the conclusions of earlier studies, benzo[a]pyrene can induce tumors at distal sites.

25 In summary, benzo[a]pyrene is the most appropriate compound to use as an index
26 chemical for carcinogenic PAHs. It is well-studied, with a robust database of both bioassay data
27 and mode of action information. Benzo[a]pyrene is a complete carcinogen with both initiating
28 and promoting properties, is among the most potent PAH carcinogens, and is prevalent in many
29 complex environmental mixtures. No alternative index chemical was identified from the list of
30 target PAHs.

31 32 **2.4. SIMILARITIES IN MODE OF CARCINOGENIC ACTION FOR PAHs**

33 Toxicological similarity of chemicals is the basis for the assumption of dose additivity
34 that underlies the RPF approach (U.S. EPA, 1990). The carcinogenic mode of action for PAHs
35 has been extensively reviewed (Ramesh, 2004; CCME, 2003; Bostrom et al., 2002; Larsen and
36 Larsen, 1998; WHO, 1998; Muller et al., 1997; Sjogren et al., 1996; ATSDR, 1995; Malcolm
37 and Dobson, 1994; U.S. EPA, 1990). Key events that have been associated with PAH
38 carcinogenicity include:
39

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12
- Oxidative metabolism to reactive intermediates that covalently bind to DNA, RNA, and proteins (benzo[a]pyrene metabolism is illustrated in Figure 2-2);
 - Formation of DNA adducts;
 - Tumor initiation due to mutations in cancer-related genes (e.g., tumor suppressor genes or oncogenes); and
 - Tumor promotion related to cytotoxicity and formation of reactive oxygen species, and/or Ah receptor (AhR) affinity and upregulation of genes related to biotransformation, growth, and differentiation.



13

14

15 Reprinted from Impact of cellular metabolism on the biological effects of benzo[a]pyrene

16 and related hydrocarbons, 2001 by Miller, KP; Ramos, KS; with permission of Taylor &

17 Francis.

18

19 Source: Miller and Ramos (2001).

20

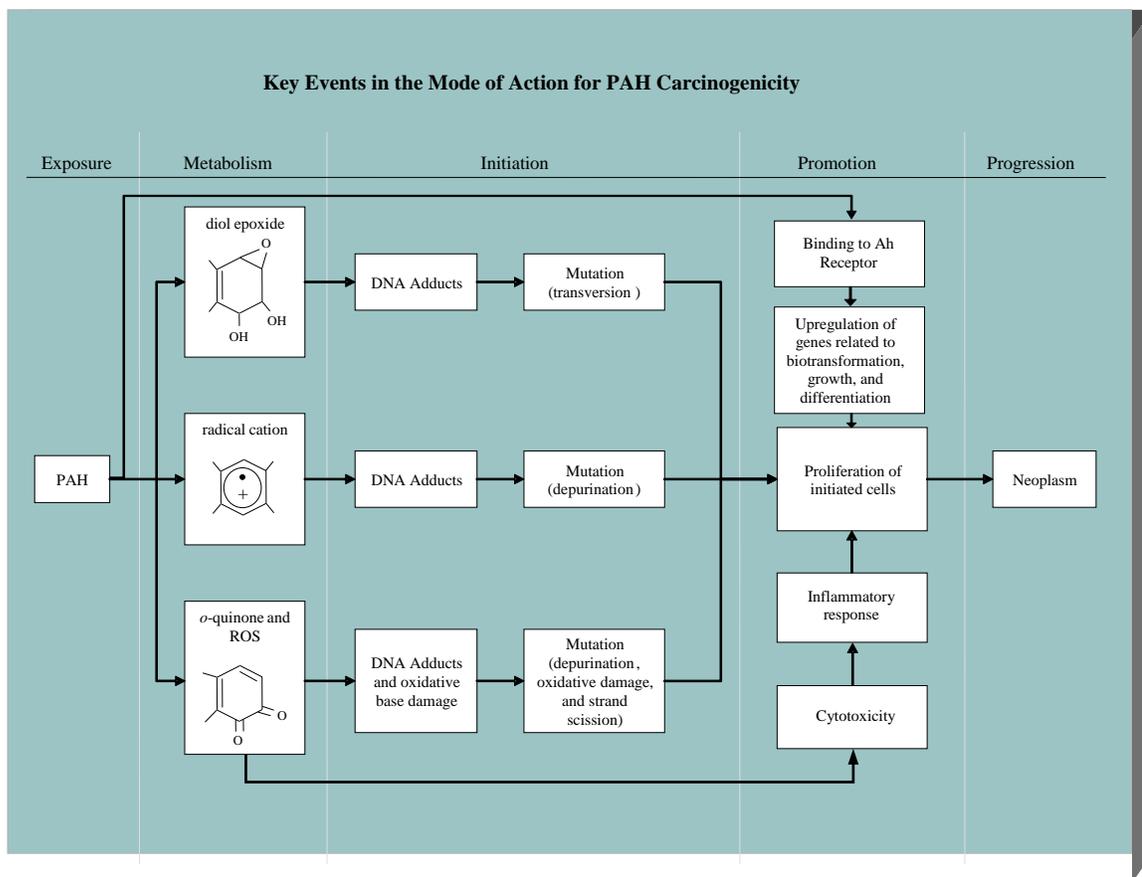
21 **Figure 2-2. Metabolic pathways for benzo[a]pyrene.**

22

1 *Formation of reactive intermediates and DNA adducts.* Each of the key events identified
2 above is affected by the chemical structure of the individual PAH. At least three distinct
3 molecular mechanisms have been proposed to explain the tumor initiation process of PAHs (Xu
4 et al., 2009; Jiang et al., 2007, 2005; Xue and Warshawsky, 2005; Bolton et al., 2000; Penning et
5 al., 1999; Harvey, 1996; Cavalieri and Rogan, 1995). These modes of action include the
6 formation of diol epoxides, radical cations, and o-quinones (Figure 2-3). Diol epoxide formation
7 leads to stable and unstable DNA adducts, mainly at guanine and adenine, which can lead to
8 mutations in proto-oncogenes and tumor-suppressor genes. Radical cation formation may lead to
9 the generation of unstable adducts at guanine and adenine, leading to apurinic sites and mutation
10 in *HRAS*. o-Quinone formation could lead to stable and unstable DNA adducts and generation of
11 reactive oxygen species, inducing mutations in *RP53*. The evidence supporting the role of these
12 reactive metabolites in tumor initiation includes a characterization of the specific DNA adducts
13 arising from PAH metabolism and observations of mutagenesis resulting from direct exposure.
14 Figure 2-3 illustrates the proposed key steps in the mode of action for PAH carcinogenesis.
15 These include the interaction of reactive metabolites with DNA to form adducts, induction of
16 depurination, transversion mutations (e.g., GC→TA or AT→TA), and oxidative damage to
17 DNA, and tumor promotion mediated by AhR-mediated effects on gene regulation.

18

1
2
3



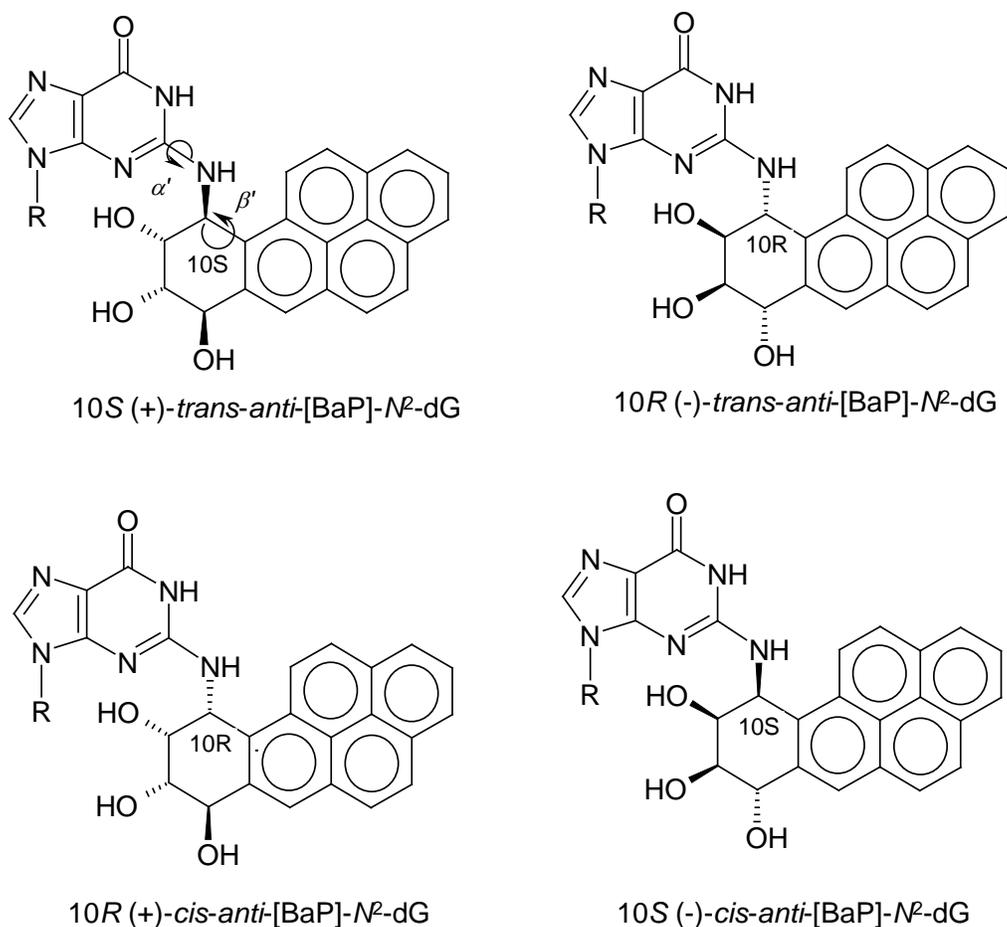
4
5
6

Figure 2-3. Overview of the proposed key events in the mode of action for PAH carcinogenicity.

7 The formation of diol epoxides is a proposed key step in the most established mode of
8 action for PAH-induced carcinogenicity. Extensive studies of the metabolism of carcinogenic
9 PAHs suggest that bay- and fjord-region diol epoxides are some of the ultimate reactive
10 metabolites of PAHs (Jerina et al., 1978; Jerina and Lehr, 1977). These metabolites are
11 generally formed through cytochrome P450 (CYP) oxidation to form epoxides and epoxide
12 hydrolase cleavage resulting in diol formation. CYP1A1 appears to be the primary isozyme
13 involved in diol epoxide formation; however, other isozymes may also contribute to PAH
14 metabolism (i.e., CYP1A2, CYP1B1, CYP3A4) (Bostrom et al., 2002; ATSDR, 1995). Non-
15 alternant PAHs, composed of fused benzenoid and five-membered rings, may be metabolized
16 through other pathways resulting in the formation of reactive intermediates that bind to DNA.
17 Classic bay- and fjord-region diol epoxides may be formed from these compounds; however,
18 epoxide formation at cyclopenta-ring structures has also been demonstrated to result in DNA
19 adduct formation (Bostrom et al., 2002).

20 Many studies have been performed to evaluate the formation of DNA adducts following
21 in vivo or in vitro exposure to PAHs. Diol epoxide metabolites interact preferentially with the
22 exocyclic amino groups of deoxyguanine and deoxyadenine (Geacintov et al., 1997; Jerina et al.,

1 1991). Adducts may give rise to mutations, unless these adducts are removed by DNA repair
2 processes prior to replication. The stereochemical nature of the diol epoxide metabolite (i.e.,
3 anti- versus syn-diol epoxides) affects the number and type of adducts and mutation that occurs.
4 Figure 2-4 presents the structures of four stereoisomeric adducts arising from the interaction of
5 benzo[a]pyrene diol epoxide metabolites with the deoxyguanosine (dG) residues in DNA
6 (Geacintov et al., 1997). Transversion mutations (e.g., GC→TA or AT→TA) are the most
7 common type of mutation found in mammalian cells following diol epoxide exposure (Bostrom
8 et al., 2002).



9

10 Source: Geacintov et al. (1997).

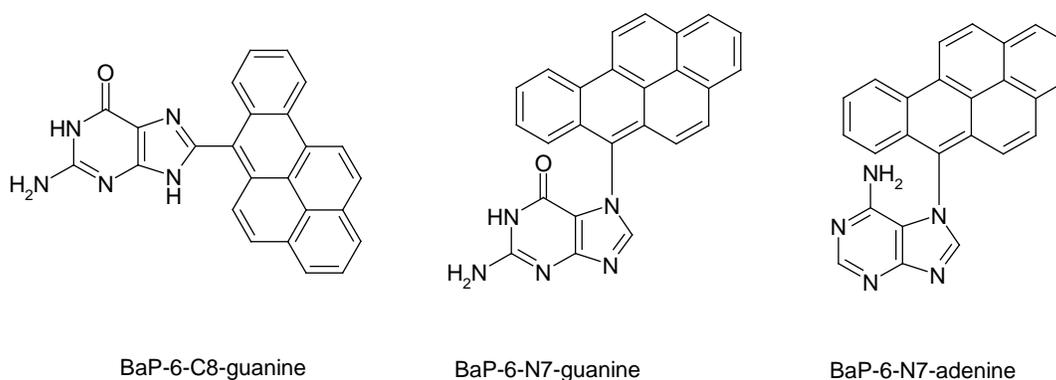
11

12 **Figure 2-4. Structures of the four stereoisomeric adduct moieties,**
13 ***anti*-[BaP]-N²-dG, derived from the *trans*- or *cis*- covalent binding of**
14 **(+)-*anti*-BaP diol epoxide or (-)-*anti*-BaP diol epoxide to dG residues in DNA.**

15

16 Radical cation formation involves a one-electron oxidation that produces electrophilic
17 radical cation intermediates (Cavalieri and Rogan, 1995, 1992). Oxidation of this type can occur
18 by CYP or peroxidase enzymes (i.e., horseradish peroxidase, prostaglandin H synthetase).
19 Radical cations can be further metabolized to phenols and quinones (Cavalieri et al., 1988a), or

1 they can form unstable adducts with DNA that ultimately result in depurination (Cavalieri et al.,
2 2005, 1993; Rogan et al., 1993). Radical cations have been shown to play a major role in
3 formation of DNA adducts for several carcinogenic PAHs (e.g., 7,12-dimethylbenzanthracene,
4 benzo[a]pyrene, dibenzo[a,l]pyrene). The predominant depurinating adducts occur at the
5 N-3 and N-7 positions of adenine and the C-8 and N-7 positions of guanine (Cavalieri and
6 Rogan, 1995; Li et al., 1995). Figure 2-5 illustrates three depurinating adducts of
7 benzo[a]pyrene formed by one-electron oxidation. Abasic sites resulting from base depurination
8 undergo error-prone excision repair to induce mutations. In the case of dibenzo[a,l]pyrene-
9 treated mouse skin, repair error from abasic sites resulted in H-ras oncogene mutations that
10 underwent rapid clonal expansion and regression (Chakravarti et al., 2000). H-ras mutations in
11 mouse skin papillomas also corresponded to adenine and guanine depurinating adducts resulting
12 from exposure to dibenzo[a,l]pyrene, 7,12-dimethyl-benz[a]anthracene, benzo[a]pyrene, and
13 benzo[a]pyrene-7,8-dihydrodiol (Chakravarti et al., 2008).



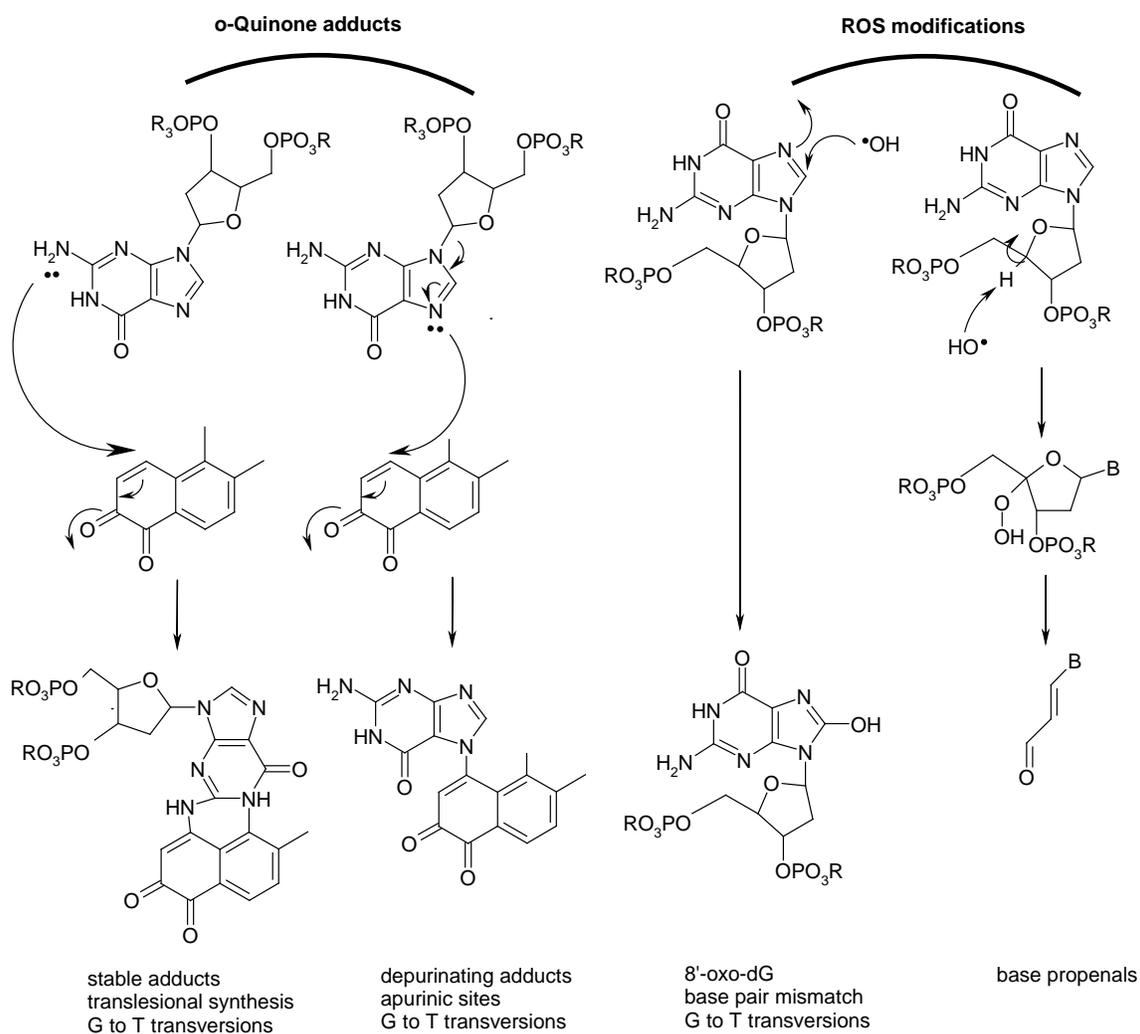
27 Reprinted from Central role of radical cations in metabolic activation of polycyclic
28 aromatic hydrocarbons, 1995 by Cavalieri, EL; Rogan, EG; with permission of Taylor &
29 Francis.

30
31 Source: Cavalieri and Rogan (1995).

32
33 **Figure 2-5. Depurinating adducts of benzo[a]pyrene formed by one-electron**
34 **oxidation.**
35

36 o-Quinone metabolites of PAHs are formed by enzymatic dehydrogenation of
37 dihydrodiols (Bolton et al., 2000; Penning et al., 1999; Harvey, 1996; ATSDR, 1995).
38 Dihydrodiol dehydrogenase enzymes are members of the α -keto reductase gene superfamily.
39 o-Quinone metabolites are potent cytotoxins, are weakly mutagenic, and are capable of
40 producing a broad spectrum of DNA damage. These metabolites can interact directly with DNA
41 and can also result in production of reactive oxygen species (i.e., hydroxyl and superoxide
42 radicals) that may produce further cytotoxicity and DNA damage. The DNA damage caused by

1 o-quinones may include the formation of stable adducts (Balu et al., 2006), N-7 depurinating
 2 adducts (McCoull et al., 1999), oxidative base damage (i.e., 8-oxo-2'-dG or 8-oxo-dG) (Park et
 3 al., 2006, 2005), and strand scission (Flowers-Geary et al., 1997). The reactive oxygen species
 4 generated by the o-quinone of benzo[a]pyrene and other PAH o-quinones have been shown to
 5 induce mutation in the p53 tumor suppressor gene (Park et al., 2008; Shen et al., 2006; Yu et al.,
 6 2002). Figure 2-6 illustrates the spectrum of DNA adducts associated with PAH o-quinones.
 7



8
 9 Source: Bolton et al. (2000).

10
 11 **Figure 2-6. Spectrum of DNA adducts anticipated with PAH o-quinones.**

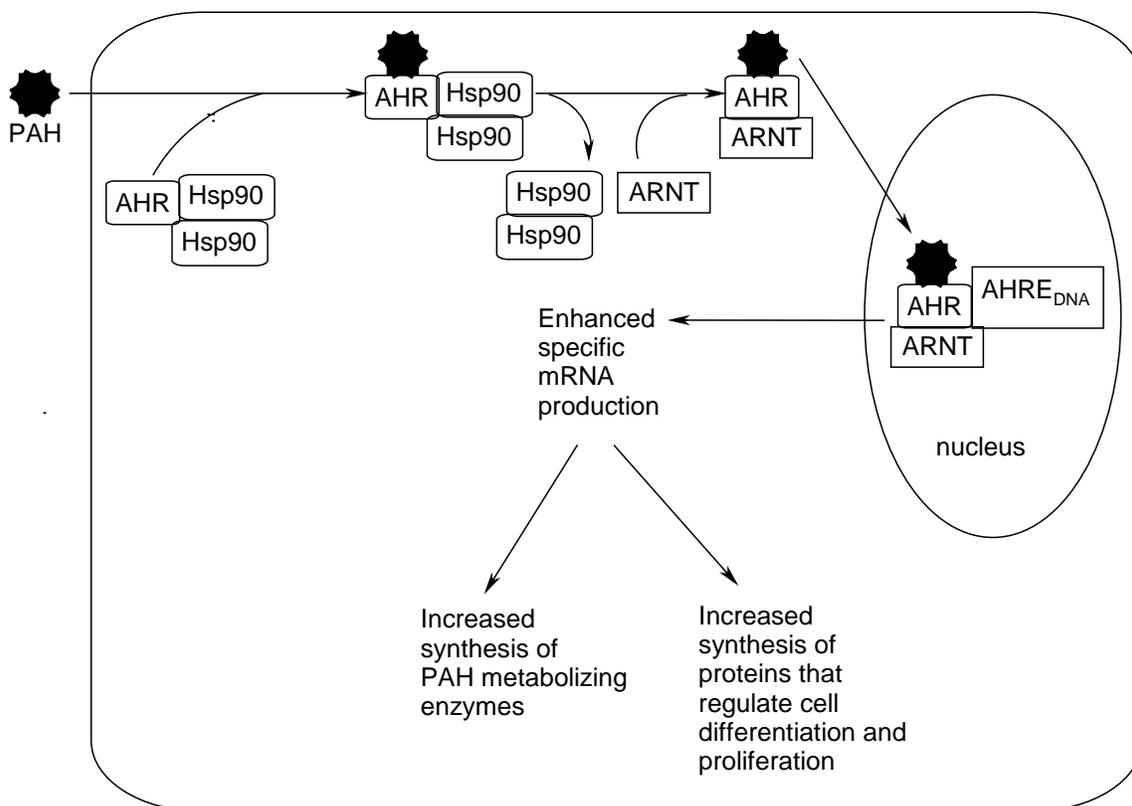
12
 13 The cytotoxicity of o-quinone metabolites may also contribute to tumor promotion via
 14 inflammatory responses leading to cell proliferation (Burdick et al., 2003).

15 *Genotoxicity and mutagenicity.* The genotoxicity and mutagenicity of PAHs have been
 16 demonstrated in various bacterial and mammalian assays (see Section 4.3.2 below) (reviewed in
 17 WHO, 1998; ATSDR, 1995). Mutagenesis of PAHs in the Ames assay (*Salmonella*

1 *typhimurium*) as well as other bacterial assays requires the presence of a mammalian metabolic
2 enzyme system. In most cases, this is supplied by postmitochondrial supernatant (S9) from the
3 liver of rodents treated with an enzyme inducer. Mammalian cell mutagenesis in Chinese
4 hamster V79 cells and mouse lymphoma L5178Y cells also requires metabolic activation in the
5 form of a rodent S9 mix or co-cultivation with metabolically active rodent cells (i.e., cell-
6 mediated assay). Several studies have noted a correlation between mutagenic potency and tumor
7 initiation potency in the two-stage dermal carcinogenicity assay for multiple PAH compounds
8 (LaVoie et al., 1985, 1979; Raveh et al., 1982).

9 *Tumor promotion and the AhR.* The ability of certain PAHs to act as tumor promoters as
10 well as initiators may increase their carcinogenic potency (Andrews et al., 1978). The
11 promotional effects of PAHs appear to be related to AhR affinity and the upregulation of genes
12 related to growth and differentiation (Bostrom et al., 2002). Figure 2-7 illustrates the function of
13 the AhR and depicts the genes regulated by this receptor as belonging to two major functional
14 groups (i.e., induction of metabolism or regulation cell differentiation and proliferation). PAHs
15 bind to the cytosolic AhR in complex with heat shock protein 90. The ligand-bound receptor is
16 then transported to nucleus in complex with the AhR nuclear translocator protein. The AhR
17 complex interacts with AhR elements of DNA to increase the transcription of proteins associated
18 with induction of metabolism and regulation of cell differentiation and proliferation.

19



1

2 Reprinted from Molecular biology of the aromatic hydrocarbon (dioxin) receptor, 1994
 3 by Okey, AB; et al. with permission of Elsevier.

4

5 Source: Okey et al. (1994).

6

7 **Figure 2-7. Interaction of PAHs with the AhR – regulation of genes related**
 8 **to induction of metabolism and cell differentiation and proliferation.**

9

10 *Tumor promotion and cytotoxicity.* PAHs are metabolized to o-quinones, which are
 11 cytotoxic and can generate reactive oxygen species (Bolton et al., 2000; Penning, 1999). PAH
 12 o-quinones reduce the viability and survival of rat and human hepatoma cells (Flowers-Geary et
 13 al., 1996, 1993). Inflammatory responses to cytotoxicity may contribute to the tumor promotion
 14 process. For example, benzo[a]pyrene quinones (1,6-, 3,6-, and 6,12-benzo[a]pyrene-quinone)
 15 generated reactive oxygen species and increased cell proliferation by enhancing the epidermal
 16 growth factor receptor pathway in cultured breast epithelial cells (Burdick et al., 2003). Dermal
 17 exposure of mice to dibenzo[a,l]pyrene and dimethyl-benz[a]anthracene resulted in an
 18 inflammatory response that was correlated with epidermal hyperplasia and skin tumor promotion
 19 (Casale et al., 2000, 1997). The extent of epidermal hyperplasia was correlated with the cytokine
 20 mRNA response in lymph nodes and skin of treated mice (Casale et al., 2000).

21 *Genetic targets and tumor formation.* DNA adducts and oncogenes/tumor suppressor
 22 gene mutations have been demonstrated in tumor tissue from humans and laboratory animals.

1 DeMarini et al. (2001) demonstrated mutations in the p53 tumor suppressor gene and the K-ras
2 oncogene in the lung tumors of nonsmokers, whose tumors were associated with exposure to
3 smoky coal. Lung tumors were obtained from 24 nonsmoking women from China (age 30–
4 63 years, mean age 48.5 ± 8.8 years) who used smoky coal in their homes without chimneys.
5 Bronchioloalveolar adenocarcinoma and acinar adenocarcinoma were observed in 54 and 46% of
6 the women studied, respectively. The observed mutations in lung tumors were primarily G→T
7 transversions at either K-ras or p53. The mutation hotspots in the lung tumors that were
8 examined corresponded with hot spots for PAH adducts (codon 154), cigarette smoke associated
9 mutations (codon 249), and both of these events together (codon 273). The mutation spectrum
10 was described as unique and consistent with exposure to PAHs in the absence of cigarette smoke.

11 Mutations in the K-ras, H-ras, and p53 genes were assessed in forestomach tumors
12 ($n = 31$) of mice fed benzo[a]pyrene in the diet (0, 5, 25, or 100 ppm) for 2 years (Culp et al.,
13 2000). Sixty-eight percent of 31 forestomach tumors analyzed had K-ras mutations, which were
14 G→T or C transversions in codon 12 or 13. H-ras (codon 13) and p53 mutations characterized
15 as G→T or C transversions were also each found in 10% of forestomach tumors.
16 [³²P]-postlabeling of forestomach DNA of benzo[a]pyrene-treated mice revealed one major
17 adduct characterized as dG N² BPDE. In mice exposed to benzo[a]pyrene at several
18 concentrations in the diet for 4 weeks (5, 25, and 100 ppm), there was an approximate linear
19 relationship between the daily dose of benzo[a]pyrene (in units of $\mu\text{g}/\text{day}$) and the concentration
20 of dG-N²-BPDE-DNA adducts in the forestomach (Culp et al., 2000, 1996a). In contrast, the
21 tumor dose-response data in mice exposed for 2 years showed a sharp increase in incidence
22 between the 5-ppm group (6% of mice had forestomach tumors) and the 25-ppm group (78% had
23 forestomach tumors) (Culp et al., 1996a). The appearance of increased levels of BPDE-DNA
24 adducts in the target tissue at 28 days is temporally consistent with the contribution of these
25 adducts to the initiation of forestomach tumors at 25 and 100 ppm benzo[a]pyrene in the diet.
26 However, the absence of a sharp increase in the BPDE-DNA relationship between 5 and 25 ppm
27 benzo[a]pyrene is consistent with the possible contributions of mutagenic modes of action other
28 than the diol epoxide pathway (i.e., formation of depurinated DNA adducts from the radical
29 cation or aldo-keto-reductase pathways and reactive oxygen species DNA damage from the aldo-
30 keto-reductase pathway).

31 A series of experiments designed to evaluate the mechanistic relationship between PAH
32 DNA adducts, oncogene mutations, and lung tumorigenesis were performed in the A/J mouse
33 lung model (Nesnow et al., 1998a, 1996, 1995; Mass et al., 1993). Tumorigenic potency in the
34 lung of A/J mice varied over 2 orders of magnitude following a single intraperitoneal injection of
35 seven PAHs of varying structure (benzo[a]pyrene, benzo[b]fluoranthene, benz[j]aceanthrylene,
36 dibenz[a,h]anthracene, dibenzo[a,l]pyrene, cyclopenta[c,d]pyrene, and 5-methylchrysene).
37 When considering the non-alkylated PAHs, the number of lung adenomas per mouse was highest

1 for benz[j]aceanthrylene and cyclopenta[c,d]pyrene, each of which contain a pentacyclic ring
2 feature. The major DNA adducts identified in the mouse lung included:

- 3
- 4 (1) Bay region diol epoxide adducts for benzo[a]pyrene, dibenz[a,h]anthracene, and
5 5-methylcholanthrene;
- 6
- 7 (2) Phenolic diol epoxide adducts for benzo[b]fluoranthene;
- 8
- 9 (3) Cyclopenta-ring adducts for cyclopenta[c,d]pyrene and benz[j]aceanthrylene;
- 10
- 11 (4) Bisdihydrodiol epoxide adducts for dibenz[a,h]anthracene; and
- 12
- 13 (5) Fjord-region diol epoxide adducts for dibenzo[a,l]pyrene (Nesnow et al., 1998a,
14 1996, 1995; Mass et al., 1993).
- 15

16 Guanine adducts were most common for all PAHs; however, adenine adducts were also
17 demonstrated for dibenzo[a,l]pyrene and benz[j]aceanthrylene. Quantitative analysis of DNA
18 adducts by [³²P]-postlabeling illustrates the importance of measuring DNA adduct levels over
19 time. A time-integrated DNA adduct level (TIDAL) was linearly related to the dose of a
20 particular PAH. The relationship of TIDAL level to tumor formation was similar for PAHs that
21 produce different types of adducts and different mutations in the Ki-ras oncogene. This suggests
22 that the probability of tumor formation for these PAHs may be related to the extent of overall
23 DNA damage and repair rather than the formation of a specific adduct at specific sites.

24 The DNA sequence analysis of Ki-ras mutations in lung adenomas at codons 12 and 61
25 was generally consistent with the DNA adduct data in that PAHs that produced guanine adducts
26 also produced Ki-ras guanine mutations (Nesnow et al., 1998a, 1996, 1995; Mass et al., 1993).
27 Cyclopenta[c,d]pyrene, benz[j]aceanthrylene, and 5-methylchrysene produced large numbers of
28 adenomas per mouse (>90) and also produced a large proportion of tumors with CGT mutations
29 at Ki-ras codon 12. Cyclopenta-ring adduct formation by cyclopenta[c,d]pyrene and
30 benz[j]aceanthrylene was correlated with the formation of GGT→CGT mutations at Ki-ras
31 codon 12. The primary mutation type for benzo[a]pyrene, benzo[b]fluoranthene, and
32 dibenzo[a,l]pyrene was the GGT→TGT mutation, which is associated with the formation of diol
33 epoxide guanine adducts. Dibenz[a,h]anthracene did not induce mutations in Ki-ras codons 12
34 or 61; however, diol epoxide guanine adducts and lung adenomas in A/J mice were observed.
35 This suggests that a different genetic target may be involved in carcinogenicity of this
36 compound.

37 H-ras mutations were studied in skin papillomas of SENCAR mice resulting from dermal
38 initiation by benzo[a]pyrene or benzo[a]pyrene-7,8-dihydrodiol (400 nmol) followed by
39 12-O-tetra-decanoylphorbol-13-acetate (TPA) promotion (Chakravarti et al., 2008). Polymerase
40 chain reaction (PCR) amplification of the H-ras gene and sequencing revealed that codon 13

1 (GGC to GTC) and codon 61 (CAA to CTA) mutations in papillomas corresponded to the
2 relative levels of depurinating adducts of guanine and adenine, despite the formation of
3 significant amounts of stable DNA adducts.

4 Other studies also suggest that multiple genetic targets may be involved in PAH
5 mutagenicity and carcinogenicity (Conney et al., 2001; Smith et al., 2000). Smith et al. (2000)
6 indicated that diol epoxide adducts and mutations were observed in the p53 tumor suppressor
7 gene following in vitro exposure of cultured human bronchial epithelial cells to metabolites of
8 benzo[a]pyrene, chrysene, benzo[c]phenanthrene, and benzo[g]chrysene. PAH adducts and
9 corresponding mutations preferentially formed at lung mutational hot spots (codons 154, 157,
10 158, 245, 248, and 273), suggesting that PAHs may contribute to the mutation spectrum
11 observed in human lung cancer. Conney et al. (2001) provided evidence that dose-dependent
12 differences may exist for the mutation spectra seen in PAH-induced tumors. Skin papillomas
13 induced by benzo[a]pyrene in female mice were examined for mutations in the c-Ha-ras proto-
14 oncogene. The major difference between high- and low-dose groups was mutations at exon 2 of
15 the c-Ha-ras gene, with the proportion of AT base pair mutations higher in the low-dose group.
16 Dose-dependent changes in the mutation profile were also evident in Chinese hamster V79 cells
17 exposed to the diol epoxides of benzo[a]pyrene and benzo[c]phenanthrene (i.e., the proportion of
18 AT mutations decreased with increasing concentration).

19 In conclusion, there is evidence that an assumption of a similar toxicological action is
20 reasonable for PAHs; however, the carcinogenic process for individual PAHs is likely to be
21 related to some unique combination of multiple molecular events resulting from formation of
22 several reactive species. For these reasons, the use of an RPF approach to estimate cancer risk
23 associated with PAH exposure is considered appropriate. A common mutagenic mode of action
24 for carcinogenic PAHs is hypothesized based on information available for the indicator
25 chemical, benzo[a]pyrene (U.S. EPA, 2005b). The uncertainties and limitations related to the
26 mode of action assumption for PAH-induced cancer are further discussed in Section 8.5.

27 28 **2.5. STRUCTURAL ALERTS FOR PAH CARCINOGENESIS**

29 The carcinogenic activity of PAH compounds is influenced by specific structural
30 features. For example, alternant PAHs having four or more benzene rings exhibit greater
31 carcinogenic potency than PAHs with two or three benzene rings (Boström et al., 2002). The
32 carcinogenic activity of PAHs is also related to the specific arrangement of the benzene rings.
33 As described in Section 2.4, PAHs that form bay- and fjord-region diol or dihydrodiol epoxides
34 are more potent carcinogens compared with linear PAHs that lack this structural feature
35 (Boström et al., 2002). These metabolites are resistant to detoxification due to stereochemical
36 effects and, consequently, are more likely to be mutagenic and cause cancer (Buterin et al., 2000;
37 Chang et al., 1981; Buening et al., 1979; MacLeod et al., 1979; Flesher et al., 1976).
38 Dihydrodiol epoxides formed at other positions on the PAH molecule (i.e., not the bay- or fjord-

1 regions) are more accessible to glutathione transferase detoxification and are less potent
2 mutagens and carcinogens (MacLeod et al., 1979; Flesher et al., 1976). Nonalternant PAHs
3 containing fused benzenoid and five-membered rings, can also be metabolized to bay- and fjord-
4 region diol epoxides (Bostrum et al., 2002); however, epoxide formation at the cyclopenta- ring
5 structure may also contribute to carcinogenicity (Bostrum et al., 2002; Nyholm et al., 1996).

6 PAHs with at least four rings and a classic bay- or fjord-region (formed entirely by
7 benzene rings; see Figure 2-1) may be characterized as containing structural alerts for
8 carcinogenesis. However, this structural characterization is likely to be overly simplistic and
9 other features may be important to carcinogenesis. Recent studies have applied quantitative
10 structure activity relationship (QSAR) methods to evaluate the relationship between specific
11 PAH structural features and mechanistic events related to carcinogenesis (Bruce et al., 2008;
12 Vijayalakshmi et al., 2008).

13 14 **2.6. SIMILARITIES IN RELATIVE POTENCY ACROSS ENDPOINTS**

15 Studies that have evaluated the association between cancer-related endpoints and
16 tumorigenicity of PAHs are briefly summarized below.

17 Several studies have been performed that compare the bacterial or mammalian cell
18 mutagenicity of various PAHs with tumor initiating activity or complete carcinogenesis
19 (Blackburn et al., 1996; LaVoie et al., 1985, 1981, 1979; Raveh et al., 1982; Andrews et al.,
20 1978). In general, mutagenicity appears to correlate best with tumor initiation. Complete
21 carcinogenicity is not well-predicted by positive findings in short-term mutagenicity assays.
22 Andrews et al. (1978) tested 24 PAHs for bacterial mutagenicity in the Ames test and compared
23 these findings to evidence of carcinogenicity (parent and metabolites) from previously published
24 studies. Positive findings of both mutagenicity and carcinogenicity were only reported for 14 of
25 the 24 PAHs evaluated. Eight of the 10 remaining PAHs were found to be mutagenic in the
26 Ames assay, but were not carcinogenic in animal studies. LaVoie et al. (1979) compared the
27 mutagenicity, tumor-initiating activity, and complete carcinogenicity of several series of
28 structurally related PAHs. Tumor-initiating activity was found to correspond with complete
29 carcinogenicity. Quantitation of mutagenicity in the Ames assay for structurally related PAHs
30 failed to provide a reliable indication of tumor-initiating activity or complete carcinogenicity. In
31 addition, mutagenicity results could not be used to predict which PAHs would be
32 noncarcinogenic. Many PAHs were active mutagens, but were not shown to be carcinogenic.
33 Studies using methylated derivatives of anthracene demonstrated a correlation between
34 mutagenicity of specific metabolites and tumor initiating activity in mouse skin (LaVoie et al.,
35 1985). Raveh et al. (1982) reported that the mutagenic response to PAHs in Chinese hamster
36 V79 cells was similar to the skin tumor initiating activity observed in SENCAR mice.
37 Benzo[a]pyrene was demonstrated to be a more potent mutagen and skin tumor initiator than
38 cyclopenta[c,d]pyrene.

1 Blackburn et al. (1996) compared the predictive power of a mutagenicity test (the
2 Modified Ames Test, which uses enhanced extraction techniques and greater levels of S9 to
3 improve performance when oils are tested) and DNA adduct formation (measured by
4 P32-postlabelling) to predict the dermal carcinogenicity of 120 PAH-containing oils. The
5 Modified Ames Test provided greater accuracy in predicting carcinogenicity (96%). In addition,
6 the mutagenicity index estimated from this test correlated strongly ($r^2 \geq 0.83$) with PAH content
7 of the oils. The DNA adduct assay predicted carcinogenicity correctly with about 73% accuracy;
8 however, the study authors indicated that the lower predictability may have resulted from the use
9 of adduct data that were collected while the assay was still undergoing development.

10 Sjogren et al. (1996) performed a multivariate analysis of data for 29 PAHs to evaluate
11 the relevance of different biological assays to the carcinogenic properties of PAHs. This analysis
12 considered carcinogenicity (International Agency for Research on Cancer [IARC] weight of
13 evidence and QSAR predictions), bacterial mutagenicity, inhibition or enhancement of bacterial
14 mutagenicity, AhR affinity, and enzyme induction. Bacterial mutagenicity data were poorly
15 correlated with observed and predicted cancer data, while AhR affinity variables were
16 statistically relevant to describe these data.

17 Other studies suggest that the relationship between affinity for the AhR and carcinogenic
18 potency is unclear. For example, highly mutagenic fjord-region PAHs are potent carcinogens
19 despite exhibiting lower AhR affinity (reviewed by Bostrom et al., 2002). Likewise, some PAHs
20 that strongly activate the AhR, such as benzo[k]fluoranthene (Machala et al., 2001), are only
21 weakly carcinogenic. In addition, some studies have demonstrated the formation of DNA
22 adducts in the liver of AhR knock-out mice following intraperitoneal or oral exposure to
23 benzo[a]pyrene (Sagredo et al., 2006; Uno et al., 2006; Kondraganti et al., 2003), indicating that
24 Ah responsiveness is not strictly required for metabolic activation and genotoxicity. These
25 findings suggest that there may be alternative (i.e., non-AhR mediated) mechanisms of
26 benzo[a]pyrene activation in the mouse liver, and that AhR affinity would not be a good
27 predictor of carcinogenic potency.

28 AhR-mediated CYP1A1 induction by PAHs is considered to contribute to tumorigenesis
29 by increasing the production of DNA-reactive metabolites (Ayrton et al., 1990). However,
30 CYP1A1 induction potency alone does not appear to correlate well with carcinogenic potency of
31 PAHs. Ethoxyresorufin O-deethylase (EROD) activity was evaluated as a measure of CYP1A1
32 induction in rat hepatocytes (Bosveld et al., 2002; Till et al., 1999; Willett et al., 1997) and trout
33 liver cells (Bols et al., 1999). Till et al. (1999) additionally measured levels of CYP1A1 protein
34 and mRNA. Machala et al. (2001) measured PAH activation of the AhR using a chemical-
35 activated luciferase reporter gene assay. Comparable results were observed across studies, and
36 benzo[k]fluoranthene was consistently demonstrated to be the most potent inducer of CYP1A1.
37 Chrysene, benzo[b]fluoranthene, dibenz[a,h]anthracene, and indeno[1,2,3-c,d]pyrene were also
38 demonstrated to be more potent inducers of CYP1A1 than benzo[a]pyrene. However, most of

1 these PAH compounds (except dibenz[a,h]anthracene) are considerably less potent as
2 carcinogens in animal bioassays.

3 Ross et al. (1995) evaluated the relationship between TIDAL values for DNA adduct
4 formation and lung adenoma formation in A/J mice. The TIDAL value versus tumor relationship
5 was similar for five different PAHs, suggesting a correlation between adduct levels and tumor
6 formation (regression analysis was not performed). As described above, the relationship of
7 TIDAL level to tumor formation was similar for PAHs that produce different types of adducts
8 and different mutations in the Ki-ras oncogene, suggesting that the probability of tumor
9 formation may be related to the extent of overall DNA damage and repair (Nesnow et al., 1998a,
10 1996, 1995; Mass et al., 1993).

11 To summarize, various cancer-related endpoints have been associated with PAH
12 carcinogenicity. Tumor initiation ability was shown to correspond well with complete
13 carcinogenicity, while some studies suggested that bacterial mutagenesis assays of individual
14 PAHs were not highly correlated with tumor formation (Sjogren et al., 1996; Lavoie et al., 1979).
15 DNA adduct formation corresponded with lung adenoma formation in A/J mice for several
16 PAHs (Sjogren et al., 1996; Ross et al., 1995; LaVoie et al., 1979). The development of RPFs in
17 this analysis considered both tumorigenicity and cancer-related endpoints (e.g., mutagenicity,
18 clastogenicity, morphological transformation). Studies of AhR binding/activation were not
19 considered for use in deriving RPFs because there does not appear to be a clear relationship
20 between affinity for the AhR and carcinogenic potency of PAHs.

21 22 **2.7. SIMILARITIES IN RELATIVE POTENCY ESTIMATES ACROSS SPECIES AND** 23 **EXPOSURE ROUTES**

24 Available studies suggest that the potency of individual PAHs is generally consistent
25 across species and study protocols. The consistency of potency estimates based on in vivo
26 tumorigenicity studies conducted using different study protocols and exposure routes in varying
27 species/strains of test animals is summarized below.

28 Nisbet and LaGoy (1992) and Clement Associates (1988) reported that RPFs for PAHs
29 are reasonably consistent across different study protocols using varying species/strains of
30 laboratory animals. RPF estimates were calculated in multiple test systems including mouse skin
31 complete carcinogenesis studies, mouse skin tumor initiation studies, studies in rat lung
32 (implantation), other rat studies (intrapulmonary injection, subcutaneous injection), and newborn
33 mouse studies (intraperitoneal injection). The RPF estimates for specific PAHs calculated from
34 different assay systems varied by less than an order of magnitude. The relative potency of
35 individual PAHs to benzo[a]pyrene was also shown to be very similar when based on data in
36 different strains of mice using different mouse tumor initiation models (Slaga and Fisher, 1983).
37 Muller et al. (1997) compared the relative potency of benzo[a]pyrene and 3-methylcholanthrene
38 from data generated in three species (rat, mouse, and hamster). Similar RPF values (i.e., within a

1 factor of 2) were derived for oral exposures in mice, rats, and hamsters. In their comparison
2 across different exposure routes (oral, respiratory, and dermal), Muller et al. (1997) reported
3 similar relative potencies for benzo[a]pyrene and 3-methylcholanthrene (within a factor of 2) for
4 data from rats exposed via oral and respiratory routes, and for mice exposed via oral and dermal
5 routes. The relative potency for respiratory exposure in mice was an order of magnitude lower
6 than relative potencies for the other two exposure routes.

7 Schneider et al. (2002) performed a more recent evaluation of the impact of exposure
8 route on the determination of RPFs. Potency ratios were calculated for several carcinogenicity
9 bioassays by dividing the carcinogenic potency of a PAH mixture by the carcinogenic potency of
10 benzo[a]pyrene as a single substance. The potency ratios were observed to vary by exposure
11 route and target organ. For example, potency ratios associated with forestomach tumors from
12 oral exposure ranged from 0.7 to 1.2 (i.e., the potencies of the PAH mixtures and benzo[a]pyrene
13 to induce forestomach tumors were approximately equal). This suggested that these tumors may
14 be attributable to the benzo[a]pyrene content of the mixture. Potency ratios for skin tumor
15 production from dermal exposure ranged from 2 to 11, whereas RPFs calculated for lung tumors
16 from oral exposure, pulmonary implantation, or inhalation were greater than 20. These results
17 suggested that the benzo[a]pyrene content of PAH mixtures may be only slightly responsible for
18 lung and dermal carcinogenicity. Schneider et al. (2002) suggested that RPF estimates should be
19 derived separately for oral, dermal, and inhalation exposure using studies with the relevant
20 exposure pathway.

21 To summarize, there is some consistency within the in vivo carcinogenicity database for
22 relative potency estimates derived from different species and strains exposed by various routes,
23 although this is an area for which further research is needed. However, Schneider et al. (2002)
24 have cautioned that potency ratios appear to cluster by exposure route and target organ and have
25 suggested that route-specific RPFs be developed. There is also some concern regarding the use
26 of benzo[a]pyrene as an index chemical to estimate lung cancer from PAH mixtures, considering
27 that the lung is relatively insensitive to benzo[a]pyrene-induced tumorigenicity following oral
28 exposure (Gaylor et al., 1998). Section 8.6 provides a comparison of RPF values calculated in
29 this report, using bioassay data from different exposure routes and study designs. RPF values
30 were comparable across most exposure routes, with the exception of the newborn mouse
31 intraperitoneal injection studies.

32 33 **2.8. DOSE ADDITIVITY OF PAHs IN COMBINED EXPOSURES**

34 Use of the RPF approach assumes that doses of component chemicals that act in a similar
35 manner can be added together, after scaling the potencies relative to the index chemical, and that
36 interaction effects do not occur at low environmental exposure levels (U.S. EPA, 2000, 1986).
37 The level of confidence in the RPF approach is increased if dose additivity can be demonstrated
38 experimentally, even with simple mixtures. For PAHs, the assumption of dose additivity at low

1 exposures cannot be confirmed or refuted based on the available experimental data. It appears
2 that interactions may occur at higher doses of complex PAH mixtures (see below).

3 The complexity of potential interactions for tumorigenesis of binary mixtures of PAHs is
4 illustrated in Table 2-2. The nature of the interaction varies with the PAHs evaluated and the
5 study conditions (e.g., vehicle used, dose selection, study method). Many studies were designed
6 to evaluate the combined administration of a known carcinogen with either a weak carcinogen or
7 a noncarcinogenic PAH. The true nature of the interaction (i.e., additive, synergistic, or
8 antagonistic) can be difficult to determine in studies wherein the tumorigenic response is not
9 measured for both PAHs given alone and in combination. These studies can distinguish between
10 an enhanced or cocarcinogenic response and an inhibitory response, but a further classification
11 cannot be made. The interactions described as cocarcinogenic in Table 2-2 may be either
12 additive or synergistic in nature.

13

Table 2-2. Studies of binary mixtures of PAHs and tumorigenicity

Reference	Endpoint	Findings	Net effect
Cavalieri et al., 1983	Mouse skin carcinogenicity	BaP and CPcdP given together resulted in a synergistic effect at low and intermediate doses; three- to sevenfold increase in relative risk at intermediate dose of both BaP and CPcdP as compared to the sum of the relative risk for the same dose of each PAH given alone.	S
DiGiovanni et al., 1982	Skin tumor initiation in mice	BeP increased BaP tumor initiation (30% ↑), inhibited tumor initiation by DMBA (84% ↓) and DBahA (48% ↓) and produced no change in combination with 3-MC; DBacA inhibited tumor initiation by DMBA (92% ↓), DBahA (39% ↓), and 3-MC (61% ↓) and produced no change in combination with BaP.	Co, I
Falk et al., 1964	Sarcoma induction in mice by subcutaneous injection	PH inhibited tumor response of DBahA in ethyl laurate vehicle (approximately 30% ↓, estimated from graph); tumor response was enhanced in triethylene glycol vehicle (approximately 50% ↑ to 100% tumor-bearing animals, estimated from graph).	Co, I
Lavik et al., 1942	Mouse skin tumors	3-MC and BaP, DBahA, or BaA essentially additive.	A
Pfeiffer, 1973	Sarcoma induction in mice by subcutaneous injection	BaP and DBahA less than additive; tumor response for combined treatment was within 10% of DBahA response.	I
Slaga et al., 1979	Skin tumor initiation in mice	BeP, Pyr, or FA increased skin tumor initiation by BaP (30, 35, and 23% ↑, respectively); BeP, Pyr, or FA decreased skin tumor initiation by DMBA (84, 50, and 34% ↓, respectively).	Co, I
Steiner, 1955; Steiner and Falk, 1951	Sarcoma induction in mice by subcutaneous injection	DBahA and 3-MC in combination roughly additive; BaA and CH in combination resulted in a synergistic effect (9% ↑ above additive response); BaA and DBahA in combination resulted in inhibition (48% ↓ below additive response).	A, S, and I
Van Duuren and Goldschmidt, 1976; Goldschmidt et al., 1973	Mouse skin carcinogenicity	BeP, BghiP, Pyr, or FA and BaP increased tumors over BaP alone (>50% increase in incidence, also ↑ multiplicity); no tumors were observed for PAHs without BaP.	S
Van Duuren et al., 1973	Mouse skin carcinogenicity	BaP and BghiP had cocarcinogenic effect (23% ↑ over BaP response alone).	Co
Warshawsky et al., 1993	Mouse skin carcinogenicity	Nontumorigenic dose of BaP increased tumor incidence produced by CH (16% ↑), AC (8% ↑), and FA (8% ↑).	S

3-MC = 3-methylchloanthrene; A = additive; Co = cocarcinogenic (enhanced tumorigenicity, study design does not allow for determination of A or S); DMBA = 7,12-dimethyl-benz[a]anthracene; I = inhibitory; S = synergistic

1

2

3

4

5

Slooff et al. (1989) reviewed the available data addressing the carcinogenicity of individual PAHs and in combination. It was concluded that a generally additive effect was observed following administration of more than two different PAHs in weight ratios similar to those occurring in ambient air or in various emissions. Combinations of only two PAHs

1 produced either additive, synergistic, or inhibitory effects. The complexity of the interaction
2 among single PAH compounds is thought to be related to effects on metabolic enzyme systems
3 including induction processes and competitive inhibition. The generally additive response noted
4 for a more complex mixture may reflect the balance between inhibitory and synergistic
5 processes.

6 Additivity has been observed in carcinogenicity studies of complex mixtures of PAHs.
7 Schmähl et al. (1977) evaluated the production of skin tumors following combined dermal
8 treatment with 11 PAHs found as constituents of automobile exhaust. Tumor findings were
9 presented separately for two groups of PAHs. High potency carcinogens (Group 1) included
10 benzo[a]pyrene, dibenz[a,h]anthracene, benz[a]anthracene, and benzo[b]fluoranthene. Lower
11 potency PAHs (Group 2) included anthracene, benzo[e]pyrene, benzo[g,h,i]perylene, chrysene,
12 fluoranthene, phenanthrene, and pyrene. Chronic dermal exposure to PAHs in both groups
13 resulted in an additive response when compared to the tumor response for each group alone.

14 Nesnow et al. (1998b) evaluated lung tumor formation in A/J mice following combined
15 administration of five carcinogenic PAH compounds (benzo[a]pyrene, benzo[b]fluoranthene,
16 dibenz[a,h]anthracene, 5-methylchrysene, and cyclopenta[c,d]pyrene). High and low doses were
17 selected for each PAH in this study based on toxicity, survival, range of response, and predicted
18 tumor yield. The ratio of PAH doses was designed to simulate PAH ratios found in
19 environmental air and emissions samples. PAHs were administered to mice in a 2⁵ factorial
20 study design yielding 32 dose groups (combination of five PAHs at high and low doses). The
21 formation of lung adenomas was evaluated 8 months following intraperitoneal injection of PAH
22 mixtures. A response surface model was used to evaluate specific interactions among PAHs.
23 The results of the study indicated that greater-than-additive effects were seen at low doses, while
24 less-than-additive effects were observed at high doses. However, the magnitude of the
25 interactions was relatively small (twofold), suggesting that potential interactions are limited in
26 extent.

27 Dermal application of binary mixtures of PAHs has also been shown to produce additive,
28 synergistic, and inhibitory effects on DNA binding in mouse skin (Hughes and Phillips, 1993,
29 1990). Hermann (1981) demonstrated that many PAHs could both enhance and inhibit the
30 bacterial mutagenicity of benzo[a]pyrene depending on the relative concentrations in the binary
31 mixture. Binary mixtures of benzo[a]pyrene and benzo[e]pyrene produced a synergistic
32 response in the TA98 strain of *S. typhimurium* (which detects frameshift mutations) and
33 antagonistic and additive effects in strain TA100 (which detects a broad spectrum of mutations)
34 depending on the concentration (Hass et al., 1981). Binary mixtures of PAHs have also been
35 shown to produce antagonistic or less-than-additive effects in the Ames assay of bacterial
36 mutagenicity (Barrai et al., 1992; Salamone et al., 1979a). Vaca et al. (1992) demonstrated an
37 additive effect for sister chromatid exchange induction by combined administration of

1 benzo[a]pyrene and fluoranthene in human peripheral lymphocytes cocultured with
2 polychlorinated biphenyl-induced rodent liver cells.

3 The effects of binary PAH mixtures on gene expression, DNA adduct formation,
4 apoptosis, and cell cycle are additive compared to the effects of the individual compounds in
5 human hepatoma cells (HepG2) (Staal et al., 2007). Equimolar and equitoxic mixtures of
6 benzo[a]pyrene with either dibenzo[a,l]pyrene, dibenz[a,h]anthracene, benzo[b]fluoranthene,
7 fluoranthene, or 1-methylphenanthrene were studied. PAH mixtures showed an additive effect
8 on apoptosis and on cell cycle blockage. The effects of binary mixtures of PAHs on gene
9 expression were generally additive or slightly antagonistic.

10 Additivity has also been observed for the mutagenicity of PAHs administered as a
11 complex mixture (Bostrom et al., 1998; Kaden et al., 1979). Kaden et al. (1979) evaluated the
12 bacterial mutagenicity of the PAH fraction of kerosene soot using resistance to 8-azaguanine as a
13 genetic marker for forward mutation in *S. typhimurium*. Approximately half of the PAHs tested
14 (34 of 70) produced a significant increase in the mutant fraction in this assay system. The
15 mutagenicity of the complex soot mixture was demonstrated to be approximately equal to the
16 additive mutagenicity of the individual components. Bostrom et al. (1998) reported additivity in
17 the Ames test of bacterial mutagenesis (i.e., reversion to histidine independence) for a mixture of
18 four PAHs (benzo[a]pyrene, benz[a]anthracene, fluorene, and pyrene) using four different strains
19 of *S. typhimurium*.

20 Mechanistic studies have suggested that the outcome of the interaction between two
21 PAHs in a binary mixture is dependent on changes in metabolism. PAHs can act as both
22 inducers and competitive inhibitors of the CYP enzymes that are responsible for generation of
23 reactive metabolites. Benzo[e]pyrene has been shown to alter the oxidative metabolism of
24 benzo[a]pyrene, which may be related to the cocarcinogenic effect seen in skin tumor initiation
25 studies (Baird et al., 1984). Alterations in the types and amounts of benzo[a]pyrene metabolites
26 suggest that benzo[e]pyrene-induced changes may be isozyme specific (Smolarek and Baird,
27 1984). An increase in the formation of benzo[a]pyrene DNA adducts has also been
28 demonstrated for coadministration of benzo[e]pyrene in SENCAR mouse skin (Smolarek et al.,
29 1987). Fluoranthene and pyrene have been shown to increase the formation of benzo[a]pyrene-
30 DNA adducts in mouse skin following a combined treatment (Rice et al., 1988, 1984).
31 Enhancement of the metabolism of benzo[a]pyrene to diol epoxide metabolites and subsequent
32 DNA binding may explain the increased carcinogenic effect in this case. Phenanthrene did not
33 increase the formation of benzo[a]pyrene-DNA adducts and was not shown to be cocarcinogenic
34 following combined administration with benzo[a]pyrene in this study. Cherng et al. (2001)
35 demonstrated that benzo[g,h,i]perylene increased the formation of benzo[a]pyrene adducts in
36 hepatoma cells (HepG2) by enhancing benzo[a]pyrene induction of CYP1A1. Benzo[g,h,i]-
37 perylene increased the nuclear accumulation of the AhR and/or the activation of the AhR to a
38 DNA-binding form (Cherng et al., 2001). Benzo[k]fluoranthene altered the metabolic profile of

1 benz[a]anthracene by increasing the activity of CYP1A1 (Schmoltdt et al., 1981). The bacterial
2 mutagenicity of benz[a]anthracene was enhanced by use of a rodent liver S9 that was obtained
3 from animals previously exposed to other PAHs (Norpoth et al., 1984). Coadministration of
4 benzo[a]pyrene and benz[a]anthracene to hamster embryo cell cultures resulted in decreases in
5 the metabolism of benzo[a]pyrene, the level of DNA binding, and the mutation frequency in
6 hamster V79 cells (Smolarek et al., 1986).

7 In summary, combined administration of binary mixtures of PAHs can result in several
8 types of joint action (i.e., additive, synergistic, or antagonistic). The nature of the joint action
9 appears to be dependent on the characteristics of the individual PAHs, related changes in
10 metabolism and possibly the test species/strain. PAHs can act as both inducers and competitive
11 inhibitors of the CYP enzymes that are responsible for generation of reactive metabolites.
12 Additivity has been observed for some complex mixtures of PAHs, suggesting a balance in the
13 relative metabolism of individual PAHs. For the purposes of this analysis, an assumption is
14 made that the combination of individual PAHs results in additive effects. Additional research is
15 needed to characterize the validity of this assumption.

16

1 **3. DISCUSSION OF PREVIOUSLY PUBLISHED RPF APPROACHES**
2
3

4 There are multiple analyses available for the derivation of relative potency estimates for
5 individual PAHs. All of these analyses utilize benzo[a]pyrene as the index chemical. Table 3-1
6 compares relative cancer potency values for PAHs presented by several authors. A review of the
7 derivation of these relative potency values follows.
8
9

Table 3-1. Comparison among various relative potency estimates for PAHs from the published literature and regulatory agencies (1984–2004)

PAH	Abbr	U.S. EPA (1993)	Chu and Chen (1984)	Clement (1988)	Clement (1990)	Rugen et al. (1989)	Slooff et al. (1989)	Kroese et al. (2001)	Nisbet and LaGoy (1992)	Malcolm and Dobson (1994)	Meek et al. (1994)	Muller et al. (1997)	Larsen and Larsen (1998)	Collins et al. (1998)	California EPA (2004)
Acenaphthene	AN								0.001	0.001					
Acenaphthylene	ANL								0.001	0.001					
Anthanthrene	AA			0.32	0.316							0.28	0.3		
Anthracene	AC						0	0	0.01	0.01			0.0005		
Benzo[a]pyrene	BaP	1	1	1	1	1	1	1	1	1	1	1	1	1	
Benz[a]anthracene	BaA	0.1	0.013	0.145		0.004–0.006	0–0.04	<0.1	0.1	0.1		0.014	0.005	0.1	
Benzo[b]fluoranthene	BbF	0.1	0.08	0.14	0.1228	0.0235			0.1	0.1	0.06	0.11	0.1	0.1	0.62
Benzo[c]phenanthrene	BcPH											0.023	0.023		
Benzo[e]pyrene	BeP			0.004	0.007					0.01		0	0.002		
Benzo[g,h,i]perylene	BghiP			0.022	0.0212		0.01–0.03	0.03	0.01	0.01		0.012	0.02		
Benzo[j]fluoranthene	BjF			0.061	0.0523	0.0763				0.1	0.05	0.045	0.05	0.1	0.52
Benzo[k]fluoranthene	BkF	0.01	0.004	0.066	0.0523		0.03–0.09	<0.1	0.1	0.1	0.04	0.037	0.05	0.1	
Chrysene	CH	0.001	0.001	0.0044			0.05–0.89	0.1–0.03	0.01	0.01		0.026	0.03	0.01	0.17
Coronene	CO									0.001					
Cyclopenta[c,d]pyrene	CPcdP			0.023						0.1		0.012	0.02		
Dibenz[a,h]anthracene	DBahA	1	0.69	1.11		0.599			5	1		0.89	1.1		
Dibenz[a,c]anthracene	DBacA									0.1					
Dibenzo[a,e]pyrene	DBaeP												0.2	1	
Dibenzo[a,h]pyrene	DBahP											1.2	1	10	11
Dibenzo[a,i]pyrene	DBaiP											1.1	0.1	10	12
Dibenzo[a,l]pyrene	DBalP												1	10	
Fluoranthene	FA						0–0.06	0.01	0.001	0.001			0.05		
Fluorene	FE								0.001	0.001					
Indeno[1,2,3-c,d]pyrene	IP	0.1	0.017	0.232	0.278	0.00599	0–0.08	0.1	0.1	0.1	0.12	0.067	0.1	0.1	
Perylene	Pery									0.001					

Table 3-1. Comparison among various relative potency estimates for PAHs from the published literature and regulatory agencies (1984–2004)

PAH	Abbr	U.S. EPA (1993)	Chu and Chen (1984)	Clement (1988)	Clement (1990)	Rugen et al. (1989)	Slooff et al. (1989)	Kroese et al. (2001)	Nisbet and LaGoy (1992)	Malcolm and Dobson (1994)	Meek et al. (1994)	Muller et al. (1997)	Larsen and Larsen (1998)	Collins et al. (1998)	California EPA (2004)
Phenanthrene	PH						0.01	<0.01	0.001	0.001		0.00064	0.0005		
Pyrene	Pyr			0.081					0.001	0.001		0	0.001		

Abbr = abbreviation

1 U.S. EPA (1993) presented RPFs (termed EOPPs) for seven PAHs (benzo[a]pyrene,
2 benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene,
3 dibenz[a,h]anthracene, indeno[1,2,3-c,d]pyrene) as *Provisional Guidance* for the risk evaluation
4 of PAHs. On the IRIS database, the current entries for all seven of these compounds contain a
5 cancer weight of evidence classification of Group B2 (probable human carcinogen, based on
6 sufficient evidence of carcinogenicity in animals) (www.epa.gov/iris). U.S. EPA (1993)
7 indicated that the data for PAHs did not meet the criteria for the development of toxicity
8 equivalency factors (TEFs). In particular, the existing database was limited primarily to studies
9 of metabolism, genotoxicity, and cancer, and the assumptions of the dose-additivity model (i.e.,
10 toxicological similarity and no interactions at low concentrations) were not proven or refuted.
11 The EOPP terminology was used because this approach was limited to skin painting data and
12 was based on benzo[a]pyrene exposure from a single (oral) pathway (for the derivation of the
13 slope factor). This analysis considered only a small subset of PAHs routinely measured in PAH
14 mixtures at hazardous waste sites. The EOPP values were based on previous evaluations
15 conducted by Chu and Chen (1984) and Clement Associates (1988) and were calculated for
16 various test systems (i.e., mouse skin carcinogenesis, subcutaneous injection in mice,
17 intrapulmonary administration to rats, tumor initiation on mouse skin, and intraperitoneal
18 injection in newborn mice) (Clement Associates, 1988). Various statistical methods for
19 combining data sets were considered; however, final EOPP values were based on a single test
20 system (skin painting) and were rounded to the closest order of magnitude. The EOPPs were
21 recommended for the oral exposure route only, because the quantitative dose-response
22 assessment for benzo[a]pyrene was from an oral carcinogenicity bioassay (i.e., an oral cancer
23 slope factor). This recommendation was, however, complicated by the fact that the EOPPs were
24 derived from comparisons based on dermal exposure.

25 Chu and Chen (1984) presented RPF values for the seven PAH compounds described in
26 the *Provisional Guidance* described above (U.S. EPA, 1993) (see Table 3-1). These values were
27 calculated using mouse skin painting data only. Tumor incidence data were modeled using the
28 linearized multistage model and the resulting ED₁₀ and q1* (upper confidence limit of the linear
29 slope) were presented for target PAHs and benzo[a]pyrene. The RPFs listed in Table 3-1
30 represent the ratio of the q1* value for a PAH compound to the q1* value for benzo[a]pyrene
31 (i.e., $q1^*_{\text{PAH}} \div q1^*_{\text{BaP}}$).

32 Clement Associates (1988) identified 11 published studies that concurrently compared
33 the carcinogenicity of benzo[a]pyrene with one or more other PAHs, and used the data to derive
34 relative cancer potencies for 13 PAHs, including benzo[a]pyrene. Test protocols used in this
35 analysis included mouse skin complete carcinogenesis, initiation-promotion on mouse skin,
36 subcutaneous injection into mice, lung implantation in rats, and intraperitoneal injection into
37 newborn mice. Tumor incidence data were fit to a simplified version of the Moolgavkar-
38 Venson-Knudsen (MVK) two-stage model and to the linearized multistage model to obtain low-

1 dose cancer potency values (transition rates and low-dose slope factors, respectively). Most of
2 the estimates were derived using data for multiple exposure levels and controls, but some were
3 based on a single exposure level and a control. RPFs were calculated as the ratio of the
4 estimated transition rate or slope factor for a particular PAH to the corresponding values for
5 benzo[a]pyrene from the same study. Clement Associates (1988) selected representative RPFs
6 for each of the studied PAHs based on evaluations of the quality of the studies from which the
7 estimates were obtained.

8 Clement Associates (1990) also derived relative cancer potencies for eight PAHs based
9 on tumor incidence data from rat lung implantation data only (Deutsch-Wenzel, 1983). The data
10 were restricted to a single group of studies using a defined experimental protocol in order to
11 address issues of questionable data quality associated with other studies. Data quality concerns
12 cited for other studies include variation in survival, saturation of the carcinogenic effect,
13 outmoded pathological classification, and inadequate controls. The RPF values based on rat lung
14 implantation data were comparable to those originally derived by Clement Associates (1988)
15 (see Table 3-1).

16 Rugen et al. (1989) proposed a relative potency approach to establish acceptable
17 exposure levels (AELs) for six carcinogenic PAHs in drinking water (listed in Table 3-1). These
18 authors reviewed mouse skin painting studies in which the cancer potency of benzo[a]pyrene
19 was compared with those of other PAHs (Bingham and Falk, 1969; Wynder and Hoffmann,
20 1961, 1959a, b). The following relationship was used to calculate conversion factors to derive
21 AELs for these PAHs from the AEL for benzo[a]pyrene: relative tumor dose (RTD) =
22 $(d_1/n_1)/(d_2/n_2)$; where d_1 and n_1 represented a dosage level and associated tumor incidence after a
23 given exposure duration to a certain PAH, PAH₁, and d_2 and n_2 represented similar quantities for
24 exposure to the index PAH, benzo[a]pyrene, for the same exposure duration. The AEL for a
25 particular PAH was then derived with the following relationship: $AEL_{(PAHi)} = AEL_{(benzo[a]pyrene)} \times$
26 $RTD_{(PAHi)}$. In this approach, RTDs for PAHs more potent than benzo[a]pyrene were less
27 than 1 and RTDs for PAHs less potent than benzo[a]pyrene were greater than 1. The reciprocal
28 of the RTDs derived by Rugen et al. (1989) were comparable to the RPFs presented by other
29 authors and are presented as such in Table 3-1.

30 The Netherlands (RIVM) proposed RPF values for 10 PAHs (naphthalene, anthracene,
31 phenanthrene, fluoranthene, chrysene, benz[a]anthracene, benzo[k]fluoranthene, benzo[a]pyrene,
32 benzo[g,h,i]perylene, and indeno[1,2,3-c,d]pyrene) (Slooff et al., 1989). RPFs were calculated
33 as a ratio of ED₅₀ values that were calculated using a simple linear model. For dermal studies in
34 which the latency period was determined, the tumor incidence was divided by latency and
35 concentration, and the values were averaged for the different concentrations. Kroese et al.
36 (2001) provided an update of the RPF values calculated by Slooff et al. (1989) by incorporating
37 more recent evaluations conducted by other authors (Larsen and Larsen, 1998; Nesnow et al.,

1 1998b; Muller, 1997; Nisbet and LaGoy, 1992). The RPF values for chrysene and fluoranthene
2 were decreased, while other values remained similar to those originally proposed (see Table 3-1).

3 Nisbet and LaGoy (1992) proposed toxicity equivalence factors for 17 PAHs commonly
4 found at hazardous waste sites. These authors reviewed published studies in which the
5 tumorigenic potencies of one or more PAHs were compared with benzo[a]pyrene (essentially the
6 same as those reviewed by Clement Associates, 1988) and rounded, to an order of magnitude, the
7 estimates presented by Clement Associates (1988) for seven carcinogenic PAHs (dibenz[a,h]-
8 anthracene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, indeno[1,2,3-c,d]-
9 pyrene, benzo[g,h,i]perylene, and chrysene) (see Table 3-1). Nisbet and LaGoy (1992) argued
10 that the rounded estimates more accurately reflected the uncertainty in the estimates than the
11 values presented by Clement Associates (1988). Nisbet and LaGoy (1992) stated that Clement
12 Associates (1988) proposed a TEF of 0.32 for anthracene (CASRN 120-12-7), but examination
13 of the original report shows that Clement Associates (1988) proposed this value for anthanthrene
14 (CASRN 191-26-4) and did not propose a value for anthracene. Nisbet and LaGoy (1992)
15 assigned a value of 0.01 to anthracene. In addition, Nisbet and LaGoy (1992) arbitrarily
16 assigned TEFs of 0.001 to eight other PAHs for which adequate evidence of carcinogenicity in
17 animals was not available (acenaphthene, acenaphthylene, fluoranthene, fluorene, 2-methyl-
18 naphthalene, naphthalene, phenanthrene, and pyrene). In defense of this assignment, the
19 argument was made that some of these PAHs have been shown to have some, albeit limited,
20 evidence for carcinogenic or genotoxic activity in some studies (e.g., phenanthrene and
21 naphthalene³). The RPF value proposed for dibenz[a,h]anthracene was substantially higher than
22 that proposed by Clement Associates (1988). Nisbet and LaGoy (1992) indicate that their
23 analysis of the dose-response data suggests that an RPF value of 5 is more appropriate for
24 environmental exposures where the chemically-related tumor incidence rate would be
25 approximately <25%.

26 Malcolm and Dobson (1994) used RPFs for 23 PAHs to calculate environmental
27 assessment levels for atmospheric PAHs (sponsored by the Great Britain Department of the
28 Environment). The RPFs were derived from previously reported review papers (Nisbet and
29 LaGoy, 1992; Rugen et al., 1989; Clement Associates, 1988; Chu and Chen, 1984), as well as the
30 primary literature describing pulmonary implant, skin painting, subcutaneous injection, and
31 mouse skin DNA binding studies. No information was provided regarding the methodology used
32 to derive RPFs from specific experimental studies. The proposed RPF values for individual
33 PAHs were the highest values reported in the literature. Many of the RPF values are similar to
34 those reported by Nisbet and LaGoy (1992). RPFs were additionally reported for
35 benzo[e]pyrene, coronene, cyclopenta[c,d]pyrene, dibenz[a,c]anthracene, and perylene. The
36 benzo[e]pyrene and cyclopenta[c,d]pyrene RPFs were apparently calculated directly from mouse

³It should be noted that a recent bioassay for naphthalene has shown increased incidence of nasal tumors in exposed rats (NTP, 2000).

1 skin painting studies (Habs et al., 1980; Hoffmann and Wynder, 1966; Wynder and Hoffmann,
2 1959a, b). Coronene and perylene were arbitrarily assigned RPF values of 0.001 given the IARC
3 and U.S. EPA designation as “not classifiable as to human carcinogenicity” (similar approach to
4 Nisbet and LaGoy, 1992). Dibenz[a,c]anthracene was assigned an RPF value of 0.1 based on the
5 IARC designation of “possibly carcinogenic to humans.”

6 Health Canada (Meek et al., 1994) proposed RPFs for five PAHs (benzo[a]pyrene,
7 benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[j]fluoranthene, and indeno[1,2,3-cd]pyrene)
8 based on the results of multistage modeling of incidence data in Osborne-Mendel rats treated by
9 lung implantation (Deutsch-Wenzel et al., 1983). Values were based on a comparison of the
10 doses that caused a 5% increase in tumor incidence (ED₀₅). RPFs were calculated as the ratio of
11 the ED₀₅ for benzo[a]pyrene to the ED₀₅ for a specific PAH compound.

12 The Ontario Ministry of Environment and Energy (Muller et al., 1997) proposed RPF
13 values for 209 PAHs using data from dermal studies in mouse skin or rat lung bioassays. Most
14 of these PAHs were alkylated PAHs, PAH metabolites, or heterocyclic PAH compounds. The
15 17 unsubstituted PAHs that were evaluated in this analysis are listed in Table 3-1. Muller et al.
16 (1997) derived a standard time of observation in order to account for varying study duration
17 across experiments. Several dose-response models were considered for the evaluation of tumor
18 incidence and multiplicity, and linear regression was selected as the preferable method.
19 Tumorigenic potency (i.e., the slope of incidence/mg) was determined separately for each data
20 set based on the following order of preference regarding study type: tumor initiation in
21 CD-1 mice, tumor initiation in SENCAR mice, rat lung implantation, and complete
22 carcinogenicity in C57BL mice. RPFs were determined as the ratio of PAH potency to the
23 potency of benzo[a]pyrene. RPF values derived by Muller et al. (1997) were comparable to
24 values estimated by other authors.

25 Larsen and Larsen (1998) estimated RPFs for 23 PAHs based on a compilation of
26 available carcinogenicity data in animals using oral, pulmonary, and skin application of PAHs.
27 The authors indicated that these values represent an entirely subjective estimate of relative
28 potency; however, further detail regarding the derivation of RPF estimates was not provided.

29 Collins et al. (1998) developed RPFs (termed potency equivalency factors [PEFs]) for
30 21 PAHs; 10 of these were either methyl- or nitro-substituted or heterocyclic PAHs. A hierarchy
31 of data types was utilized to provide an order of preference for data utilization in calculating
32 RPFs. Because the analysis focused on PAHs as air contaminants, tumor data from inhalation
33 studies were preferred (although none were found), followed by intratracheal or intrapulmonary
34 instillation, oral administration, skin-painting, and subcutaneous or intraperitoneal injection.
35 Genotoxicity and structure activity data were considered the least-preferred data type for
36 calculation of RPFs. Collins et al. (1998) noted that a wide range of PEFs were observed for
37 individual chemicals using different types of data (e.g., mutagenicity versus tumor data). The
38 basis for the derivation of individual RPF values was presented in a California EPA (2002)

1 technical support document. RPF values for benz[a]anthracene, benzo[b]fluoranthene,
2 benzo[j]fluoranthene, benzo[k]fluoranthene, indeno[1,2,3-c,d]pyrene, and chrysene were similar
3 to those described by Clement Associates (1988). Additional RPFs for dibenzo[a,e]pyrene,
4 dibenzo[a,h]pyrene, dibenzo[a,i]pyrene, and dibenzo[a,l]pyrene were calculated using mouse
5 skin and rat mammary gland data (Cavalieri et al., 1991, 1989). A cancer slope factor was
6 directly calculated for dibenz[a,h]anthracene using the tumor incidence data from a drinking
7 water study (Snell and Stewart, 1962). The relative potency of dibenz[a,h]anthracene was
8 estimated to be 0.1, when compared to the oral potency for benzo[a]pyrene.

9 Revised California EPA RPFs were recently developed for benzo[b]fluoranthene,
10 benzo[j]fluoranthene, chrysene, dibenzo[a,h]pyrene, and dibenzo[a,i]pyrene (California EPA,
11 2004). Cancer potency estimates were derived from lung adenoma data in newborn mice treated
12 by intraperitoneal injection. Potency estimates represented the upper 95% confidence limit on
13 the linear term of the multistage model fit for the newborn mouse dose-response data. Because
14 benzo[a]pyrene was demonstrated to be 75 times more toxic in newborn mouse intraperitoneal
15 assays than in adult oral studies, oral equivalent potencies for individual PAHs were derived by
16 adjusting the cancer potency downward by a factor of 75. The RPFs listed in Table 3-1 were
17 calculated as the ratio of the oral equivalent potency for a PAH to the oral potency estimate for
18 benzo[a]pyrene. This methodology resulted in a significant increase in RPF values for
19 benzo[b]fluoranthene, benzo[j]fluoranthene, and chrysene when compared with other
20 approaches.

21 In summary, several approaches are available for the determination of RPFs for PAHs.
22 RPF values are proposed in at least one study for a total of 27 PAHs (see Table 3-1). Because
23 these approaches generally rely on similar bioassay data and modeling methods, the resulting
24 RPF values are fairly comparable for most PAHs across studies. Reports by Larsen and Larsen
25 (1998) and Malcolm and Dobbs (1994) did not provide sufficient information on the
26 methodology used to calculate RPF estimates and are therefore more uncertain. Variable RPF
27 estimates were reported for benz[a]anthracene, chrysene, and indeno[1,2,3-c,d]pyrene. RPF
28 values were also highly variable for dibenzo[a,e]pyrene, dibenzo[a,h]pyrene, dibenzo[a,i]pyrene,
29 and dibenzo[a,l]pyrene; however, these were only presented in a few recent studies. As
30 indicated above, the recent California EPA (2004) approach to estimating RPFs provides
31 considerably higher RPF values for benzo[b]fluoranthene, benzo[j]fluoranthene, and chrysene,
32 compared with other approaches.

33 U.S. EPA is reevaluating the RPF approach for PAHs in this analysis due to the evolution
34 of the state of the science and increased understanding of PAH toxicology. A great deal of
35 scientific research on PAHs has been conducted since the 1993 *Provisional Guidance* was
36 developed. Toxicological data are available for a larger number of PAHs and cancer-related
37 endpoints. However, the database for PAHs still does not meet the criteria for the derivation of
38 TEFs. U.S. EPA (2000) defines TEFs as special types of RPFs that are derived when there are

1 abundant data supporting a specific mode of action that is pertinent to all health endpoints. RPFs
2 may be derived when the mode of action is less certain or is known for only a subset of all health
3 endpoints. The major differences in the use of TEFs and RPFs is that TEFs are applied to all
4 health endpoints, exposure routes, and exposure durations (U.S. EPA, 2000), while RPFs may be
5 limited to specific endpoints, routes, or durations. In the case of PAHs, there are inadequate data
6 to identify a specific mode of action that is applicable across all health endpoints. Most of the
7 available toxicological data are limited to cancer endpoints and there are few data on the
8 potential mode(s) of action for other effects. As a result, the more generalized RPF approach is
9 considered appropriate for PAHs.

11 **3.1. PREVIOUS EFFORTS TO VALIDATE THE RPF APPROACH**

12 Several studies have attempted to validate the RPF approach by comparing the cancer
13 risk of a PAH mixture measured experimentally with the cancer risk that was predicted using the
14 RPF method (Muller et al., 1997; McClure, 1996; Goldstein et al., 1994; Clement Associates,
15 1990, 1988; Krewski et al., 1989). These studies provide semi-quantitative information on the
16 overall uncertainty in using a component-based approach. Consistent findings were not reported
17 across these studies. Some studies suggested that the RPF approach would closely predict the
18 cancer risks associated with PAH mixtures, while others indicated that cancer risks might be
19 over- or underestimated.

20 Clement Associates (1988) evaluated the usefulness of selected RPFs to predict the tumor
21 incidence observed in a mouse skin painting assay. Schmähl et al. (1977) exposed groups of
22 mice to multiple doses of benzo[a]pyrene alone or to one of two defined mixtures of PAHs. The
23 first of these mixtures was comprised of benzo[a]pyrene, dibenz[a,h]anthracene,
24 benz[a]anthracene, and benzo[b]fluoranthene. The second mixture contained seven PAHs:
25 phenanthrene, anthracene, fluoranthene, pyrene, chrysene, benzo[e]pyrene, and
26 benzo[g,h,i]perylene. The predicted tumor incidences for the animals treated with the mixtures
27 were calculated from benzo[a]pyrene equivalents of the mixture and dose-response modeling of
28 the Schmähl et al. (1977) data for benzo[a]pyrene alone. Predicted tumor incidences for the first
29 mixture were comparable to observed tumor incidences, while predicted values were greater than
30 the observed values for the second mixture.

31 Clement Associates (1990) examined the utility of a relative potency approach, in which
32 relative cancer potency estimates of eight PAHs were used, to predict the cancer potencies of
33 each of four complex mixtures containing many PAHs and other substances: gasoline engine
34 exhaust condensate, flue-gas condensate from coal-fired residential furnaces, diesel engine
35 exhaust condensate, and sidestream smoke condensate of cigarettes. Relative cancer potencies
36 (compared to benzo[a]pyrene) for each of the four complex mixtures were calculated using a
37 simplified version of the MVK two-stage model and tumor incidence data from a series of
38 published rat lung implantation studies that examined the carcinogenicity of each complex

1 mixture, various subfractions of the mixtures, and benzo[a]pyrene (Grimmer et al., 1988,
2 1987a, b, 1984). Lung implantation data (Deutsch-Wenzel, 1983) were used to calculate RPFs
3 for benzo[b]fluoranthene, benzo[e]pyrene, benzo[j]fluoranthene, benzo[k]fluoranthene,
4 indeno[1,2,3-c,d]pyrene, anthanthrene, benzo[g,h,i]perylene, and benzo[a]pyrene. The sum of
5 the benzo[a]pyrene exposure equivalents for the eight PAHs (i.e., the sum of the products of the
6 relative cancer potencies of the eight PAHs multiplied by their concentrations in the respective
7 complex mixtures) accounted for only minor fractions of the total carcinogenicity of each of the
8 four complex mixtures. When the assumption was made that each of the eight PAHs was as
9 potent as benzo[a]pyrene, the sum of the benzo[a]pyrene equivalents still accounted for only
10 minor fractions of the carcinogenicity of each mixture. Clement Associates (1990) concluded
11 that the cancer risk associated with a complex PAH mixture could not be estimated reliably from
12 measurements of a few indicator components, and further speculated that the underestimation
13 occurred because complex mixtures that occur in the environment contain many PAHs that have
14 not been studied in cancer tests, but may be carcinogenic. In addition, complex PAH mixtures
15 found in the environment contain other potential carcinogens including substituted and
16 heterocyclic PAHs and non-PAH components.

17 Krewski et al. (1989) compared the observed tumor response rate for two PAH mixtures
18 in mice with the tumor response predicted using the RPFs for 13 individual PAHs; chemical
19 characterization of the mixture was not provided. With the exception of the highest dose, the
20 predicted tumor response for mixture 1 was similar to the observed response. For mixture 2, the
21 predicted tumor response value was higher than the observed response.

22 Goldstein et al. (1994) compared the experimental carcinogenicity of a MGP residue to
23 the predicted cancer risk using the Nisbet and LaGoy (1992) RPF scheme. The RPF method
24 underestimated the carcinogenicity of the mixture. The lack of correspondence was suggested to
25 be related to the presence of unidentified carcinogens in the mixture or possible synergistic
26 interactions between PAHs.

27 McClure et al. (1996) compared the tumor response predicted using U.S. EPA's 1993
28 provisional values (i.e., EOPPs) to the observed response reported in studies of mice exposed to
29 synthetic and complex mixtures of PAHs. The results of this analysis were mixed. EOPP values
30 closely predicted the mouse tumor response to subcutaneous or dermal application of synthetic
31 mixtures containing relatively potent carcinogens, while overestimating the response to synthetic
32 mixtures containing only relatively weak carcinogens (similar to findings of Clement Associates,
33 1988). Mouse skin tumor initiation with several coal liquids was closely predicted by the EOPP
34 approach; however, this method underestimated the tumor response from lung implantation of
35 coal furnace emission condensate and its PAH-containing neutral fraction.

36 The validation analyses that were performed by Muller et al. (1997) consisted of
37 component versus whole mixture risk comparisons using data for smoky coal and coke oven
38 emissions. The human lung cancer risks that were estimated using the RPF approach were

1 compared to the whole mixture cancer risk derived from epidemiology studies. The relative
2 content of PAHs (compared to benzo[a]pyrene) in the mixture was determined analytically (for
3 smoky coal and coke oven emissions) or was estimated as a standard mixture assumed to
4 represent an average PAH profile. The RPF method produced PAH cancer risk estimates that
5 were significantly lower than the risk estimates derived from epidemiology studies.

6

4. EVALUATION OF THE CARCINOGENICITY OF INDIVIDUAL PAHs

4.1. DATABASE OF STUDIES ON PAH CARCINOGENICITY AND CANCER-RELATED ENDPOINTS

A database of primary literature relevant to the RPF approach for PAHs was developed. This was accomplished through the following means:

- Definition of the study types that were considered relevant to relative potency development;
- Review of reference lists from review articles and other secondary sources;
- Identification of selected PAHs to be included in search of open literature;
- Performance of targeted searches of open literature on selected PAHs; and
- Population of the database with references and meaningful keywords.

The study types that were considered most useful for RPF derivation were rodent carcinogenicity bioassays (all routes) in which one or more PAH was tested at the same time as benzo[a]pyrene. In addition, in vivo and in vitro data for cancer-related endpoints (in which one or more PAH and benzo[a]pyrene was tested simultaneously) were obtained, including studies on the formation of DNA adducts, mutagenicity, chromosomal aberrations, aneuploidy, DNA damage/repair/recombination, unscheduled DNA synthesis, and cell transformation. Although it would be possible to calculate RPFs from studies where a PAH and benzo[a]pyrene were tested by the same laboratory using the same test system but at different times, this approach was not considered because it could introduce differences in the dose-response information that are unrelated to the chemical (e.g., variability associated with laboratory environment conditions, animal handling, food supply). Thus, studies in which benzo[a]pyrene was not tested simultaneously with another PAH were not considered for use in calculating RPFs. Studies that did not include benzo[a]pyrene were, however, considered useful for evaluating the weight of evidence for selecting PAHs to be included in the RPF approach.

Several study types were initially excluded from the database because they did not provide carcinogenicity or cancer-related endpoint information for individual PAHs. These include biomarker studies measuring DNA adducts in humans, studies of PAH metabolism, and studies of PAH mixtures. Although these studies contain important information on human exposure to PAH mixtures and the mode of action for PAH toxicity, they generally do not contain dose-response information that would be useful for calculation of RPF estimates. In addition to the primary bioassay and cancer-related endpoint studies described above, the RPF

1 database also includes information on PAH mode of carcinogenic action, interactions among
2 PAHs in mixtures, and the influence of exposure route on carcinogenic action of PAHs.

3 Primary studies were identified through the review of available secondary sources and
4 review articles, supplemented by a targeted literature search. A complete list of the secondary
5 sources that were reviewed is contained in Appendix A. A literature search strategy was
6 developed by first constructing a list of the individual PAHs to be included. The list of PAHs
7 was restricted to unsubstituted PAHs with three or more fused aromatic rings containing only
8 carbon and hydrogen atoms, because these are the most widely studied members of the PAH
9 chemical class. Heterocyclic PACs or PAHs with substituted groups (e.g., alkyl, hydroxyl,
10 sulfhydryl, amino, or nitro groups) were not included. An initial search yielded a list of PAHs
11 for which toxicological data are available. Individual PAHs were then chosen for the literature
12 search because they were known to have toxicological information relevant to cancer, and in
13 most cases, their presence in environmental sources of PAH exposure was known. Using these
14 criteria and excluding benzo[a]pyrene, 74 PAHs were identified from primary and secondary
15 sources (see Table 2-1 in Chapter 2).

16 A search of the open literature was conducted in the MEDLINE (PubMed) database for
17 the 74 PAHs that were identified. This database encompasses many of the studies that would
18 also be found in TOXLINE and CANCERLIT (the latter is no longer available as a separate
19 database). MEDLINE was searched by CASRN in conjunction with cancer and cancer-related
20 endpoint keywords. The search was not limited by publication date to ensure that all relevant
21 studies were identified. A few compounds did not show any result when searched by CASRN.
22 For these PAHs, an additional search by name was conducted. Search results, including
23 MEDLINE keywords, were downloaded directly into the working RPF database.

24 In addition to MEDLINE, computer searches of the following databases and websites
25 were conducted: IARC, World Health Organization (WHO), Agency for Toxic Substances and
26 Disease Registry (ATSDR), Health Canada, the National Toxicology Program (NTP), California
27 EPA's Office of Environmental Health Hazard Assessment (OEHHA), the Substance Registry
28 System, the Chemical Carcinogenesis Research Information System (CCRIS), the Toxic
29 Substance Control Act Test Submission (TSCATS) database, and the Distributed Structure-
30 Searchable Toxicity (DSSTOX) database.

31 Primary and secondary studies were entered in the RPF database and relevant keywords
32 (identifying study type, whether benzo[a]pyrene was included, route of administration, target
33 organ, etc.) were identified for each study. The list of keywords was developed in order to
34 facilitate database searching for references on a specific topic. Quality assurance procedures
35 were employed to ensure that database references were properly keyword-coded for retrieval.

36

4.2. STUDIES IN HUMANS

Numerous studies have evaluated cancer outcomes in PAH-exposed individuals (reviewed in Bostrom et al., 2002; WHO, 1998; ATSDR, 1995; IARC, 1987, 1983, 1973). However, since these exposures were to complex mixtures containing multiple PAH carcinogens, they did not provide adequate data to evaluate the human carcinogenicity of individual PAH compounds. Epidemiology studies have focused on occupational exposure to PAH mixtures. Emissions from coke production, coal gasification, aluminum production, iron and steel founding, coal tars, coal tar pitches, and soot have produced lung cancer in humans (Bostrom et al., 2002). Skin and scrotal cancers have resulted from exposure to coal tar, coal tar pitches, nonrefined mineral oils, shale oils, and soot (Larsen and Larsen, 1998; WHO, 1998; ATSDR, 1995). Occupational studies clearly demonstrate exposure-response relationships for PAH mixtures; however, quantitative estimates of risk are limited primarily to lung cancer in coke oven workers (Bostrom et al., 2002; Larsen and Larsen, 1998; ATSDR, 1995).

Biomonitoring of exposure to PAHs includes measurement of DNA and protein adducts and measurement of urinary metabolites of PAHs, studies on genetic polymorphisms of CYP450 and other enzymes, and changes in PAH metabolism (Bostrom et al., 2002; Larsen and Larsen, 1998; ATSDR, 1995). While these studies demonstrate the degree of exposure to PAHs from various settings, quantitative dose-response data for humans exposed to individual PAHs are not available. Cancer-related endpoint studies that were performed using human cell lines are presented with similar assays in other mammalian species in Section 4.3.

4.3. STUDIES IN ANIMALS

The database of studies investigating cancer or cancer-related endpoints in animals exposed to PAHs is extensive. For the purpose of developing relative potency estimates, only those studies that included at least one selected PAH and benzo[a]pyrene as a reference compound were reviewed. Studies were excluded if PAH potency comparisons were not conducted in the same laboratory in concurrent experiments. Studies without benzo[a]pyrene are listed in two separate bibliographies in Appendix B. Table B-1 shows PAHs that were assayed with or without benzo[a]pyrene. Table B-1 shows that 32 of the 74 PAHs were assayed with benzo[a]pyrene; an additional 14 PAHs were not tested in the same study as benzo[a]pyrene. The remaining 28 PAHs either have only cancer-related endpoint data, or have neither bioassays nor cancer-related endpoint data. Bioassays without benzo[a]pyrene were considered in the weight of evidence evaluation for individual PAHs (Section 6.1). Studies that provided only information on PAH mixtures or PAH metabolites were not reviewed or summarized for this analysis.

References in the database were sorted by keyword into the following major categories: cancer bioassays, in vivo studies of cancer-related endpoints, and in vitro studies of cancer-related endpoints. These categories were further divided by route (for bioassays) or by endpoint

1 (for cancer-related endpoints). Each study was reviewed, and critical study details were
2 extracted into tables (Tables 4-1 through 4-14) for each individual endpoint. Studies with data
3 on selected PAHs and benzo[a]pyrene were used, even if a particular PAH has not been
4 evaluated by U.S. EPA or IARC for carcinogenicity. Studies were included in the analysis if the
5 following selection criteria were met:

- 6
- 7 • Benzo[a]pyrene was tested simultaneously with another PAH;
- 8
- 9 • A statistically increased incidence of tumors was observed with benzo[a]pyrene
10 administration;
- 11
- 12 • Benzo[a]pyrene produced a statistically significant change in a cancer-related
13 endpoint finding;
- 14
- 15 • Quantitative results were presented;
- 16
- 17 • The carcinogenic response observed in either the benzo[a]pyrene- or other PAH-
18 treated animals at the lowest dose level was not saturated (i.e., tumor incidence at the
19 lowest dose was <90%); and
- 20
- 21 • There were no study quality concerns or potential confounding factors that precluded
22 use (e.g., no concurrent control, different vehicles, strains, etc. were used for the
23 tested PAH and benzo[a]pyrene; use of cocarcinogenic vehicle; PAHs of questionable
24 purity; unexplained mortality in treated or control animals).
- 25

Table 4-1. Study summaries: dermal bioassays of benzo[a]pyrene and at least one other PAH

Record number	Reference	Mouse ^a strain	Exposure	Follow up	Vehicle	Promoter	Tumor type	Positive result	Nonpositive result	Meets selection criteria?	Comments
<i>Complete carcinogenicity studies</i>											
480	Bingham and Falk, 1969	CH3/He	3 times/wk	50 wk	Toluene or n-dodecane	None	Malignant and benign	BaA		No	BaP administered in different vehicle. n-Dodecane cocarcinogenic with BaA. No concurrent untreated, toluene, or n-dodecane control.
600	Habs et al., 1980	NMRI	2 times/wk (4 times for CO) for life	Until moribund or dead	Acetone (DMSO for CO)	None	Papilloma, carcinoma, sarcoma	BbF	BkF, BjF, CPcdP, CO, IP	Yes	
22390	Wynder and Hoffmann, 1959a	Swiss	3 times/wk	6–14 mo	Cyclohexane	None	Papilloma, carcinoma	BbF, BjF	BghiF, BkF	No	Deaths prior to first tumor appearance. No concurrent control.
19320	LaVoie et al., 1979	HA/ICR Swiss albino	3 times/wk	Unspecified	Acetone	None	Unspecified	CH, BbF, BjF, DBaeP, DBahP, DBaiP	AC, Pyr, BghiF, BkF, AA, BeP, DBelP, IP, BghiP, N23eP	No	Reiterates data published elsewhere.
22400	Wynder and Hoffmann, 1959b	Swiss	3 times/wk	10–22 mo	Acetone	None	Papilloma, carcinoma	CH, DBahA, DBaiP	AC, BeP, Pyr, FA	No	Deaths prior to first tumor appearance. Not clear if BaP administered simultaneously. No concurrent control.
13640	Cavalieri et al., 1983	Swiss	2 times/wk for 48 wk	Until 2 cm tumor or 61 wk	Acetone	None	Papilloma, adenoma, carcinoma	CPcdP		Yes	Reports both incidence and multiplicity.
13650	Cavalieri et al., 1981b	Swiss	2 times/wk for 30 wk	Until 2 cm tumor, moribund, or 57 wk	Acetone	None	Primarily squamous cell carcinoma	CPcdP	ACEP	Yes	Tumor incidence not useable because BaP tumor incidence was 100%. Tumor multiplicity data available for dose-response assessment.
620	Hoffmann and Wynder, 1966	Ha/ICR/Mil Swiss	3 times/wk for 12 mo	Up to 15 mo	Dioxane	None	Papillomas	DBaeP, DBahP, DBaiP, DBaeF		Yes	Paper in German. Paper reports compound as DBalP; LaCassagne et al. (1968) state that it is actually DBaeF. DBahP incidence ≥90% at lowest dose.
17660	Cavalieri et al., 1977	Swiss	2 times/wk for 30 wk	Until moribund, dead, or after 70 wk	Acetone	None	Papilloma, kerato-acanthoma, carcinoma	DBahP, AA	BaA	Yes	DBahP incidence ≥90% at lowest dose.
610	Higginbotham et al., 1993	Swiss	2 times/wk	40 wk	Acetone	None	Papilloma, carcinoma	DBalP		No	No tumors with BaP.
19760	Masuda and Kagawa, 1972	Ha/ICR/Mil Swiss	3 times/wk for 60 applications	7 mo	Dioxane	None	Unspecified	DBalP		No	No concurrent untreated or vehicle control; lowest dose DBalP gave 100% incidence.
18570	Hecht et al., 1974	Ha/ICR/Mil Swiss	3 times/wk for 17 mo	72 wk	Acetone	None	Unspecified	CH		No	BaP dose not reported.

Table 4-1. Study summaries: dermal bioassays of benzo[a]pyrene and at least one other PAH

Record number	Reference	Mouse ^a strain	Exposure	Follow up	Vehicle	Promoter	Tumor type	Positive result	Nonpositive result	Meets selection criteria?	Comments
21310	Shubik et al., 1960	Syrian golden hamster	2 times/wk for 10 wk	75 wk	Mineral oil	None	None		DBahA, BaA	No	Small number of animals (5/sex/dose).
23310	Pfeiffer and Allen, 1948	Rhesus monkey	various	Various	Sesame oil	None	Various	Multiple		No	Sequential exposure to multiple compounds; no concurrent untreated control.
23840	Barry et al., 1935	Un-specified	2 times/wk	1–2+ yr	Benzene	None	Epithelioma, papilloma	Multiple		No	Test compounds from various sources gave differing results; purity may be suspect; use of benzene vehicle confounds tumorigenicity results; no benzene or untreated control.
<i>Initiation studies</i>											
24800	Nesnow et al., 1984	SENCAR	Single	31 wk	Acetone	TPA 2 µg 2 times/wk for 30 wk	Papilloma	BeAC, BIAC		Yes	Reports both incidence and multiplicity.
21410	Slaga et al., 1978	CD-1	Single	27 wk	Acetone	TPA 10 µg 2 times/wk for 26 wk	Papilloma	BaA		Yes	Tumor incidence data not useable because BaP gave 93% tumor incidence. Tumor multiplicity data available for dose-response assessment.
630	LaVoie et al., 1982	CrI:CD-1[ICR]BR	10 subdoses every other d	Unspecified	Acetone	TPA 2.5 µg 3 times/wk for 20 wk	Primarily squamous cell papilloma	BbF, BjF, BkF		Yes	Reports both incidence and multiplicity.
16310	Weyand et al., 1992	CrI:CD-1	5 or 10 applications given every other d	Until promotion complete	Acetone	TPA 2.5 µg 3 times/wk for 20 wk	Unspecified	BjF		Yes	Tumor incidence data not useable because BaP gave 100% tumor incidence. Tumor multiplicity data available for dose-response assessment. DNA adducts, mutagenicity also evaluated.
10200	El-Bayoumy et al., 1982	CrI:CD-1[ICR]BR	10 subdoses every other d	Unspecified	Acetone	TPA 2.5 µg 3 times/wk for 25 wk	Primarily squamous cell papilloma	CH	Pery, Pyr	Yes	Tumor incidence data not useable because single dose CH gave 100% tumor incidence; BaP gave 90% tumor incidence. Tumor multiplicity data available for dose-response assessment.
18570	Hecht et al., 1974	Ha/ICR/Mil Swiss	10 subdoses every other d	Until promotion complete	Acetone	TPA 2.5 µg 3 times/wk for 20 wk	Unspecified	CH		Yes	Reports both incidence and multiplicity.
22500	Van Duuren et al., 1966	ICR/HA	Single	63 wk	Acetone	Croton resin, 25 µg 3 times/wk	Papilloma, carcinoma	CH, BbF	BghiF	No	BaP gave 100% tumor incidence. Corollary data with acetone only as promotion agent not included.

Table 4-1. Study summaries: dermal bioassays of benzo[a]pyrene and at least one other PAH

Record number	Reference	Mouse ^a strain	Exposure	Follow up	Vehicle	Promoter	Tumor type	Positive result	Nonpositive result	Meets selection criteria?	Comments
24300	Rice et al., 1985	CD-1	10 subdoses every other d	Until promotion complete	Acetone	TPA 0.0025% 3 times/wk for 20 wk	Unspecified	CH, CPdefC		Yes	Tumor incidence data not useable because all compounds gave >90% tumor incidence. Tumor multiplicity data available for dose-response assessment.
19320	LaVoie et al., 1979	HA/ICR Swiss albino	10 subdoses every other d	Until promotion complete	Acetone or dioxane	TPA 2.5 µg 3 times/wk for 20 wk or croton oil 2.5% 3 times/wk	Unspecified	CH, DBaeP, DBahP, DBaiP, N23eP	FA, AA, DBelP, BghiP, IP	No	Reiterates data published elsewhere.
21420	Slaga, et al., 1980	SENCAR	Single	15 wk	Acetone	TPA 2 µg 2 times/wk	Papilloma	CH, DBahA,	BeP, DBacA	Yes	Not clear if BaP done simultaneously but protocol, vehicle, and follow-up are the same. Reports both incidence and multiplicity.
15640	Raveh et al., 1982	SENCAR	Single	25 wk	Un-specified	TPA 2 µg 2 times/wk for 25 wk	Papilloma	CPcdP		Yes	Reports both incidence and multiplicity.
620	Hoffmann and Wynder, 1966	Ha/ICR/Mil Swiss	Single	6 mo	Dioxane	Croton oil	Papillomas	DBaeF, DBaeP, DBahP, DBaiP, N23eP	IP, AA, BghiP, DBelP	Yes	Paper reports compound as DBalP; LaCassagne et al. (1968) state that it is actually DBaeF.
610	Higginbotham et al., 1993	SENCAR	Single	27 wk	Acetone	TPA 2.6 nmol, 2 times/wk	Papillomas, few carcinomas	DBalP		No	No tumors with BaP.
13660	Cavalieri et al., 1991	SENCAR	Single	16 wk and 27 wk (two experiments)	Acetone	TPA 3.24 nmol 2 times/wk for 11 wk	Primarily papilloma	DBalP		Yes	Tumor incidence data not useable because lowest dose DBalP gave >90% tumor incidence. Tumor multiplicity data from both experiments available for dose-response assessment.
19360	LaVoie et al., 1985	CrI:CD/1 (ICR)BR	10 subdoses every other d	Unspecified	Acetone	TPA 2.5 µg 3 times/wk for 20 wk	Unspecified		AC	Yes	
13650	Cavalieri et al., 1981b	CD-1	10 subdoses every other d	57 wk	Acetone	TPA 0.017 µmol 2 times/wk for 40 wk	Papilloma	CPcdP	ACEP	Yes	Reports both incidence and multiplicity.
20830	Roe, 1962	Albino	Single	Until promotion complete	Acetone	Croton oil once/wk for 20 wk	Papilloma		PH	No	BaP not simultaneous.

Table 4-1. Study summaries: dermal bioassays of benzo[a]pyrene and at least one other PAH

Record number	Reference	Mouse ^a strain	Exposure	Follow up	Vehicle	Promoter	Tumor type	Positive result	Nonpositive result	Meets selection criteria?	Comments
16440	Wood et al., 1980	CD-1	Single	27 wk	Acetone	TPA 16 nmol 2 times/wk for 26 weeks	Unspecified		Pyr, CPcdP	Yes	
17450	Brune et al., 1978	NMRI	Unspecified	Unspecified	Un-specified	TPA	Unspecified		AC	No	Study design not reported. Results reported qualitatively.
18680	Hoffmann et al., 1972	Ha/ICR/ Mil Swiss	10 subdoses every other d	Until promotion complete	Acetone	Croton oil 2.5% for 20 wk	Unspecified		FA	Yes	
19420	LaVoie et al., 1981	HA/ICR Swiss albino	10 subdoses every other d	Unspecified	Acetone	TPA 2.5 µg 3 times/wk for 20 wk	Unspecified		PH	Yes	
13660	Cavalieri et al., 1991	SENCAR	Single	27 wk	Acetone	None	Primarily papilloma	DBaP		Yes	Initiating dose only; no promoter. Tumor incidence data not useable because lowest dose DBaP gave >90% tumor incidence. Tumor multiplicity data available for dose-response assessment.
15700	Rice et al., 1988	CD-1	10 subdoses every other d	24 wk	Acetone	TPA 2.5 µg 3 times/wk for 20 wk	Unspecified	CH, BbcAC, CPdefC		Yes	Not clear if BaP done simultaneously for all PAHs.
<i>Cocarcinogenicity studies</i>											
18700	Horton and Christian, 1974	C3H	2 times/wk for 80 wk	82 wk	n-Do- decane/ decalin mixture	None	Carcinoma, papilloma	DBacA, Pyr	CH, FA, Tphen, Pery,	No	Not clear if BaP done simultaneously. Experiments with decalin (noncarcinogen) and 50/50 decalin/dodecane mix (cocarcinogenic). No data for BaP in 50/50 mix. No vehicle control in decalin.
21430	Slaga et al., 1979	CD-1	Single	30 wk	Acetone	TPA 10 µg 2 times/wk for 30 wk	Papilloma	BeP		No	No concurrent control. Study aimed at exploring interactions; not clear if BaP done simultaneously.
21840	Van Duuren and Goldschmidt, 1976	ICR/Ha Swiss	3 times/wk	368 or 440 d	Acetone	None	Papilloma		Pyr, BghiP, BeP, FA	Yes	
21850	Van Duuren et al., 1973	ICR/HA	3 times/wk for 52 wk	52 wk	Acetone	None	None		Pyr, BghiP, BeP	No	Qualitative results reported.
21920	Warshawsky et al., 1993	C3H/HEJ	2 times/wk	Until lesion developed or 104 wk	Toluene or n-do- decane	None	Unspecified		AC, CH, Pyr, FA, PH	No	No tumors with BaP.

^aExcept where noted, all studies were conducted in mice.

DMSO = dimethyl sulfoxide

Table 4-2. Study summaries: intraperitoneal bioassays of benzo[a]pyrene and at least one other PAH

Record number	Reference	Mouse strain ^a	Exposure	Follow up	Vehicle	Target organ(s)	Tumor type(s)	Positive result	Non-positive result	Meets selection criteria?	Comments
<i>Newborn mouse studies</i>											
13610	Busby et al., 1984	Swiss-Webster BLU:Ha (ICR)	1st, 8th, 15th d	26 wk	DMSO	Lung	Adenoma, adenocarcinoma	FA		Yes	Tumor incidence data not useable because lowest dose BaP gave >90% tumor incidence. Tumor multiplicity data available for dose-response assessment.
17560	Busby et al., 1989	Swiss-Webster BLU:Ha (ICR)	1st, 8th, 15th d	26 wk	DMSO	Lung	Adenoma, adenocarcinoma	FA	Pyr, CH	Yes	Reports both incidence and multiplicity.
640	LaVoie et al., 1987	CD-1	1st, 8th, 15th d	52 wk	DMSO	Lung, liver	Adenoma, hepatoma	BbF, BjF	BkF, IP	Yes	
7510	LaVoie et al., 1994	CD-1	1st, 8th, 15th d	12 mo	DMSO	Lung, liver	Foci, adenoma, carcinoma	FA		Yes	Reports both incidence and multiplicity.
22040	Weyand and LaVoie, 1988	CD-1	1st, 8th, 15th d	Not reported	DMSO	Lung, liver	Unspecified	Not reported		No	Abstract only; dose-response information not included.
22510	Wislocki et al., 1986	CD-1	1st, 8th, 15th d	12 mo	DMSO	Lung, liver, lymphatic system	Adenoma, carcinoma, lymphoma	CH, BaA	Pyr	Yes	Reports both incidence and multiplicity.
<i>Studies in A/J mice</i>											
11190	Mass et al., 1993	A/J	Single	8 mo	Tri-caprylin	Lung	Adenoma, carcinoma	BjAC		No	Reiterates data reported elsewhere (Record 24590).
23960 and 23450	Nesnow et al., 1998a, 1995	A/J	Single	8 mo	Tri-caprylin	Lung	Adenoma	BbF, DBahA, CPcdP		No	Reiterates data reported elsewhere (Record 24590).
22670	Nesnow et al., 1996	A/J	Single	8 mo	Tri-caprylin	Lung	Adenoma	BbF, DBahA, CPcdP		No	(Reiterates data reported elsewhere (Record 24590).)
24590	Nesnow et al., 1998b	A/J	Single	8 mo	Tri-caprylin	Lung	Adenoma	CPcdP, BbF, DBahA, BjAC, DBaP		Yes	Raw data (both incidence and multiplicity) obtained courtesy of S. Nesnow.

Table 4-2. Study summaries: intraperitoneal bioassays of benzo[a]pyrene and at least one other PAH

Record number	Reference	Mouse strain ^a	Exposure	Follow up	Vehicle	Target organ(s)	Tumor type(s)	Positive result	Non-positive result	Meets selection criteria?	Comments
20920	Ross et al., 1995	A/J	Single	240 d	Tri-caprylin	Lung	Adenoma	BbF, DBahA, CPcdP	Pyr	No	Reiterates data reported elsewhere (Record 24590).
24801	Weyand et al., 2004	A/J	Single	260 d	Tri-caprylin	Lung	Adenoma	BcFE		Yes	

^aAll studies were conducted in mice.

1

Table 4-3. Study summaries: subcutaneous bioassays of benzo[a]pyrene and at least one other PAH

Record number	Reference	Species	Strain	Exposure site	Exposure	Follow up	Vehicle	Target organ(s)	Tumor type(s)	Positive result	Nonpositive result	Meets selection criteria?	Comments
23840	Barry et al., 1935	Mouse	Unspecified	Unspecified	Single	1–2+ yr	Lard	Injection site	Sarcoma	Multiple		No	Test compounds from various sources gave differing results; purity may be suspect; no untreated control.
220	Bryan and Shimkin, 1943	Mouse	C3H	Right axilla	Single	until 20 mm tumor	Tricaprylin	Injection site	Unspecified	DBahA		No	No concurrent untreated control.
18350	Grant and Roe, 1963	Mouse	Albino	Neck	1st d after birth	52–62 wk	Aqueous gelatin	Lung	Adenoma		PH	Yes	
23200	Homburger et al., 1972	Hamster	Various	Groin	Single	52 wk	Tricaprylin	Injection site; lung	Various	BaA		No	Study aimed at evaluating strain specificity of tumorigenicity. BaA results equivocal. Not clear if BaP treatment simultaneous. "Aged" mice used as controls; aged mice allowed to live 16 weeks longer.
660	Pfeiffer, 1977	Mouse	NMRI	Neck	Single	114 wk	Tricaprylin	Injection site	Sarcoma	DBahA		No	Less than 10% of 100 control mice alive at 114 wk; control data not provided.
23310	Pfeiffer and Allen, 1948	Monkey	Rhesus	Various	Various	variable	Sesame oil	Various	Various	Multiple		No	Sequential exposure to multiple compounds; no concurrent untreated control.
24290	Rask-Nielson, 1950	Mouse	Street	Thymus, lung, mammary area	Single	30 mo	Paraffin	Various	Various	DBahA		No	Number of control and exposed varies by tumor type reported; BaP nontumorigenic; DBahA results equivocal; results unclear.
24310	Roe and Waters, 1967	Mouse	Swiss albino	Not specified	1st d after birth	50–60 wk	Aqueous gelatin	Liver	Hepatoma	PH		No	Study methodology and results not detailed; PH results equivocal.
21560	Steiner, 1955	Mouse	C57BL	Interscapular	Single	22–28 mo	Tricaprylin	Injection site	Sarcoma	DBahA, BaA, CH	AC, PH	No	No concurrent untreated control; study aimed at evaluating interactions.

1

Table 4-4. Study summaries: oral bioassays of benzo[a]pyrene and at least one other PAH

Record number	Reference	Species	Strain	Exposure route	Exposure	Follow up	Target organ(s)	Tumor type(s)	Positive result	Non-positive result	Meets selection criteria?	Comments
17280	Biancifiiori and Caschera, 1962	Mouse	BALB/c	Gavage	2 times/wk, 15 wk	Variable; 50–60 wk	Mammary gland	Carcinomas and sarcomas	DBahA		No	Tumors observed after DBahA only in pseudopregnant mice, not virgin mice.
23880	Huggins and Yang, 1962	Rat	Sprague-Dawley	Gavage	Single	Not reported	Mammary gland	Unspecified		BaA, PH	No	Untreated control information not included.
24801	Weyand et al., 2004	Mouse	A/J	Diet	Daily, 260 d	260 d	Lung	Adenoma	BcFE		Yes	

2

3

Table 4-5. Study summaries: other route bioassays of benzo[a]pyrene and at least one other PAH

Record number	Reference	Species	Strain	Exposure route	Exposure	Follow up	Vehicle	Target organ(s)	Tumor type(s)	Positive result	Non-positive result	Meets selection criteria?	Comments
21750	Topping et al., 1981	Rat	F344	Implantation in transplanted tracheas	Release from pellet	28 mo	Beeswax pellet	Tracheal epithelium	Carcinoma, sarcoma		BeP	No	Interaction information included.
17620	Cavalieri et al., 1988b	Rat	Sprague-Dawley	Intramamillary	Single	20 wk	None	Mammary	Adeno-carcinoma, adenofibroma, fibrosarcoma		DBahA, BaA	No	Control data from untreated mammary glands of same rats.
13660	Cavalieri et al., 1991	Rat	Sprague-Dawley	Intramamillary	Single	Until 2 cm tumor or 24 wk	Trioctanoin	Mammary, other	Adeno-carcinoma, adenofibroma, fibrosarcoma, squamous cell carcinoma	DBalP		No	DBalP produced tumors in all animals at the lowest dose.
21620	Sugiyama, 1973	Rat	Long-Evans	Intramuscular	Single	9 mo	Sesame oil	Injection site	Sarcoma		BaA	No	BaP gave 100% tumor incidence.
20280	Pataki and Huggins, 1969	Rat	Sprague-Dawley	Intravenous	3 doses 3 d apart	98 d	Lipid emulsion	Mammary	Unspecified		BaA	No	No control group.
17940	Deutsch-Wenzel et al., 1983	Rat	Osborne-Mendel	Lung implantation	Release from pellet	Until moribund or dead	Beeswax/trioctanoin	Lung	Carcinoma, sarcoma	BbF, BjF, BkF, IP, AA, BghiP	BeP	Yes	
22000	Wenzel-Hartung et al., 1990	Rat	Osborne-Mendel	Lung implantation	Release from pellet	Until moribund or dead	Beeswax/trioctanoin	Lung	Carcinoma	CH, DBahA	PH	Yes	
21500	Solt et al., 1987	Hamster	Syrian golden	Painting buccal pouch	2 times/wk for 20 wk	Up to 44 wk	Paraffin oil	Buccal pouch	Carcinoma		BaA	No	Fewer than 20 animals per group; negative result.
23910	Nikonova, 1977	Mouse	A	Subcutaneous (F0) and transplacental (F1)	GD 18 or 19	1 yr	Sunflower oil	Lung, mammary, liver, injection site	Adenoma		Pyr	No	Transplacental exposure not quantified.

Table 4-6. Study summaries: in vivo DNA adducts with benzo[a]pyrene and at least one other PAH

Record number	Reference	Route of administration	Exposure frequency	Hours between dosing and sacrifice	Tissue analyzed	Method of analysis	PAHs evaluated ^a	Meets selection criteria?	Comments
6210	Arif et al., 1997	Intramamillary	Single dose	48	Mammary epithelium, lung	[³² P] postlabeling	DBaP	Yes	
17420	Brookes and Lawley, 1964	Dermal	Single dose	various to ~12 d	Skin	[³ H] prelabeling	DBaC, DBaH	No	Data on individual compounds not reported.
17630	Cavaliere et al., 1981a	Dermal	Single dose	4, 24	Skin	[³ H] or [¹⁴ C] prelabeling	CPcdP, ACEP	Yes	
18810	Hughes and Phillips, 1990	Dermal	Single dose	0.5, 1, 2, 4, 7, 21, 84 d	Skin, lung	[³² P] postlabeling	DBaP, DBaE, DBaH, DBaI	Yes	24-hr experiment with DBaE and DBaP; 84-d experiment with all.
18790	Hughes and Phillips, 1991	Dermal	Single dose	24	Skin	[³² P] postlabeling	DBaE	No	No quantitative information; abstract only.
10900	Koganti et al., 2000	Oral-diet	14 d	not stated	Lung	[³² P] postlabeling	BcFE, BaFE, BbFE	No	Not quantified.
13200	Li et al., 2002	Gavage or oral-diet	1 time/d for 1–4 d; diet 14 d		Mammary gland and liver; lung	[³² P] postlabeling	BcFE	No	Not quantified; BaP administered by gavage, BcFE admin in diet.
11190	Mass et al., 1993	Intraperitoneal	Single dose	24, 48, 72	Lung	[³² P] postlabeling	BjAC	Yes	
8010	Nesnow et al., 1993b	Intraperitoneal	Single dose	1, 3, 7, 14, 28, 56 d	Lung, liver, peripheral blood lymphocytes	[³² P] postlabeling	BbF	Yes	Peaks differ temporally; study also correlates number of adducts in organs.
22670	Nesnow et al., 1996	Intraperitoneal	Single dose	7 d	Lung	[³² P] postlabeling	BbF, DBaH, CPcdP	No	Not quantified.
23960	Nesnow et al., 1995	Intraperitoneal	Single dose	7 d	Lung	[³² P] postlabeling	BbF, DBaH, CPcdP	No	Not quantified.
24590	Nesnow et al., 1998a	Intraperitoneal	Single dose	various to 21 d	Lung	[³² P] postlabeling	BbF, CPcdP, DBaH, DBaP	Yes	Used data from Ross et al., 1995 (ref 20920) to calculate slope.
22810	Phillips et al., 1979	Dermal	Single dose	19, 24, 48, 72, 96, 120, 144	Skin	[³ H]-Prelabeling	BaA, DBaC, DBaH	Yes	
20650	Reddy et al., 1984	Dermal	4 doses (0, 6, 30, 54 hr)	24	Skin	[³² P] postlabeling	AC, BaA, BghiP, BeP, CH, DBaC, DBaH, Pery, Pyr	No	Semiquantitative data only.
20920	Ross et al., 1995	Intraperitoneal	Single dose	0, 1, 3, 5, 7, 14, 21 d	Lung	[³² P] postlabeling	BbF, CPcdP, DBaH	No	Reiterates data published elsewhere (Record 24590).
16310	Weyand et al., 1992	Dermal	Single dose	24	Skin	[³² P] postlabeling	BjF	No	Not quantified.
22040	Weyand and LaVoie, 1988	Intraperitoneal	Postnatal d 1, 8, 15	24	Lung, liver	[³² P] postlabeling	BbF, BjF, BkF	No	No quantitative data; abstract only.

Table 4-6. Study summaries: in vivo DNA adducts with benzo[a]pyrene and at least one other PAH

Record number	Reference	Route of administration	Exposure frequency	Hours between dosing and sacrifice	Tissue analyzed	Method of analysis	PAHs evaluated ^a	Meets selection criteria?	Comments
24801	Weyand et al., 2004	Oral-diet or intraperitoneal	14 d diet; single dose intraperitoneal	24	Lung, forestomach	[³² P] postlabeling	BcFE	Yes	
24790	Kligerman et al., 2002	Intraperitoneal and oral	Single dose	7 d	Peripheral blood lymphocytes	[³² P] postlabeling	BaA, BbF, CH	Yes	Data in both rats and mice.

^aPositive findings were reported for all PAHs evaluated.

1

Table 4-7. Study summaries: in vivo clastogenicity or sister chromatid exchange with benzo[a]pyrene and at least one other PAH

Record number	Reference	Species	Strain	Route of administration	Vehicle	Exposure	Hours between dosing and sacrifice	Tissue analyzed	Clastogenic endpoint	Positive results	Non-positive results	Meets selection criteria?	Comments
24740	Allen et al., 1999	Mice	A/J or p53 +/+, +/-, and -/-	Intraperitoneal	Tricaprylin	Single	48 or 72 hr	Bone marrow or peripheral blood	Micro-nuclei	DBaP		Yes	
14270	He and Baker, 1991	Mice	HRA/Skh hairless	Dermal	Acetone	Single	24 hr	Keratinocytes	Micro-nuclei	CH	Pyr	Yes	
17190	Bayer, 1978	Hamsters	Chinese	Intraperitoneal	Tricaprylin	Single	24 hr for aberrations; 30 hr for micronuclei	Bone marrow	Gaps, breaks, micro-nuclei, sister chromatid exchanges	PH (high dose only)		Yes	
19030	Katz et al., 1981	Mice	B6C3F ₁ /BR	Intraperitoneal	DMSO	At 0 and 24 hr	various; 24, 30, 48, 72 hr after last dose	Bone marrow	micro-nuclei		DBaP, AC, BghiP, Pyr	No	No quantitative data.
24720	Kligerman et al., 1986	Mice	C57BL6	Gavage	Corn oil	Single	23.5–25 hr	Peripheral blood	Sister chromatid exchanges	BIAC		Yes	
24790	Kligerman et al., 2002	Mice and rats	CD-1 Swiss mice; CD rats	Oral and intraperitoneal	Sunflower seed oil	Single	7 d	Whole blood or mono-nuclear leukocytes	Sister chromatid exchange, micro-nuclei	BaA, BbF, CH		Yes	All positive for sister chromatid exchange via intraperitoneal administration; mixed results for oral administration.
20200	Oshiro et al., 1992	Mice	CD-1	Peroral	Polyethylene glycol	1 time/d, 4 d	24 hr after 2nd and 4th treatment	Peripheral blood	Micro-nuclei		Pyr, AC	No	No quantitative data; published as abstract.
20230	Paika et al., 1981	Mice	CBA/J	Intraperitoneal	DMSO	single	16–20 hr	Bone marrow	Sister chromatid exchanges		Pyr	No	No quantitative data.
20950	Roszinsky-Kocher et al., 1979	Hamsters	Chinese	Intraperitoneal	Tricapryline	2 doses 24 hr apart	24 hr after 2nd treatment	Bone marrow	Sister chromatid exchanges, micro-nuclei, aberrations	PH, CH, DBaA, BaA, BbF, BeP	AC	Yes	Positive results for sister chromatid exchanges, not aberrations.
21050	Salamone et al., 1981	Mice	B6C3F ₁	Intraperitoneal	Not specified	2 doses 24 hr apart	24, 48, 72 hr after 2nd treatment	Bone marrow	Micro-nuclei		AC, Pyr	Yes	
21770	Tsuchimoto and Matter, 1981	Mice	CD-1	Intraperitoneal	DMSO	2 doses 24 hr apart	6 hr after 2nd treatment	Bone marrow	Micro-nuclei		Pyr	Yes	

Table 4-7. Study summaries: in vivo clastogenicity or sister chromatid exchange with benzo[a]pyrene and at least one other PAH

Record number	Reference	Species	Strain	Route of administration	Vehicle	Exposure	Hours between dosing and sacrifice	Tissue analyzed	Clastogenic endpoint	Positive results	Non-positive results	Meets selection criteria?	Comments
21390	Sirianni and Huang, 1978	Mice	C3H/St	V79 cells in diffusion chamber implanted in peritoneal cavity of mice				Chinese hamster V79 cells	Sister chromatid exchanges		AC, Pyr, Pery	Yes	
21620	Sugiyama, 1973	Rats	Long-Evans	Intravenous	Lipid emulsion	Single	12, 24 hr	Bone marrow	Gaps, breaks		BaA	Yes	

1

Table 4-8. Study summaries: in vivo mutagenicity with benzo[a]pyrene and at least one other PAH

Record number	Reference	Species/strain	Route of administration	Exposure frequency/follow up	Mutagenic endpoint	Positive result	Non-positive result	Meets selection criteria?	Comments
18130	Fahmy and Fahmy, 1980	<i>Drosophila melanogaster</i>	Suspension in media	48–72 hr	Somatic mutation; eye color mosaicism		BaA	Yes	
13980	Frolich and Wurgler, 1990	<i>D. melanogaster</i>	Suspension in media	48–72 hr	Somatic mutation and recombination test; wing spots		BaA	No	Inconsistent results for BaA; significant effects only seen with cross-breeding of strains selected for enhanced metabolic activity (not standard strains).
11190	Mass et al., 1993	A/J mice	Intraperitoneal	3 d/8 mo	Mutations in codon 12 of the Ki-ras oncogene; PCR and DNA sequencing of lung tumor DNA	BjAC		No	Quantitative dose-response data were not available. Different mutation sequences observed; GGT→TGT for BaP and GGT→CGT for BjAC; mutation sequence for BjAC may correlate with cyclopenta-adduct formation.
23960	Nesnow et al., 1995	A/J mice	Intraperitoneal	Single injection/8 mo	Mutations in codon 12 of the Ki-ras oncogene; PCR and DNA sequencing of lung tumor DNA	BbF, DBahA, CPcdP		No	Quantitative dose-response data were not available. GGT→TGT mutations for BaP and BbF; GGT→CGT for CPcdP; no mutations seen for DBahA.
22670	Nesnow et al., 1996	A/J mice	Intraperitoneal	Single injection/8 mo	Mutations in codon 12 of the Ki-ras oncogene; PCR and DNA sequencing of lung tumor DNA	BbF, DBahA, CPcdP		No	Quantitative dose-response data were not available. GGT→TGT mutations for BaP and BbF; GGT→CGT for CPcdP; no mutations seen for DBahA.
24590	Nesnow et al., 1998b	A/J mice	Intraperitoneal	Single injection/8 mo	Mutations in codons 12 and 61 of the Ki-ras oncogene; PCR and DNA sequencing of lung tumor DNA	BbF, DBahA, CPcdP, BjAC, DBalP		No	Quantitative dose-response data were not available. Mutations in codon 12, GGT→TGT for BaP, BbF, and DBalP; GGT→CGT for CPcdP and BjAC; no mutations seen for DBahA; GTT mutations seen for all other PAHs. Only DBalP caused mutations in codon 61.
21370	Simmon et al., 1979	Swiss Webster mice	PAHs intramuscular or peroral; microorganisms intraperitoneal	Single injection/4 hr	Intraperitoneal host mediated assay; mutagenicity in <i>S. typhimurium</i> and <i>Saccharomyces cerevisiae</i> of recovered microorganisms		AC, BaA, BeP, CH, PH	No	Assay was not considered sensitive enough for detecting carcinogens.
21830	Valencia and Houtchens, 1981	<i>D. melanogaster</i>	Filter feeding	48–72 hr	Sex-linked recessive lethal test		Pyr	No	Results were negative for BaP.
22450	Zijlstra and Vogel, 1984	<i>D. melanogaster</i>	Abdominal injection	Not applicable	Sex-linked recessive lethal test; 2–3 translocation and ring-X loss		BaA	No	Results were negative for BaP.

Table 4-9. Study summaries: in vitro bacterial mutagenicity with benzo[a]pyrene and at least one other PAH

Record number	Reference	Salmonella strain(s)	Activation system	Positive result	Nonpositive result	Meets selection criteria?	Comments
17030	Andrews et al., 1978	TA100, TA1527, TA1538	Ar S9 and others	AA, DBahA, DBajA, DBacA, BghiP, BeP		Yes	TA100 results include BaP.
23830	Baker et al., 1980	TA100	Guinea pig MC S9 and others	DBaiP, BaA, DBacA, DBahA		Yes	
23660	Bartsch et al., 1980	TA100, TA1535, TA98	Rat MC S9	BaA		Yes	
17380	Bos et al., 1988	TA98, TA100	Rat Ar S9	PH, Pyr		Yes	Qualitative data for other PAHs (no BaP); quantitative data with BaP comparison for PH and Pyr in TA100.
9560	Carver et al., 1985	TA98, TA100	S9	Pery		No	The response varied at different concentrations of S9; BaP was more potent at low S9 while Pery was more potent at high S9.
17590	Carver et al., 1986	TA100	Ar rat and Ar hamster S9	BaA, BghiF, Pery		Yes	Qualitative data also presented for other PAHs. S9 concentration varied; 400 µL/plate optimal.
17630	Cavalieri et al., 1981a	TM677	Ar S9	CPcdP, ACEP, Pyr		Yes	BaP data from previous publication used. Dose-response data not provided for Pyr.
9620	Chang et al., 2002	TA100	Rat Ar S9	BghiF, BcPH		Yes	
24030	De Flora et al., 1984	TA1535, TA1537, TA1538, TA98, TA100	Rat AR S9	BaA, Pery, BeP	AC	Yes	
13860	Devanesan et al., 1990	TA100, TA98	Rat Ar S9	DBaeP, DBalP		No	No concurrent control.
18030	Dunkel et al., 1984	TA1535, TA1537, TA1538, TA98, TA100	Rat, mouse, hamster Ar S9	BaA, BeP, PH, Pyr	AC	No	Dose-response data not provided.
18050	Eisenstadt and Gold, 1978	TA1537, TA100	Rat Ar S9	CPcdP		Yes	
18180	Florin et al., 1980	TA98, TA100	Rat Ar and MC S9	BaA, CH, Pery, CO		Yes	
24080	Gibson et al., 1978	TA1535, TA1537, TA1538, TA98	Nonenzymatic (gamma radiation)	BaA, BghiP, CH, FE, Pyr	DBahA, AC, Pic, Tphen	Yes	AN, PH also tested; toxicity interfered with mutagenicity testing.
14080	Gold and Eisenstadt, 1980	TA100	Rat MC S9	CPcdP		Yes	BaP and CPcdP maximal responses occurred at different S9 levels.
14170	Guthrie et al., 1982	TA98, TA100	Rat Ar S9 compare to PGS from ram seminal vesicles	BaA, CH		No	BaP tested in TA98, BaA and CH tested in TA100.
14260	Hass et al., 1981	TA98, TA100	Rat Ar S9		BeP	Yes	

Table 4-9. Study summaries: in vitro bacterial mutagenicity with benzo[a]pyrene and at least one other PAH

Record number	Reference	Salmonella strain(s)	Activation system	Positive result	Nonpositive result	Meets selection criteria?	Comments
18650	Hermann, 1981	TA98	Rat Ar S9	BbA, BaA, CH, FA, Tphen, BeP, DBacA, DBahA, BbF, Pery, DBalP, DBaiP, AA, CO	AC, PH, FE, Pyr, BbFE	Yes	
10670	Johnsen et al., 1997	TA98	Rat control or PB S9	BjAC, BIAC		Yes	
19000	Kaden et al., 1979	TM677	Rat Ar or PB S9	AN, ANL, Pyr, BbFE, CPcdP, BaA, CH, Tphen, FA, BeP, Pery, BghiP, AA, DBacA, DBahA, DBbeF	FE, AC, PH, Pic, CO	Yes	Mutagenic activity relative to BaP reported.
24680	Lafleur et al., 1993	TM677	Ar PMS	CPcdP, APA, ACEA, CPhiAPA, CPhiACEA		Yes	
19320	LaVoie et al., 1979	TA98, TA100	Rat Ar S9	BeP, Pery		Yes	Several other PAHs were evaluated, but not concurrent with BaP.
19360	LaVoie et al., 1985	TA98, TA100	Rat Ar S9		AC	Yes	
23650	McCann et al., 1975	TA1535, TA1537, TA98, TA100	Rat Ar S9	DBaiP, BeP, DBacA, DBahA, CH, BaA	Pyr, AC, PH, FE	Yes	
15170	Norpoth et al., 1984	TA100	Rat and mouse S9; induction by Clophen A50 and 18 PAHs	BaA		No	S9 composition was different for BaA and BaP; result cannot be compared.
20220	Pahlman and Pelkonen, 1987	TA100	S9 from control, MC, or TCDD treated rats and mice	BaA, CH, Tphen, DBacA, DBahA	AN, AC, PH, FE, Pyr, BeP, Pery, PCE	Yes	
20530	Penman et al., 1980	TM677	Rat Ar or PB S9	Pery, CPcdP, DBacA		No	No concurrent control values were reported.
20450	Phillipson and Ioannides, 1989	TA100	S9 isolated from mouse, hamster, rat, pig, and human	BaA, DBaiP, DBahA		Yes	
20490	Poncelet et al., 1978	TA1530, TA1535, TA1537, TA1538, TA98, TA100	S9 (origin unknown)	CO, Tphen, FA, BghiP	BbF	No	Qualitative data reported in published abstract.
20560	Probst et al., 1981	TA1530, TA1535, TA1537, TA1538, TA98, TA100	Rat Ar S9	BbA, DBacA	AC, DBahA, PH, Pyr, DBaiP	No	Data reported as minimum mutagenic concentration (nmol/mL).
20880	Rosenkranz and Poirier, 1979	TA1530, TA1535	Uninduced rat S9		AC, BaA, BeP, CH, PH	Yes	
21000	Sakai et al., 1985	TA97, TA98, TA100	Rat Ar S9	FE (equiv.), AC, PH, FA, CH, Pyr, BeP, Pery, BghiP, CO		Yes	
21040	Salamone et al., 1979a	TA1535, TA1537, TA1538, TA98, TA100	Rat Ar S9	BaA, BeP (equiv.), BghiP, DBaiP, BPH, CH, CO, DBacA, PCE	AC, BaFE, BbFE, FA, Pery, Pyr	No	Increase in spontaneous mutation rate was indicated, but dose data were not provided.

Table 4-9. Study summaries: in vitro bacterial mutagenicity with benzo[a]pyrene and at least one other PAH

Record number	Reference	Salmonella strain(s)	Activation system	Positive result	Nonpositive result	Meets selection criteria?	Comments
13260	Salamone et al., 1979b	TA98, TA100	Rat Ar S9	DBaiP		No	Dose-response data were not completely reported; maximal response information (dose and number of revertants) was presented in text; BaP max response at different S9 than DBaiP.
11860	Sangaiah et al., 1983	TA1535, TA1537, TA1538, TA98, TA100	Rat Ar S9	BjAC		Yes	Dose-response data for BaP was presented for TA98 only.
21360	Simmon, 1979a	TA1535, TA1536, TA1537, TA1538, TA98, TA100	Rat Ar S9	BaA, BeP	AC, CH, PH	Yes	
21640	Teranishi et al., 1975	TA1535, TA1536, TA1537, TA1538	S9 from rats treated with PB and MC or DBahA	DBaiP, DBaeP	DBahA, BaA, BeP	Yes	
16180	Utesch et al., 1987	TA100	Intact or homogenized hepatocytes from Ar treated rats	BaA		Yes	
16440	Wood et al., 1980	TA98, TA100	Rat Ar S9 and purified MFO enzymes system	CPcdP		Yes	

Ar = Arochlor 1254-treated; MC = 3-methylcholanthrene-treated; PB = phenobarbital-treated; PMS = postmitochondrial supernatant

1

Table 4-10. Study summaries: in vitro mammalian mutagenicity assays with benzo[a]pyrene and at least one other PAH

Record number	Reference	Cell type	Metabolic activation	Mutagenesis assay	Positive result	Non-positive result	Meets selection criteria?	Comments
16900	Allen-Hoffmann and Rheinwald, 1984	Human epidermal keratinocyte	None	6-Thioguanine resistance (HPRT)		BaA	Yes	
16920	Amacher and Paillet, 1982	Mouse lymphoma cells (L5178Y)	Syrian golden hamster S9 mix or cocultivated hamster hepatocytes	Trifluorothymidine resistance (thymidine kinase locus [TK])	BaA		Yes	
16930	Amacher and Paillet, 1983	Mouse lymphoma cells (L5178Y)	Cocultivated rat hepatocytes	Trifluorothymidine resistance (TK)		BaA	Yes	
16940	Amacher and Turner, 1980	Mouse lymphoma cells (L5178Y)	S9 from eight rodent species or strain; one rat strain induced by Ar	Trifluorothymidine resistance (TK)	AC, BaA		Yes	AC data not useable; BaP not simultaneous.
16910	Amacher et al., 1980	Mouse lymphoma cells (L5178Y)	Rat Ar and noninduced S9	Trifluorothymidine resistance (TK)	BaA	AC, Pyr	Yes	
13440	Baird et al., 1984	V79 Chinese hamster cells	Hamster embryo cells	6-Thioguanine resistance (HPRT)		BeP	Yes	
17140	Barfknecht et al., 1982	TK6 human lymphoblast cells	Rat Ar S9	Trifluorothymidine resistance (TK)	FA, BaA, CH, Tphen, CPcdP	PH, AC, ACEP	Yes	
24670	Durant et al., 1999	H1A1v2 human lymphoblastoid cells	Transfected with cyp1a1 cDNA	Trifluorothymidine resistance (TK)	BaPery, BbPery, DBaeF, DBafF, DBahP, DBaiP, DBelP, N23aP, N23eP	DBjIF, N12bF	Yes	
18260	Gehly et al., 1982	C3H/10T1/2 clone 8 mouse fibroblast cells	None	Ouabain resistance (HPRT)		BeP	Yes	
14250	Hass et al., 1982	V79 Chinese hamster cells	Hamster embryo cells	Ouabain and 6-thioguanine resistance (HPRT)	DBaiP, DBahP		Yes	
18750	Huberman, 1975	V79 Chinese hamster cells	Hamster cells	8-Azaguanine resistance (HPRT)		BaA, Pyr	Yes	
18740	Huberman and Sachs, 1976	V79 Chinese hamster cells	Hamster embryo cells	Ouabain and 8-azaguanine resistance (HPRT)	DBacA, DBahA (both weak)	Pyr, PH, CH, BaA	Yes	
24120	Huberman and Sachs, 1974	V79 Chinese hamster cells	Hamster embryo cells	8-Azaguanine resistance (HPRT)		BaA	Yes	
18990	Jotz and Mitchell, 1981	Mouse lymphoma cells (L5178Y)	Rat Ar S9	Trifluorothymidine resistance (TK)	Pyr		Yes	
24720	Kligerman et al., 1986	Mouse lymphoma cells (L5178Y)	Rat Ar S9	Trifluorothymidine resistance (TK)	BIAC		Yes	

Table 4-10. Study summaries: in vitro mammalian mutagenicity assays with benzo[a]pyrene and at least one other PAH

Record number	Reference	Cell type	Metabolic activation	Mutagenesis assay	Positive result	Non-positive result	Meets selection criteria?	Comments
19180	Krahn and Heidelberg, 1977	V79 Chinese hamster cells	Rat MC S9	6-Thioguanine resistance (HPRT)	BaA, DBacA, DBahA		Yes	DBacA and DBahA data not useable; treatment different than BaP.
24680	Lafleur et al., 1993	MCL-3 human lymphoblastoid cells	Transfected with cyp1a2 and cyp2a6 cDNA	Trifluorothymidine resistance (TK)	CPcdP, ACEA, CPhiACEA	APA, CPhiAPA, BghiF	Yes	
24170	Langenbach et al., 1983	V79 Chinese hamster cells	Cocultivation with primary rodent cells from liver, lung, kidney, and bladder	Ouabain resistance (HPRT)		AC	Yes	
7550	Li and Lin, 1996	HS1 HeLa cells (human epithelial cells)	None	6-Thioguanine resistance (HPRT)	BaA		Yes	
19870	Mishra et al., 1978	Fischer rat embryo cells infected with Rauscher leukemia virus	Rat Ar S9	Ouabain resistance (HPRT)		AC, PH, Pyr, BeP	Yes	
20040	Myhr and Caspary, 1988	Mouse lymphoma cells (L5178Y)	Rat Ar and noninduced S9	Trifluorothymidine resistance (TK)	AC, BaA, BeP		No	Results reported as ranges.
11450	Nesnow et al., 1984	V79 Chinese hamster cells	Rat Ar S9	6-Thioguanine resistance (HPRT)	BIAC, BeAC, BjAC		Yes	
15630	Raveh and Huberman, 1983	V79 Chinese hamster cells	Hamster embryo fibroblasts	6-Thioguanine resistance (HPRT); phorbol myristate acetate used to enhance recovery	CPcdP	BaA	Yes	
15640	Raveh et al., 1982	V79 Chinese hamster cells	Hamster embryo fibroblasts	Ouabain and 6-thioguanine resistance (HPRT)	CPcdP		Yes	Mutagenicity correlated with skin tumor initiation.
21410	Slaga et al., 1978	V79 Chinese hamster cells	Hamster embryo cells	Ouabain resistance (HPRT)	BaA (weak)		Yes	
21720	Tong et al., 1983	Rat liver epithelial cells (ARL-18)		6-Thioguanine resistance (HPRT)		BaA, BeP, Pyr	No	Repeats data from Record 21730 Tong et al., 1981b
21730	Tong et al., 1981b	Rat liver epithelial cells (ARL-18)	None	6-Thioguanine resistance (HPRT)		BeP, Pyr, BaA	Yes	

Table 4-10. Study summaries: in vitro mammalian mutagenicity assays with benzo[a]pyrene and at least one other PAH

Record number	Reference	Cell type	Metabolic activation	Mutagenesis assay	Positive result	Non-positive result	Meets selection criteria?	Comments
16190	Vaca et al., 1992	UV-sensitive Chinese hamster ovary (CHO) cells	Rat Ar S9	6-Thioguanine resistance (HPRT)	FA		Yes	
21900	Wangenheim and Bolcsfoldi, 1988	Mouse lymphoma cells (L5178Y)	Rat Ar S9	Trifluorothymidine resistance (TK)	Pyr, FE		Yes	

HPRT = hypoxanthine-guanine phosphoribosyl transferase mutagenicity assay (resistance to 6-thioguanine, 8-azaguanine, or ouabain); TK = thymidine kinase mutagenicity assay (resistance to trifluorothymidine)

1

Table 4-11. Study summaries: in vitro morphological/malignant cell transformation with benzo[a]pyrene and at least one other PAH

Record number	Reference	Cell type	Metabolic activation system	Positive result	Nonpositive result	Meets selection criteria?	Comments
13390	Atchison et al., 1985	BALB/3T3 mouse embryo fibroblasts	None		FA, Pyr	Yes	
17610	Casto, 1979	Syrian golden hamster embryo cells	None	DBahA	Pyr	Yes	
17730	Chen and Heidelberger, 1969	Adult C3H mouse ventral prostate cells	Cocultivated irradiated C3H mouse embryonic fibroblasts	DBahA	DBacA, Pyr	No	Control data not provided.
24750	Davis, 1999	C3H10T1/2 cells	None	DBalP, DBaeP, BcC, BgC, BcPH		No	Control data not provided.
17970	DiPaolo et al., 1969	Syrian golden hamster embryo cells	Cocultivated irradiated Sprague-Dawley rat fetal cells	DBahA, BaA, BeP, DBacA	Pyr, PH	Yes	
17990	DiPaolo et al., 1972	BALB/3T3	None		AC, Pyr	Yes	
23630	DiPaolo et al., 1973	Syrian golden hamster embryo cells	In vivo (transplacental) exposure		AC, PH, Pyr	No	No quantitative information.
18020	Dunkel et al., 1981	Balb/3T3, Syrian golden hamster embryo, and Rauscher murine leukemia virus-infected F344 rat embryo cells	None	BaA	BeP, PH, AC	Yes	Qualitative data only for R-MuLV-RE cells. BaA positive in SHEM, equivocal in Balb/3T3.
18080	Emura et al., 1980	Syrian golden hamster fetal lung cells	None	BbF, BaA, IP	BkF, BeP	Yes	
23640	Evans and DiPaolo, 1975	Strain 2 guinea pig fetal cells	None		AC, Pyr, PH	No	No quantitative information.
18260	Gehly et al., 1982	C3H10T1/2CL8 mouse embryo fibroblasts	None		BeP	Yes	
14130	Greb et al., 1980	BHK 21/CL 13	Rat Ar S9	CH, BaA, BbF, DBahA, BeP	PH, AC	Yes	
23890	Kakunaga, 1973	BALB/3T3 subclone A31-714	None		PH, Pyr	No	Not clear if BaP administered simultaneously.
14640	Krolewski et al., 1986	C3H10T1/2CL8 mouse embryo fibroblasts	None	CPcdP		Yes	
14700	Laaksonen et al., 1983	Newborn NMRI nu/nu nude mouse skin fibroblasts	None	BaA	AC	Yes	
14850	Lubet et al., 1983	C3H10T1/2CL8 mouse embryo fibroblasts	None	BeP	AC, DBahA, PH	Yes	
19870	Mishra et al., 1978	Rauscher leukemia virus-infected Fischer rat embryo	None		AC, PH, Pyr, BeP	No	No quantitative information.
24710	Mohapatra et al., 1987	C3H10T1/2CL8 mouse embryo fibroblasts	None	BeAC, BjAC, BIAC	BkAC	Yes	
24700	Nesnow et al., 1990	Human neonatal foreskin fibroblasts	None	BIAC		Yes	
7980	Nesnow et al., 1997	C3H10T1/2CL8 mouse embryo fibroblasts	None	DBalP		Yes	
7990	Nesnow et al., 1994	C3H10T1/2CL8 mouse embryo fibroblasts	None	DBahA		Yes	
8000	Nesnow et al., 1993a	C3H10T1/2CL8 mouse embryo fibroblasts	None	DBkmnoAPH	DBjmnoAPH, N123mnoAPH	Yes	
20120	Nesnow et al., 1991	C3H10T1/2CL8 mouse embryo fibroblasts	None		ACEA	Yes	

Table 4-11. Study summaries: in vitro morphological/malignant cell transformation with benzo[a]pyrene and at least one other PAH

Record number	Reference	Cell type	Metabolic activation system	Positive result	Nonpositive result	Meets selection criteria?	Comments
23720	Pienta et al., 1977	Syrian golden hamster embryo	Cocultivated X-irradiated cells of same type	BaA, DBaA	CH, BeP, Pyr, AC, DBaA, PH	Yes	
8490	Sheu et al., 1994	BALB/3T3 A31-1-1	None		Pyr, BaA, CH	Yes	

1

Table 4-12. Study summaries: in vitro DNA adducts with benzo[a]pyrene and at least one other PAH

Record number	Reference	Cell type or DNA source	Incubation time	Activation system	Method of analysis	PAHs evaluated ^a	Meets selection criteria?	Comments
16890	Allen and Coombs, 1980	Mouse embryo cells from TO mice	24 hr	None	[³ H] prelabeling	BaA	Yes	
6300	Binkova et al., 2000	Human diploid lung fibroblast cells	Various up to 24 hr	None	[³² P] postlabeling	DBalP	Yes	
9510	Bryla and Weyand, 1992	Calf thymus DNA	1 hr	None	[³² P] postlabeling	BaA, DBaC, PH	Yes	PH did not form measurable DNA adducts. Adduct formation enhanced when reacted under white light.
6570	Cherng et al., 2001	Human hepatoma HepG2 cells	24 hr	None	[³² P] postlabeling	BghiP	Yes	BghiP did not form measurable DNA adducts.
13780	Cooper et al., 1982	Fibroblasts and epithelial cells from Wistar rat mammary tissue	24 hr	None	[³ H] prelabeling	BaA	Yes	BaA formed little or no measurable DNA adducts.
22800	Grover and Sims, 1968	Salmon testes DNA	Not specified	Rat liver microsomes	[³ H] prelabeling	DBaH, DBaC, BaA, Pyr, PH	Yes	
10660	Johnsen et al., 1998	Human lymphocytes and human promyelocytic HL-60 cells	24 hr	None	[³² P] postlabeling	BjAC, BIAC	Yes	
10670	Johnsen et al., 1997	Rat lung Clara cells, Type 2 cells, and macrophages	2 hr	PCB pretreatment of whole animals	[³² P] postlabeling	BjAC, BIAC	Yes	
13200	Li et al., 2002	MCF-7 cells or rat lung DNA	7–24 hr	Human mammary microsomes with rat lung DNA	[³² P] postlabeling	DBalP, BcPH, DBaH	No	No quantitative results.
7870	Melendez-Colon et al., 2000	Human mammary carcinoma MCF-7 cells and leukemia HL-60 cells	4 or 24 hr	None	[³² P] postlabeling	DBalP	Yes	No adducts formed in HL-60 cells that lack significant P450 activity.
7990	Nesnow et al., 1994	C3H10T1/2CL8 fibroblasts	24 hr	None	[³² P] postlabeling	DBaH	No	No quantitative results.
20120	Nesnow et al., 1991	C3H10T1/2 cells	24 hr	None	[³² P] postlabeling	ACEA	No	Measures repair of adducts only, not synthesis.
21200	Segerback and Vodicka, 1993	Calf thymus DNA	3 hr	Rat Ar S9	[³² P] postlabeling, ³ H-binding	CH, BaA, BbF, DBaH, FA, BghiP, Pyr	Yes	
24810	Baird et al., 2002	MCF-7 cells	24 hr	Morpholinos inhibition (antisense oligomer that blocks protein synthesis of CYP1A1)	[³² P] postlabeling	DBalP	No	Confounded by CYP1A1 inhibition by morpholinos.

^aExcept where noted, positive findings were reported for all PAHs evaluated.

Table 4-13. Study summaries: in vitro DNA damage, repair, or synthesis with benzo[a]pyrene and at least one other PAH

Record number	Reference	Cell type	Metabolic activation	Endpoint	Assay	Positive result	Nonpositive result	Meets selection criteria?	Comments
16840	Agrelo and Amos, 1981	Human fibroblasts	Rat Ar S9	Unscheduled DNA synthesis	[³ H] Thymidine uptake	Pyr		Yes	
17610	Casto, 1979	Syrian golden hamster embryo	Intrinsic	Unscheduled DNA synthesis	[³ H] Thymidine uptake		DBahA, Pyr, PH	Yes	
24030	De Flora et al., 1984	<i>Escherichia coli</i> WP2, WP67, and CM871	Rat Ar S9	DNA damage	Differential killing repair-deficient strains	AC, BaA	Pery, BeP	No	Semiquantitative data.
18030	Dunkel et al., 1984	<i>E. coli</i> WP-2 <i>uvrA</i>	Rat, mouse, hamster Ar S9	DNA damage	Differential killing repair-deficient strains	BaA, BeP, PH, Pyr	AC	No	Dose-response data not provided.
23790	Ichinotsubo et al., 1977	<i>E. coli</i> Rec BC	S9 (origin unknown)	DNA damage		DBaiP, DBahA		Yes	
10670	Johnsen et al., 1997	Rat lung Clara cells, Type 2 cells, and macrophages	PCB pretreatment of whole animals	DNA damage	Alkaline elution		BjAC, BIAC	No	No untreated control.
10660	Johnsen et al., 1998	Human lymphocytes and human promyelocytic HL-60 cells	Rat or human liver microsomes	DNA damage	Alkaline elution	BjAC, BIAC		Yes	
19270	Lake et al., 1978	Human foreskin epithelial cells	None	Unscheduled DNA synthesis	[³ H] Thymidine uptake	DBahA	AC, BeP, PH, Pyr	No	Doses reported as ranges.
19680	Mamber et al., 1983	<i>E. coli</i> WP2 and WP100	Rat Ar S9	DNA damage	Growth inhibition of repair deficient strains		AC, FE, Pyr	Yes	
19690	Mane et al., 1990	Human and rat mammary epithelial cells	None	Inhibition of DNA synthesis	[³ H] Thymidine uptake	BaA (in human MEC only)	BeP	No	Positive response for BaA not observed consistently.
19730	Martin and McDermid, 1981	HeLa S3 cells	PB-induced rat liver postmitochondrial supernatant	Unscheduled DNA synthesis	[³ H] Thymidine uptake	Pyr (authors: "dubious" result)	AC	No	No quantitative information.
19740	Martin et al., 1978	HeLa S3 cells	3-MC induced rat liver postmitochondrial supernatant	Unscheduled DNA synthesis	[³ H] Thymidine uptake	BeP, BaA, DBacA, DBahA	Pyr, AC	Yes	
23800	McCarroll et al., 1981	<i>E. coli</i> WP2, WP2 <i>uvrA</i> , WP67, CM611, WP100, W3110 <i>polA</i> +, and p3478 <i>polA</i> -	Rat Ar S9	DNA damage	Differential killing repair-deficient strains		AC, PH	Yes	

Table 4-13. Study summaries: in vitro DNA damage, repair, or synthesis with benzo[a]pyrene and at least one other PAH

Record number	Reference	Cell type	Metabolic activation	Endpoint	Assay	Positive result	Nonpositive result	Meets selection criteria?	Comments
19830	Mersch-Sundermann et al., 1992	<i>E. coli</i> PQ37	Rat Ar S9	Induction of SOS system	SOS chromotest	AA, BaA, BbF, BghiF, BjF, BbFE, BghiP, BeP, CH, DBacA, DBahA, DBalP, DBahP, DBaiP, FA, IP, PH, Tphen	AC, BaFE, CO, FE, Pery, Pyr	Yes	
19850	Milo et al., 1978	Human skin fibroblast NF and Detroit 550 cells	None	DNA damage	Alkaline elution		AC, Pyr, PH, BeP	Yes	
20050	Nagabhushan et al., 1990	Hamster buccal pouch epithelial cells and tissue fragments	Not specified	Inhibition of DNA synthesis	[³ H] Thymidine uptake		BaA	No	Abstract only. BaA inhibited synthesis 4%.
20560	Probst et al., 1981	Rat hepatocyte primary culture	None	Unscheduled DNA synthesis	[³ H] Thymidine uptake	BbA, DBacA	AC, DBahA, PH, Pyr, DBaiP, FE, BeP	No	Artifact of counting method resulted in control responses reported as negative values.
20810	Robinson and Mitchell, 1981	Human fibroblasts WI-38 cells	Rat Ar S9	Unscheduled DNA synthesis	[³ H] Thymidine uptake	Pyr (with activation)		Yes	
23900	Rosenkranz and Leifer, 1980	<i>E. coli</i> pol A1-	Rat liver S9	DNA damage	Differential killing repair-deficient strains		AC, BaA, BeP, CH, PH	Yes	
20880	Rosenkranz and Poirier, 1979	<i>E. coli</i> pol A1-	Uninduced rat S9	DNA damage	Differential killing repair-deficient strains		AC, BaA, BeP, CH, PH	Yes	
20940	Rossmann et al., 1991	<i>E. coli</i> WP2s(λ)	Rat liver S9	DNA damage	Λ prophage induction	AC, DBacA, DBahA, PH	BeP, FA, Pyr	Yes	
21380	Simmon, 1979b	<i>S. cerevisiae</i> D3	Rat Ar S9	induced recombination	Colony pigmentation on adenine medium		AC, BaA, BeP, CH, PH	Yes	
21720	Tong et al., 1983	Rat hepatocyte primary culture	None	Unscheduled DNA synthesis	[³ H] Thymidine uptake	BaA	BeP, AC, CH, Pyr	No	Repeats data from 21730 Tong et al., 1981b.
21730	Tong et al., 1981b	Rat hepatocyte primary culture	None	Unscheduled DNA synthesis	[³ H] Thymidine uptake	BaA	BeP, AC, CH, Pyr	Yes	
21790	Tweats, 1981	<i>E. coli</i> WP2, WP67(uvrA polA), CM871 (uvrA lexA recA)	Rat Ar S9	DNA damage	Differential killing repair-deficient strains		Pyr, AC	No	No quantitative information.
16190	Vaca et al., 1992	CHO cells	Rat Ar S9	DNA damage	Alkaline elution	FA		No	No untreated or vehicle control.
22260	Williams et al., 1982	Rat hepatocyte primary culture	None	Unscheduled DNA synthesis	[³ H] Thymidine uptake		Pyr, BeP	No	No quantitative information.

Table 4-14. Study summaries: in vitro clastogenicity or sister chromatid exchange with benzo[a]pyrene and at least one other PAH

Record number	Reference	Cell type	Metabolic activation	Clastogenic endpoint(s)	Positive results	Non-positive results	Meets selection criteria?	Comments
16740	Abe and Sasaki, 1977	Pseudodiploid Chinese hamster D-6	None	Aberrations and sister chromatid exchanges		AC, Pyr	Yes	
17890	Dean, 1981	Near-diploid epithelial-type rat liver RL ₁	None	Various aberrations		AC, Pyr	No	Semiquantitative results.
17930	DeSalvia et al., 1988	Male Chinese hamster liver epithelial cells	None	Sister chromatid exchanges		Pyr, FA	Yes	
18120	Evans and Mitchell, 1981	CHO	Rat Ar S9	Sister chromatid exchanges	Pyr (with activation)		No	No untreated or vehicle control.
23640	Evans, and DiPaolo, 1975	Diploid strain 2 guinea pig fetal cells	None	Aneuploidy		AC	No	No quantitative data. Pyr, PH also evaluated using different protocol without BaP reference.
18260	Gehly et al., 1982	CH3/10T1/2 clone 8 mouse fibroblasts	None	Sister chromatid exchanges		BeP	Yes	
14620	Kochhar, 1982	Chinese hamster V79	None	Aberrations including gaps, rings, breaks, fragments, exchanges	BaA		Yes	Dose-dependent increase in the percentage cells with aberrations.
14640	Krolewski et al., 1986	CH3/10T1/2 clone 8 mouse embryo cells	None	Sister chromatid exchanges	CPcdP		Yes	CPcdP appears to increase sister chromatid exchanges in dose-dependent fashion (two doses).
19690	Mane et al., 1990	Chinese hamster V79 cells	With and without rat mammary epithelial cell coculture	Sister chromatid exchanges	BaA	BeP	Yes	
19770	Matsuoka et al., 1979	Male Chinese hamster lung	Rat Ar S9	Aberrations and sister chromatid exchanges		PH	No	Not clear if BaP administered simultaneously. No untreated control.
20020	Murison, 1988	P3 clonal isolate from human epithelial teratocarcinoma	BJ-015 human breast epithelial cell coculture	Sister chromatid exchanges	CPcdP	BeP	No	Not clear if BaP administered simultaneously; no concurrent control.
20340	Perry and Thomson, 1981	CHO cells	Rat Ar S9	Sister chromatid exchanges	Pyr	AC	No	No untreated control.

Table 4-14. Study summaries: in vitro clastogenicity or sister chromatid exchange with benzo[a]pyrene and at least one other PAH

Record number	Reference	Cell type	Metabolic activation	Clastogenic endpoint(s)	Positive results	Non-positive results	Meets selection criteria?	Comments
20500	Popescu et al., 1977	Chinese hamster V79-4 cells	With or without irradiated Syrian golden hamster secondary embryo feeder cells	Aberrations and sister chromatid exchanges	Pery, Pyr	PH	No	BaP increased sister chromatid exchanges but Pyr and Pery increased aberrations. Pery increased aberrations w/o activation. 60% of Pyr treated cells (activated) polyploid. Increased aberrations in polyploid cells.
21710	Tong et al., 1981a	Adult rat liver epithelial (ARL 18) cells	None	Sister chromatid exchanges	BaA	BeP, Pyr, AC	Yes	
21720	Tong et al., 1983	Adult rat liver epithelial (ARL 18) cells	None	Sister chromatid exchanges	BaA	BeP, Pyr, AC	No	Repeats data from Record 21710 Tong et al., 1981a.
8780	Vienneau et al., 1995	UDP-Glucuronosyl-transferases-deficient rat (RHA- <i>J/J</i>) skin fibroblasts	None	Micronuclei		BeP	Yes	
8850	Warszawsky et al., 1995	Human lymphocytes	None	Micronuclei and sister chromatid exchanges		BaA	Yes	
21980	Weinstein et al., 1977	Human diploid fibroblasts (WI-38)	With or without rat Ar s9	Chromosomal damage, mitotic index, abnormal metaphases		Pyr	Yes	

1 If the above criteria were met, studies were selected for use in the analysis regardless of
2 whether positive or nonpositive results were reported. Studies with positive findings were used
3 for calculation of RPFs. Studies with nonpositive findings were used in a weight of evidence
4 evaluation for selecting PAHs for inclusion in the RPF approach (discussed later in Section 6.1).
5 To be considered adequate for use in the analysis, nonpositive bioassays were selected only if
6 two additional conditions were met: (1) at least 20 animals were used per dose group, and
7 (2) animals were observed for at least 6 months. More strict criteria were applied to nonpositive
8 studies due to the difficulty in demonstrating the absence of an effect. For example, if a positive
9 tumor response (i.e., statistically significant increase in incidence) was observed after 3 months
10 of treatment with a given PAH, the positive finding is clear; however, if no response (or a
11 nonsignificant response) was observed after 3 months, the absence of response might reflect a
12 lack of carcinogenic action, but might also have resulted from inadequate follow-up time. The
13 use of these additional criteria for nonpositive studies served to ensure that PAHs would not be
14 treated as noncarcinogenic based on inadequate nonpositive bioassays.

15 Study design details, findings, limitations, and a determination of whether the study met
16 selection criteria are presented in Tables 4-1 through 4-14 for each study reviewed in each
17 category. Except where noted, positive and nonpositive findings reported in the table are based
18 on the author's determination. When statistical analysis of tumor bioassay data was not included
19 in the pertinent publication, statistical analysis was conducted to determine whether the response
20 differed from control. In the sections that follow, overviews of the data available in each
21 category are presented. The overviews address the nature of the studies available, concise
22 information on general study methods, general findings for the tested compounds, and key
23 strengths and limitations of the available data for relative potency development.

24 25 **4.3.1. In Vivo Cancer Bioassays in Animals**

26 The PAH database contained a large number of cancer bioassay studies in which one or
27 more PAHs was evaluated along with benzo[a]pyrene. The vast majority of the tumor bioassay
28 studies were mouse skin painting studies (n = 43). In addition, there were 12 intraperitoneal
29 studies, 9 subcutaneous exposure studies, 3 oral studies, and 9 studies using miscellaneous
30 exposure routes.

31 32 **4.3.1.1. Dermal Exposure**

33 A summary of the 43 dermal bioassays is provided in Table 4-1. These studies were all
34 conducted in mice. Fifteen studies tested the complete carcinogenicity of PAHs, while
35 23 studies tested PAHs as initiators in initiation-promotion protocols. In some cases, both
36 complete and initiation-promotion studies were reported in the same reference. For these
37 references, two entries are included in the table.

1 Complete carcinogenicity studies were conducted in mice using either dropper or
2 paintbrush application. Swiss mice were typically preferred for these studies. PAHs, usually in
3 acetone, were applied to the shaved interscapular skin 2 or 3 times/week. The duration of
4 exposure varied from 10 weeks up to about 70 weeks; most studies continued exposure for at
5 least 30 weeks. Skin tumor counts were recorded on a weekly basis, and animals were sacrificed
6 when tumors reached a minimum size (e.g., 2 cm) or when the animals were moribund. These
7 studies generally focused exclusively on skin papillomas and carcinomas. Skin tumor data were
8 reported as incidence (i.e., number of animals with tumors) and/or tumor count (mean number of
9 tumors per animal) (indicated in Table 4-1).

10 Several PAHs consistently (in two or more studies) proved to be complete carcinogens in
11 mouse skin painting assays, including benzo[b]fluoranthene, benzo[j]fluoranthene,
12 cyclopenta[c,d]pyrene, dibenzo[a,e]pyrene, dibenzo[a,h]pyrene, dibenzo[a,i]pyrene, and
13 dibenzo[a,l]pyrene. Chrysene gave positive results in two complete carcinogenicity studies
14 (LaVoie et al., 1979; Wynder and Hoffmann, 1959) and equivocal results in a third (Hecht et al.,
15 1974). Anthanthrene, dibenzo[a,e]fluoranthene, and dibenz[a,h]anthracene each gave positive
16 tumorigenicity results in a single assay (Cavalieri et al., 1977; Hoffmann and Wynder, 1966; and
17 Wynder and Hoffmann, 1959; respectively). Nonpositive or equivocal results were reported for
18 benzo[k]fluoranthene, benzo[g,h,i]fluoranthene, dibenzo[e,l]pyrene, indeno[1,2,3-c,d]pyrene,
19 benzo[g,h,i]perylene, naphtho[2,3-e]pyrene, anthracene, pyrene, fluoranthene, 2,3-acepyrene,
20 benz[a]anthracene, coronene, and benzo[e]pyrene (see Table 4-1).

21 According to LaCassagne et al. (1968), in studies conducted prior to 1966, the compound
22 reported as dibenzo[a,l]pyrene was actually dibenzo[a,e]fluoranthene. In the text and tables of
23 this report, data from Hoffmann and Wynder (1966) are reported as dibenzo[a,e]fluoranthene in
24 Table 4-1.

25 The initiation studies in Table 4-1 were performed under a generally consistent protocol,
26 as follows. During the early part of the second telogen phase of the hair cycle (at about 7–
27 8 weeks of age), PAHs in acetone were applied to the shaved interscapular skin of mice. In
28 general, female Swiss, CD-1, or SENCAR mice were used. Some studies used dropper
29 administration, but the majority employed a painting method using a camel's hair brush. About
30 half of the initiation studies used a single initiation dose, while the other half administered the
31 initiating compound in 10 subdoses given every other day. One to 2 weeks after the final
32 initiating dose, promotion was begun with twice or thrice weekly applications of a promoting
33 agent, usually TPA or croton oil. The dose of the promoting agent varied by study. Promotion
34 usually continued for about 20 weeks (with a range across studies from 11 to 26 weeks). The
35 incidence of skin papillomas was recorded on a weekly basis until the promotion period was
36 ended. Papillomas were removed at random for histological verification. Some studies reported
37 the number of tumors per animal; some reported only the incidence.

1 The initiation studies in Table 4-1 consistently showed positive tumorigenicity across two
2 or more studies for the following compounds: benzo[j]fluoranthene, benzo[b]fluoranthene,
3 chrysene, dibenzo[a,e]pyrene, dibenzo[a,h]pyrene, dibenzo[a,i]pyrene, dibenzo[a,l]pyrene, and
4 cyclopenta[d,e,f]chrysene. In at least one study, benzo[k]fluoranthene, benz[*l*]aceanthrylene,
5 benz[e]aceanthrylene, naphtho[2,3-*e*]pyrene, dibenz[a,h]anthracene, dibenz[a,c]anthracene, and
6 benz[b,c]aceanthrylene showed positive initiating activity. Nonpositive results were reported for
7 pyrene, perylene, benzo[g,h,i]fluoranthene, fluoranthene, anthanthrene, dibenzo[e,l]pyrene,
8 benzo[g,h,i]perylene, indeno[1,2,3-*c,d*]pyrene, benzo[e]pyrene, anthracene, 2,3-acepyrene, and
9 phenanthrene. Cyclopenta[*c,d*]pyrene gave nonpositive results in one study (Wood et al., 1980)
10 and positive results in two studies (Raveh et al., 1982; Cavalieri et al., 1981b) (see Table 4-1).

11 The vast majority of the initiation and complete carcinogenicity studies were conducted
12 in female mice; thus, data on gender differences in skin tumor susceptibility are not available.

13 A few studies using dermal application (Warshawsky et al., 1993; Slaga et al., 1979; Van
14 Duuren and Goldschmidt, 1976; Horton and Christian, 1974; Van Duuren et al., 1973) were
15 designed to evaluate the cocarcinogenicity of two or more PAHs, or of a single PAH with
16 dodecane as a vehicle. These were primarily complete carcinogenicity studies, wherein PAHs
17 were administered together over a chronic time period, although Slaga et al. (1979) used an
18 initiation-promotion design. Study design was similar to other complete carcinogenicity
19 experiments. In these studies, the carcinogenicity of single PAHs was evaluated for comparison
20 with the results obtained when the PAHs were administered with a cocarcinogen. Data on single
21 PAHs (without a cocarcinogen) were generally limited to single dose levels. In the
22 cocarcinogenesis studies, only dibenz[a,c]anthracene, benzo[e]pyrene, and pyrene gave positive
23 results when administered without a cocarcinogen; results for pyrene were judged to be
24 equivocal in the absence of statistical confirmation. The PAHs chosen for cocarcinogenesis
25 studies were often those traditionally understood to be nontumorigenic or weakly tumorigenic
26 when administered alone (e.g., perylene, pyrene, benzo[e]pyrene, benzo[g,h,i]perylene,
27 phenanthrene, fluoranthene).

28 Several issues relating to the potential use of the dermal bioassay data for relative
29 potency development were identified during study review. Several studies did not include a
30 concurrent untreated or vehicle-treated control group (Masuda and Kagawa, 1972; Bingham and
31 Falk, 1969; Wynder and Hoffmann, 1959a, b). In a number of reports, it appears that bioassays
32 were done in batches and reported in a single publication. In these cases, it appears that
33 benzo[a]pyrene treatment may not have been undertaken concurrently with all of the compounds
34 in the report. For some of these studies (Horton and Christian, 1974; Bingham and Falk, 1969),
35 there are differences in the choice of vehicle or promoter, or other issues that argue against using
36 the benzo[a]pyrene data for direct comparison. In several other studies, however (Rice et al.,
37 1988; Slaga et al., 1980; Van Duuren and Goldschmidt, 1976; Wynder and Hoffmann, 1959), the
38 protocols (including vehicle and promoting agent) appear to have been the same.

1 Among the dermal tumor bioassay studies in Table 4-1, 24 studies met the selection
2 criteria for use in this analysis.

3 4 **4.3.1.2. Intraperitoneal Exposure**

5 Twelve cancer bioassays in the literature used intraperitoneal injection. Six of these
6 studies were carried out in newborn mice, while the other six used adult A/J mice. The studies
7 were focused on lung and liver tumorigenicity after PAH exposure; one study also examined
8 forestomach lesions. Study summaries for all of these references are reported in Table 4-2.
9 Tumor data were reported as incidence (i.e., number of animals with tumors) and/or tumor count
10 (mean number of tumors per animal) (indicated in Table 4-2).

11 *Newborn mouse studies.* Six cancer bioassays in newborn mice were identified (LaVoie
12 et al., 1994, 1987; Busby et al., 1989, 1984; Weyand and LaVoie, 1988; Wislocki et al., 1986).
13 In general, PAHs were administered intraperitoneally to newborn mice (usually of the Swiss or
14 CD-1 strains). The dosing schedule called for 1/7th, 2/7ths, and 4/7ths of the total dose to be
15 administered on the 1st, 8th, and 15th days of life. Typically, the mice were sacrificed at either
16 6 months or 1 year, and lung and/or liver tumors were identified and classified.

17 The studies in newborn mice showed a distinct gender difference in liver tumorigenicity.
18 Male mice appear to be substantially more susceptible to liver tumor induction than females. In
19 contrast, both male and female mice developed lung tumors after exposure. Three studies
20 (LaVoie et al., 1994; Busby et al., 1989, 1984) reported that fluoranthene induced lung tumors in
21 both male and female mice, while one study reported that fluoranthene induced liver tumors in
22 male mice only (LaVoie et al., 1994). LaVoie et al. (1987) reported that benzo[b]fluoranthene
23 and benzo[j]fluoranthene induced lung adenomas in both male and female mice, but induced
24 liver tumors only in males. Wislocki et al. (1986) reported that treatment with benz[a]anthracene
25 resulted in a significant increase in liver tumors in male mice. In this study, benz[a]anthracene
26 treatment resulted in an increased incidence of lung tumors in both males and females, although
27 the tumor incidence was significantly increased only for females. The same authors (Wislocki et
28 al., 1986) reported a significant increase in liver tumors in male mice treated with chrysene, but
29 no increase in lung tumorigenicity. The lack of lung tumorigenicity in mice treated with
30 chrysene was also reported by Busby et al. (1989).

31 Nonpositive tumorigenicity results in newborn mouse assays were reported for pyrene,
32 chrysene, benzo[k]fluoranthene, and indeno[1,2,3-c,d]pyrene (Busby et al., 1989; LaVoie et al.,
33 1987).

34 Most of the data from the newborn mouse assays met the criteria for relative potency
35 development, although Weyand and LaVoie (1988) is an abstract and does not provide dose-
36 response information. LaVoie et al. (1994) noted that liver tumorigenicity in newborn mice
37 exposed to weak tumorigenic agents may not be fully realized for 12 months; thus, the failure to

1 observe liver tumors in studies of shorter duration (Busby et al., 1989, 1984) may result from the
2 longer latency and should be taken into consideration in using these data.

3 *Lung adenoma A/J mouse studies.* Six studies (Nesnow et al., 1998a, b, 1996, 1995; Ross
4 et al., 1995; Mass et al., 1993) were carried out in 6- to 8-week-old A/J mice by the same
5 laboratory using a standard protocol (Table 4-2). Mice were given a single intraperitoneal
6 injection of PAH in tricapylin and followed for 8 months. Upon sacrifice, the lungs were
7 removed and adenomas were counted. Tumor multiplicity was reported, while tumor incidence
8 was not. Several of these studies include estimates of relative potency based on statistical
9 analysis of the tumor multiplicity data. These studies report positive tumor findings (reported as
10 an increase in the number of tumors per animal) for all of the PAHs tested (benz[j]aceanthrylene,
11 benzo[b]fluoranthene, dibenz[a,h]anthracene, cyclopenta[c,d]pyrene, and dibenzo[a,l]pyrene).
12 One additional study by a different group (Weyand et al., 2004) used the same study design to
13 assess effects of benzo[c]fluorene. In this study, both lung adenomas and forestomach lesions
14 were evaluated after 8 months. Both benzo[c]fluorene and benzo[a]pyrene were associated with
15 increased incidences of lung adenomas but not with increased forestomach lesions.

16 Among the intraperitoneal tumor bioassay studies in Table 4-2, nine studies met the
17 selection criteria for use in this analysis.

18 19 **4.3.1.3. Subcutaneous Injection Exposure**

20 Nine studies employing a subcutaneous exposure design were identified. All of the
21 subcutaneous exposure studies are more than 25 years old; the most recent is Pfeiffer (1977).
22 Study descriptions are presented in Table 4-3.

23 Two studies utilized newborn mice (Roe and Waters, 1967; Grant and Roe, 1963). In
24 these studies, phenanthrene was administered subcutaneously to newborn albino mice on the first
25 day of life. Ten mice of each group were sacrificed after 52 weeks, and the remaining animals
26 were sacrificed at 62 weeks. Grant and Roe (1963) evaluated lung tumorigenicity and observed
27 no increase with phenanthrene, while Roe and Waters (1967) reported liver tumors in the same
28 group of mice. Roe and Waters (1967) reported an elevated incidence of liver tumors in male
29 mice exposed subcutaneously to phenanthrene; however, it is not clear whether the difference
30 was significant. Roe and Waters (1967) is a brief communication with limited details of the
31 study design and results.

32 In most of the remaining studies, single subcutaneous doses of one or more PAH and
33 benzo[a]pyrene were administered to mice, followed 1–2.5 years later by an evaluation of
34 injection site and other tumors. Tumors at the injection site were most commonly reported;
35 however, in some studies, investigators also examined other organs for tumors (Homburger et
36 al., 1972; Roe and Waters, 1967; Grant and Roe, 1963; Rask-Nielsen, 1950; Pfeiffer and Allen,
37 1948).

1 Most of the subcutaneous bioassays suffer from critical shortcomings in design or
2 reporting. One study used “aged” mice for controls, allowing these animals to live 16 weeks
3 longer than the treated group (Homburger et al., 1972). Three studies gave apparently positive
4 results for dibenz[a,h]anthracene (i.e., substantial tumor induction) (Pfeiffer, 1977; Steiner, 1955;
5 Bryan and Shimkin, 1943). However, neither Bryan and Shimkin (1943) nor Steiner (1955)
6 included untreated control groups. Pfeiffer (1977) included an untreated control group in which
7 there was 90% mortality prior to sacrifice of the treated animals; data on tumor incidence in
8 controls were not reported. Several other studies (Pfeiffer and Allen, 1948; Barry et al., 1935)
9 also did not include a concurrent untreated or vehicle-treated control group. These studies were
10 not used for dose-response assessment due to the lack of appropriate controls.

11 Fundamental flaws were observed in two older studies. Pfeiffer and Allen (1948)
12 examined the effects of PAHs in Rhesus monkeys. Individual animals were exposed
13 sequentially to several PAHs via multiple exposure routes; thus, the effect of any individual PAH
14 or benzo[a]pyrene cannot be discerned. Barry et al. (1935) treated mice with PAHs from varying
15 sources and of varying purity. Given the age of the study and the attendant issues with
16 nomenclature, purity, and analysis of the treatment compounds, data from this study are excluded
17 from use in relative potency development.

18 Among the subcutaneous tumor bioassay studies in Table 4-3, only a single study met
19 selection criteria for use in this analysis.

21 **4.3.1.4. Oral Exposure**

22 The literature search identified three oral bioassays that included benzo[a]pyrene and at
23 least one other PAH. Critical aspects of the study design for these studies are reported in
24 Table 4-4.

25 Biancifiori and Caschera (1962) compared the induction of mammary tumors in virgin
26 and pseudopregnant mice (female mice mated with vasectomized males) after gavage exposure
27 to dibenz[a,h]anthracene or benzo[a]pyrene. Tumor incidence was increased in pseudopregnant
28 mice given 1 mg/week of either compound for 15 weeks, but not in virgin mice given the same
29 dose. The relevance of the positive findings in pseudopregnant mice is uncertain given that an
30 increased incidence of tumors was not observed in virgin mice treated at the same dose. One
31 possible explanation for the disparate findings is that circulating hormones in pseudopregnant
32 mice differed from those in virgin mice and interacted with the PAH to enhance tumor
33 formation. Huggins and Yang (1962) also evaluated mammary tumor incidence after a single
34 oral PAH exposure. Sprague-Dawley rats were given gavage doses of benzo[a]pyrene,
35 benz[a]anthracene, or phenanthrene. This study did not include an untreated or vehicle-treated
36 control group. No tumors were observed in the rats treated with either benz[a]anthracene or
37 phenanthrene, while mammary tumors were observed in eight of the nine benzo[a]pyrene-treated
38 animals.

1 Weyand et al. (2004) conducted an oral bioassay in which female A/J mice were fed diets
2 containing benzo[c]fluorene or benzo[a]pyrene throughout the study. At sacrifice after 260 days,
3 lung adenomas were counted and forestomach lesions were characterized. Exposure to
4 benzo[c]fluorene and benzo[a]pyrene resulted in significantly increased incidences of lung
5 adenomas, but only benzo[a]pyrene exposure resulted in forestomach neoplasms. This was the
6 only oral study that met the selection criteria for use in this analysis.

7 8 **4.3.1.5. Other Routes**

9 Nine bioassays were available that did not fit into other exposure route categories (i.e.,
10 dermal, intraperitoneal, subcutaneous, or oral) (see Table 4-5). Among these were studies using
11 intramamillary, intramuscular, and intravenous injection as well as lung implantation, tracheal
12 implantation, and transplacental exposure after subcutaneous injection. Seven studies were in
13 rats, with one each in mice and hamsters.

14 Deutsch-Wenzel et al. (1983) and Wenzel-Hartung et al. (1990) implanted
15 PAH-containing pellets (consisting of beeswax and trioctanoin) into the lungs of inbred female
16 Osborne-Mendel rats. Lung tumor incidence was reported for a total of 10 PAHs and
17 benzo[a]pyrene. The authors reported relative potency estimates based on the lung tumor data.
18 Lung tumors were induced by benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluor-
19 anthene, benzo[g,h,i]perylene, indeno[1,2,3-c,d]pyrene, anthanthrene, chrysene, and
20 dibenz[a,h]anthracene. Nonpositive findings were reported for benzo[e]pyrene and
21 phenanthrene.

22 Cavalieri et al. (1991) treated Sprague-Dawley rats with single intramamillary
23 injections of dibenzo[a,l]pyrene into the left mammary glands and followed them for up to
24 24 weeks. Tumors of the mammary gland, mesenchymal tissue, or skin were recorded.
25 Dibenzo[a,l]pyrene produced tumors in all animals at both doses.

26 In six studies, tumors were not induced after exposure to any target PAH.
27 Intramamillary injection of dibenz[a,h]anthracene and benz[a]anthracene did not induce
28 mammary tumors in rats (Cavalieri et al., 1988b). Pregnant mice receiving subcutaneous
29 injection of pyrene did not develop tumors, nor did their offspring (Nikonova, 1977). Rats
30 treated either intravenously or intramuscularly with benz[a]anthracene did not develop either
31 mammary or injection site tumors (Pataki and Huggins, 1969). Similarly, benz[a]anthracene was
32 not tumorigenic after intramuscular injection in rats (Sugiyama, 1973) or buccal pouch painting
33 in hamsters (Solt et al., 1987). Finally, benzo[e]pyrene was not tumorigenic when it was
34 implanted into tracheas transplanted subcutaneously into isogenic rats (Topping et al., 1981).

35 Among the tumor bioassays that used alternative exposure routes in Table 4-5, four
36 studies met the selection criteria for use in this analysis.

37

4.3.2. In Vivo Studies of Cancer-Related Endpoints

The database of cancer-related endpoints measured after in vivo exposure to PAHs is much smaller than the in vitro database. Endpoints examined after in vivo exposure include mutagenicity, DNA adducts, and clastogenicity or sister chromatid exchange. As with the in vitro database, only studies of selected PAHs that included benzo[a]pyrene as a reference compound were reviewed. Each study that was reviewed for consideration in relative potency development is presented in tabular format in subsequent sections. The tables summarize study-specific information and indicate whether a particular study is considered useful for dose-response assessment. The text provides an overall description of the available studies, including a general description of the methodology used for each study type, the results, and the weaknesses or problems associated with specific studies or study types.

4.3.2.1. DNA Adducts

Nineteen studies evaluating DNA adduct formation for PAHs and benzo[a]pyrene were identified in the database (Table 4-6). Nine studies presented quantitative data for DNA adduct formation and are discussed below. Among studies with data potentially useful for RPF derivation, the route of exposure was intramammillary injection in one study (Arif et al., 1997), intraperitoneal injection in seven studies (Weyand et al., 2004; Kligerman et al., 2002; Nesnow et al., 1998a, 1996, 1995; Ross et al., 1995; Mass et al., 1993), dermal in three studies (Hughes and Phillips, 1990; Cavalieri et al., 1981b; Phillips et al., 1979), and oral in two studies (Weyand et al., 2004; Kligerman et al., 2002). Adducts were identified by [³²P]-postlabeling in all of the studies except for two by Phillips et al. (1979) and Cavalieri et al. (1981b), which utilized [³H]- or [¹⁴C]-radiolabeled PAHs. Three papers described experiments with a single time point(s) at 24 or 48 hours or 14 days (Weyand et al., 2004; Arif et al., 1997; Hughes and Phillips, 1990), whereas the rest had multiple time points. The duration of exposure was as short as 4 hours (Cavalieri et al., 1981b), although 24 hours was usually the first time point(s) in time-course studies. The longest duration for a time-course study was 84 days (Hughes and Phillips, 1990), but most were ≤3 weeks. The tissues evaluated included mammary epithelium (Arif et al., 1997), skin (Hughes and Phillips, 1990; Cavalieri et al., 1981b; Phillips et al., 1979), liver and peripheral blood lymphocytes (Kligerman et al., 2002; Nesnow et al., 1993b), lung (Weyand et al., 2004; Nesnow et al., 1998a, 1993b; Arif et al., 1997; Ross et al., 1995; Mass et al., 1993; Hughes and Phillips, 1990), and forestomach (Weyand et al., 2004).

Dermal exposure studies typically involved application of the chemical in solution to the shaved dorsal skin of mice (Hughes and Phillips, 1990; Cavalieri et al., 1981b; Phillips et al., 1979). After the scheduled sacrifice, the treated skin was excised and frozen; a scalpel was used to scrape away the dermis from the epidermis that was subsequently powdered in liquid nitrogen. In one study, the lung was also excised and frozen in liquid nitrogen (Hughes and Phillips, 1990). DNA was isolated from the frozen epidermis or lung. Liquid scintillation counting was

1 used to quantify DNA adducts to PAH labeled with [³H] or [¹⁴C] (Cavalieri et al., 1981b; Phillips
2 et al., 1979). For [³²P]-postlabeling, DNA was treated to selectively dephosphorylated
3 nonadducted nucleotides; after postlabeling, adducts were resolved by sequential anion-exchange
4 thin layer chromatography on polyethyleneimine-cellulose plates in several directions using three
5 solvents (Hughes and Phillips, 1990). Adduct spots on chromatograms were located by
6 autoradiography, after which the spots were excised and radioactivity levels were determined by
7 Cerenkov counting.

8 Most studies reported the mean number of adducts formed within a tissue per unit of
9 DNA, with time-course data displayed graphically. Peak values were sometimes called out
10 specifically in the text or tables. As the shapes of dose-response curves differ among different
11 PAHs, the peak value is an imprecise measure for comparing the relative adduct-forming
12 potency of the different compounds. The TIDAL has also been used for reporting results for a
13 time-course study (Ross et al., 1995). The TIDAL value is the area under the curve (AUC) for
14 adduct persistence (based on the rate of adduct formation and repair) for the duration of the
15 study. The TIDAL value expresses the total DNA adduct burden experienced by the tissue from
16 the time of treatment to the end of the study. The TIDAL versus administered dose curve
17 provides a convenient way to compare adduct-forming potency for different PAHs in time-
18 course experiments. An important limitation of the TIDAL approach is the inherent assumption
19 that the ratios of specific adducts are relatively constant across dose and time course. Ross et al.
20 (1995) demonstrated that this assumption was valid for several different PAHs; however, it was
21 also noted that two adducts of benzo[a]pyrene in rat liver did not conform to this general pattern.

22 Ross et al. (1995) presented data for lung adenoma incidence (measured at 8 months) in
23 several ways: as a function of administered dose, as a function of adduct levels per dose
24 measured 24 hours after dosing (results for 3 days postdosing were mentioned but not shown), as
25 a function of TIDAL values measured over 21 days (during which period, adduct levels were
26 specifically quantified), and as a function of TIDAL values extrapolated to 8 months. The
27 relative tumor induction potencies of the studied PAHs were similar for each assay for a single
28 PAH when described as functions of administered dose, the adduct levels per dose at 3 days, the
29 TIDAL values over 21 days, or the TIDAL values extrapolated to 8 months. The relative
30 potencies for tumor incidence as a function of adduct levels at 24 hours were not similar to those
31 associated with the other measures of exposure. Ross et al. (1995) suggested that
32 pharmacokinetic differences in adduct formation among the PAHs were responsible for the
33 discrepancy, but suggested that peak levels could be used to compare the potencies of different
34 PAHs if adduct formation for those PAHs followed similar kinetics.

35 DNA adduct experiments were carried out in replicate and were usually analyzed
36 statistically. It should be noted that, based on the work of Ross et al. (1995), relative potencies
37 determined from studies that administered a single dose level and measured adducts at a single
38 time point will be less reliable unless the shapes of the adduct formation curves are similar.

1 However, the single dose and single measurement studies were also used for dose-response
2 assessment.

3 Among the in vivo DNA adduct studies shown in Table 4-6, nine studies met the
4 selection criteria for use in this analysis.

6 **4.3.2.2. *Clastogenicity or Sister Chromatid Exchange Frequency***

7 The database included 13 studies in which clastogenic effects or frequency of sister
8 chromatid exchanges of benzo[a]pyrene and at least one other PAH were tested in whole animal
9 systems. Table 4-7 lists the studies along with important study design details. The clastogenic
10 endpoints measured in these studies were micronuclei, chromosome gaps and breaks, and
11 nonspecific aberrations; sister chromatid exchanges were also measured. These studies were all
12 conducted in rodents, including mice, rats, and hamsters.

13 Eight of the studies evaluated micronuclei, sister chromatid exchanges, or chromosome
14 gaps or breaks in bone marrow from treated mice or hamsters (Allen et al., 1999; Katz et al.,
15 1981; Paika et al., 1981; Salamone et al., 1981; Tsuchimoto and Matter, 1981; Roszinsky-Kocher
16 et al., 1979; Bayer, 1978; Sugiyama, 1973). In these studies, one or two doses of PAH were
17 injected intraperitoneally into the animals, and sacrifice occurred at various time points thereafter
18 (typically 24 hours after). Bone marrow smears were examined microscopically and scored for
19 micronuclei, sister chromatid exchanges, gaps, or breaks.

20 He and Baker (1991) applied multiple dose levels of chrysene or phenanthrene to the skin
21 of hairless mice and harvested keratinocytes upon sacrifice 24 hours later. The keratinocytes
22 were incubated for 2 days and treated with cytochalasin B to identify binucleated cells. After
23 4 days in vitro, cells were mounted on slides and examined microscopically for micronuclei.
24 Results were reported as the percent of binucleated cells with one or more micronuclei among
25 the total number of binucleated cells scored. Chrysene treatment resulted in a dose-related
26 increase in micronuclei, while pyrene did not.

27 Kligerman et al. (2002, 1986) measured sister chromatid exchanges and/or micronuclei in
28 the blood of mice or rats given a single dose of PAH either orally or intraperitoneally. The study
29 by Oshiro et al. (1992) involved two or four oral doses of pyrene or anthracene in mice. Blood
30 obtained from the tail 24 hours after the last treatment was examined microscopically and
31 micronuclei were scored in polychromatic erythrocytes. In an unusual study design, Sirianni and
32 Huang (1978) measured sister chromatid exchanges in V79 cells placed in a diffusion chamber
33 implanted in the peritoneal cavity of mice.

34 Thirteen individual PAHs were evaluated in these studies. Only chrysene gave positive
35 results for more than one endpoint (for sister chromatid exchange and micronucleus frequency;
36 He and Baker, 1991; Roszinsky-Kocher et al., 1979). Five other PAHs (phenanthrene,
37 dibenz[a,h]anthracene, benz[a]anthracene, benzo[b]fluoranthene, and benzo[e]pyrene) increased
38 the frequency of sister chromatid exchange in hamster bone marrow after intraperitoneal

1 administration (Roszinsky-Kocher et al., 1979). Bayer (1978) also reported an increase in sister
2 chromatid exchange frequency in hamster bone marrow after phenanthrene administration (high
3 dose only). Anthracene and pyrene consistently gave nonpositive results in several studies
4 (Oshiro et al., 1992; He and Baker, 1991; Katz et al., 1981; Paika et al., 1981; Salamone et al.,
5 1981; Tsuchimoto and Matter, 1981; Roszinsky-Kocher et al., 1979; Sirianni and Huang, 1978).
6 Dibenzo[a,i]pyrene and benzo[g,h,i]perylene each gave nonpositive results in an assay for bone
7 marrow micronuclei (Katz et al., 1981).

8 Among studies with positive results, only He and Baker (1991), Kligerman et al. (1986),
9 and Bayer (1978) administered PAHs at multiple dose levels. Bayer (1978) observed a positive
10 response only with the highest dose of phenanthrene. Of the single dose studies, only
11 Roszinsky-Kocher et al. (1979) reported responses clearly differing from controls.

12 Among the in vivo clastogenicity or sister chromatid exchange studies shown in
13 Table 4-7, 10 studies met the selection criteria for use in this analysis.

15 **4.3.2.3. In Vivo Mutagenicity**

16 The PAH database contains several studies that evaluate specific mutagenic endpoints
17 following in vivo exposure to PAHs (see Table 4-8). These studies include mutagenicity
18 experiments in *Drosophila melanogaster*, an intraperitoneal host-mediated assay using
19 Salmonella strains or yeast, and DNA sequence analysis of specific codons in the Ki-ras
20 oncogene in mouse lung tumors.

21 Most *Drosophila* studies administered PAH compounds to either the suspension media or
22 to the diet for 48–72 hours prior to cross-mating and analysis of mutations (Frolich and Wurgler,
23 1990; Valencia and Houtchens, 1981; Fahmy and Fahmy, 1980). One study used abdominal
24 injection as an exposure pathway (Zijlstra and Vogel, 1984). The mutagenic endpoints evaluated
25 included somatic mutations (i.e., eye color mosaicism, wing spots) (Frolich and Wurgler, 1990;
26 Fahmy and Fahmy, 1980) or sex-linked recessive lethal mutations (Zijlstra and Vogel, 1984;
27 Valencia and Houtchens, 1981). Only two PAHs were evaluated in the *Drosophila* studies in
28 addition to benzo[a]pyrene (benz[a]anthracene and pyrene), and the results were either
29 nonpositive or inconsistent in all studies (Frolich and Wurgler, 1990; Zijlstra and Vogel, 1984;
30 Valencia and Houtchens, 1981; Fahmy and Fahmy, 1980). A significant effect was seen for
31 benz[a]anthracene only with cross-breeding of strains selected for enhanced metabolic activity
32 (Frolich and Wurgler, 1990). No effect was observed using the standard strains.

33 An intraperitoneal host-mediated assay was described by Simmon et al. (1979). Five
34 PAHs (anthracene, benz[a]anthracene, benzo[e]pyrene, chrysene, and phenanthrene) were
35 administered to Swiss Webster mice by gavage or intramuscular injection (single dose only).
36 Microorganisms (*S. typhimurium* and *Saccharomyces cerevisiae*) were injected intraperitoneally
37 into exposed mice and were recovered 4 hours later for mutation analysis. Nonpositive results

1 were observed and the host-mediated assay system was considered insensitive for detecting
2 carcinogenic PAHs.

3 A series of studies have investigated the mutation sequence in codons 12 and 61 of the
4 Ki-ras oncogene from PAH-induced lung adenomas in A/J mice (Nesnow et al., 1998a, 1996,
5 1995; Mass et al., 1993). As discussed in Section 2.4 (Similarities in Mode of Carcinogenic
6 Action for PAHs), the purpose of these studies was to correlate the tumorigenic potency of
7 specific PAHs with the formation of DNA adducts and the mutation of specific codons in the
8 Ki-ras oncogene. Six non-alkylated PAHs were utilized in these studies (benzo[a]pyrene,
9 benz[j]aceanthrylene, benzo[b]fluoranthene, dibenz[a,h]anthracene, cyclopenta[c,d]pyrene, and
10 dibenzo[a,l]pyrene). Mutation analysis of the Ki-ras oncogene at codons 12 and 61 was carried
11 out in PAH-induced lung adenomas using PCR amplification and dideoxy nucleotide sequencing
12 methods. The primary mutation type for benzo[a]pyrene, benzo[b]fluoranthene, and
13 dibenzo[a,l]pyrene was the GGT→TGT mutation. This guanine mutation was correlated with
14 the formation of diol epoxide guanine adducts. The GGT→CGT mutation was the primary
15 mutation type for benz[j]aceanthrylene and cyclopenta[c,d]pyrene. The CGT mutation was
16 associated with the formation of cyclopenta-guanine adducts and increased tumorigenic potency
17 (i.e., >90 adenomas per mouse) in A/J mice. Dibenz[a,h]anthracene was the only PAH evaluated
18 that did not induce mutations in Ki-ras codons 12 or 61. This compound produced diol epoxide
19 guanine adducts and lung adenomas in A/J mice, suggesting a possible interaction at a different
20 genetic target. The Ki-ras mutation analysis data were presented as percent of tumors with a
21 specific mutation at either codon 12 or 61. No dose-response data were provided.

22 Among the in vivo mutagenicity studies shown in Table 4-8, only one study met the
23 selection criteria for use in this analysis.

24 25 **4.3.3. In Vitro Studies of Cancer-Related Endpoints**

26 Many in vitro studies of cancer-related endpoints are present in the PAH database. As
27 previously discussed, only those studies that included at least one selected PAH and
28 benzo[a]pyrene as a reference compound were reviewed. Each study that was reviewed for the
29 purpose of RPF development is included in Tables 4-9 through 4-14. The tables summarize
30 study-specific information and indicate whether a particular study is considered useful for dose-
31 response assessment. The text provides an overall description of the available studies, including
32 a general description of the methodology used for each study type, the results, and the
33 weaknesses or problems associated with specific studies or study types.

34 35 **4.3.3.1. Bacterial Mutagenicity**

36 The bacterial mutagenicity of many PAHs has been extensively studied (39 studies with
37 benzo[a]pyrene; see Table 4-9). All of the studies used the Ames assay in *S. typhimurium*. A
38 total of 38 PAHs have been evaluated for their ability to induce mutations in bacterial systems.

1 The Ames Salmonella assay is a bacterial reverse mutation assay, which measures the
2 frequency at which histidine-independent bacteria arise from histidine-requiring bacterial strains
3 in the presence of a chemical mutagen. The results are generally expressed as either the number
4 of revertant colonies per plate or the number of revertants/nmol of the test compound (calculated
5 from the linear portion of the dose-response curve). Several strains of *S. typhimurium* have been
6 used to evaluate specific PAH mutation types; for example, TA98, TA1537, and TA1538 detect
7 various frameshift mutations, TA1535 responds to base-pair substitution, and TA100 responds to
8 a broad spectrum of mutations. Metabolism to reactive intermediates is required for PAH
9 mutagenicity in Salmonella and many metabolic activation systems have been employed. Rat
10 liver postmitochondrial supernatant (known as S9) from Aroclor-induced rats is most often used,
11 although other rodent species and enzyme inducers are sometimes employed. Isolated rat
12 hepatocytes or purified mixed-function oxidase enzymes were occasionally utilized for metabolic
13 activation of PAHs.

14 Of the PAHs tested for bacterial mutagenicity, most were considered positive in at least
15 one study under optimal study conditions. Compounds that produced nonpositive results in
16 multiple studies include anthracene, fluorene, phenanthrene, and pyrene. The primary weakness
17 of the bacterial mutagenicity database for PAHs is the limited amount of multiple-dose data for
18 many PAHs. Many studies report findings at a single dose level for several PAHs.

19 Among the in vitro bacterial mutagenicity studies shown in Table 4-9, 29 studies met the
20 selection criteria for use in this analysis.

21 22 **4.3.3.2. Mammalian Mutagenicity**

23 Studies that evaluate the mutagenicity of target PAHs in mammalian cells are described
24 in Table 4-10 (29 studies). The most common cell types used in these studies were the
25 V79 Chinese hamster cells and the L5178Y mouse lymphoma cells. Other cell types include
26 human epidermal keratinocytes, TK6 human lymphoblasts, human epithelial cells (HS1 HeLa),
27 human foreskin fibroblasts (D-550), mouse fibroblasts, rat embryo cells, rat liver epithelial cells
28 (ARL-18), and Chinese hamster ovary (CHO) cells. A total of 14 PAHs have been evaluated for
29 their ability to induce mutations in mammalian cell systems.

30 Each of the mammalian cell assays detects forward mutations that confer resistance to a
31 toxic chemical. Mutations in the hypoxanthine-guanine phosphoribosyl transferase gene (HPRT)
32 result in resistance to purine analogs such as 6-thioguanine, 8-azaguanine, and ouabain. HPRT
33 mutations induced by PAHs were most often measured in V79 Chinese hamster cells, but have
34 also been detected in human, rat, and mouse cell lines. Forward mutation at the thymidine
35 kinase (TK) locus is measured as colony growth in the presence of thymidine analogs (e.g.,
36 trifluorothymidine or 5-bromo-2'-deoxyuridine). PAH-induced TK mutations were measured in
37 mouse lymphoma cells (L5178Y) and human lymphoblasts. Forward mutation assays are
38 considered to respond to a variety of mutation types (including frameshift, base-pair substitution,

1 deletions, and rearrangements or complex mutations). Exogenous metabolic activation is
2 required for PAH mutagenicity in most mammalian cell assays. This was accomplished using a
3 rat liver S9 mix or cocultivation with other rodent cells able to metabolize PAHs to reactive
4 intermediates (i.e., hamster embryo cells, fibroblasts, or hepatocytes; rat hepatocytes). The
5 results of forward mutation assays in mammalian cell lines are generally expressed as mutant
6 frequency/10^x survivors.

7 Of the 26 PAHs tested for mammalian cell mutagenicity, all were considered positive in
8 at least one study under optimal study conditions. Compounds that produced nonpositive results
9 in some studies include anthracene, benzo[e]pyrene, phenanthrene, and pyrene. Benzo[a]-
10 anthracene produced positive findings in seven studies and nonpositive findings in four studies.
11 The mammalian mutagenicity studies generally provide more multidose data than the bacterial
12 mutagenicity studies.

13 Among the in vitro mammalian mutagenicity studies shown in Table 4-10, 27 studies met
14 the selection criteria for use in this analysis.

15 16 **4.3.3.3. Morphological/Malignant Cell Transformation**

17 Twenty-five studies examined the capacity of benzo[a]pyrene and other PAHs to
18 transform cells in culture (Table 4-11). All of these studies were conducted using mammalian
19 cells, most commonly mouse or hamster embryo cells. A few studies added feeder cells or rat
20 liver homogenate to enhance metabolic activation in the test system; however, the majority relied
21 on the intrinsic metabolic capacity of the cells. The general test protocol involved seeding the
22 cultured cells in Petri dishes followed by exposure to a solution of the test compound, usually for
23 a period of 24 hours. The cells were then cultured for about 6 weeks before being fixed and
24 stained. Transformed colonies (foci) were scored based on characteristics such as cell piling,
25 criss-crossing, basophilic staining, and/or invasion of surrounding (nontransformed) cell
26 monolayer. In studies conducted by some laboratories, foci were classified as Type II or
27 Type III; the latter category included those with invasion of the surrounding monolayer, highly
28 criss-crossed arrays, and deep staining. Data were generally reported as the number of foci
29 (colony of transformed cells) per dish or per surviving cells and/or the percent of dishes with
30 foci.

31 In a few cases (e.g., Greb et al., 1980), transformation was assessed by growth of treated
32 cells in soft agar. Transformed cell colonies growing in semi-solid agar are capable of
33 anchorage-independent growth.

34 Three studies (Evans and DiPaolo, 1975; Kakunaga, 1973; DiPaolo et al., 1972)
35 confirmed the identification of malignant cells by injecting the transformed cells into rodents and
36 following tumor induction in the animals. In all three cases, cells identified as transformed gave
37 rise to tumors, while the cells without these characteristics did not.

1 Cell transformation assays were identified that included 22 individual PAHs other than
2 benzo[a]pyrene. Dibenz[a,h]anthracene consistently gave rise to transformed cells in all but one
3 of the seven studies in which it was tested. Cyclopenta[c,d]pyrene, indeno[1,2,3-c,d]pyrene,
4 benzo[j]aceanthralene, benz[e]aceanthrylene, and dibenz[k,mno]acephenanthrylene were each
5 tested in a single study and gave positive results. Benz[a]anthracene, pyrene, phenanthrene,
6 benzo[e]pyrene, and anthracene each gave nonpositive results in a number of studies, while
7 fluoranthene, benzo[k]fluoranthene, dibenz[j,mno]acephenanthrylene, naphth[1,2,3-mno]ace-
8 phenanthrylene, and aceanthrylene were each tested in a single study and gave nonpositive
9 results. Only a single dose of the target PAH was applied in 8 of the 26 studies of in vitro
10 morphological/malignant cell transformation.

11 Among the in vitro morphological/malignant transformation studies shown in Table 4-11,
12 19 studies met the selection criteria for use in this analysis.

13 14 **4.3.3.4. DNA Adducts**

15 Several studies (14) were identified in which DNA adducts were measured after either
16 whole cells or extracted DNA were incubated with benzo[a]pyrene and at least one other PAH.
17 Table 4-12 shows general study details for these studies. Most of the studies involved
18 measurement of DNA adducts in whole mammalian cells, while some measured adducts formed
19 when PAHs were incubated with extracted DNA. Whole cells were usually incubated with
20 PAHs for about 24 hours, while extracted DNA was exposed to PAH solutions for a shorter time
21 period (1–3 hours). Some of the studies added metabolic activation (usually rat liver
22 microsomes) to the incubation solution. Melendez-Colon et al. (2000) evaluated DNA adduct
23 formation after dibenzo[a,l]pyrene exposure in two cell types: one having significant CYP450
24 activity (MCF-7 cells) and one lacking significant CYP450 activity (HL-60). The authors
25 reported that adducts were formed in the cells having CYP450 activity, but no adducts were
26 formed in the cells lacking such activity.

27 Identification and quantification of adducts was generally done using a [³²P]-postlabeling
28 assay as follows. After exposure, DNA was isolated and digested to mononucleotides.
29 Mononucleotides were radiolabeled with [³²P]-ATP, separated with thin layer chromatography,
30 and visualized by autoradiography. Relative adduct labeling was measured using a scintillation
31 counter. A few early studies used [³H]-labeled PAHs to identify and quantify adducts. In some
32 cases, adducts were identified by high-performance liquid chromatography and gas
33 chromatography-mass spectrometry.

34 The 14 studies reviewed examined 15 PAHs other than benzo[a]pyrene. Apart from
35 phenanthrene, which did not result in measurable DNA adducts when incubated with calf thymus
36 DNA under various conditions (Bryla and Weyand, 1992), each of the PAHs produced
37 measurable DNA adducts in at least one study.

1 Major limitations associated with some of the in vitro DNA adduct data for relative
2 potency development include the lack of data at multiple PAH exposure levels, the use of
3 extracted DNA rather than whole cell assays, and the inconsistent use of extrinsic metabolic
4 activation sources. Only three studies with positive adduct findings reported adduct
5 measurements at multiple doses (concentrations) of PAH (Binkova et al., 2000; Melendez-Colon,
6 2000; Bryla and Weyand, 1992). Three studies used extracted DNA rather than whole cells to
7 measure DNA binding (Segeberback and Vodicka, 1993; Bryla and Weyand, 1992; Grover and
8 Sims, 1968). Finally, the available studies on DNA adduct formation use cell types with varying
9 degrees of PAH metabolic capacity, with and without added metabolic activation sources. Both
10 the types and the quantities of DNA adducts formed are likely to depend on the level of
11 metabolic activation for most PAHs.

12 Among the in vitro DNA adduct studies shown in Table 4-12, 10 studies met the
13 selection criteria for use in this analysis.

15 **4.3.3.5. DNA Damage/Repair**

16 Twenty-four reports in the database evaluated the effects of one or more PAHs on DNA
17 damage, repair, or synthesis. Table 4-13 summarizes the study design information and results of
18 these studies. Studies included measures of unscheduled DNA synthesis and DNA damage.
19 Unscheduled DNA synthesis was generally measured by increased radiolabeled (³H) thymidine
20 uptake in treated cells versus untreated cells. DNA damage was measured either using the
21 alkaline elution assay for DNA strand breakage in mammalian cells, or using the differential
22 killing of DNA repair-deficient bacterial strains. Metabolic activation of PAHs was most often
23 accomplished using a rat liver S9 mix.

24 Twenty-eight different PAHs have been tested for effects on DNA in one or more assays.
25 In general, pyrene, anthracene, phenanthrene, perylene, fluorene, and benzo[e]pyrene gave
26 nonpositive results in multiple studies. Chrysene gave nonpositive results in four assays and
27 positive results in one assay (Mersch-Sundermann et al., 1992). More positive than nonpositive
28 results were reported for benz[a]anthracene, dibenz[a,h]anthracene, and dibenz[a,c]anthracene.
29 Other PAHs were tested only once, or gave roughly an equal frequency of positive and
30 nonpositive responses in these assays.

31 Although a large number of PAHs have been tested for DNA damage/repair, the database
32 includes both bacterial and mammalian cells and several different genotoxic endpoints. In
33 addition, the use of external metabolic activation, or cell types with intrinsic metabolic capacity,
34 was inconsistent across these studies. These limitations make it difficult to compare studies
35 using the same target PAHs.

36 Among the in vitro DNA damage/repair studies shown in Table 4-13, 15 studies met the
37 selection criteria for use in this analysis.

1 **4.3.3.6. *Clastogenicity or Sister Chromatid Exchange Frequency***

2 The database contains 18 studies in which clastogenicity or sister chromatid exchange
3 frequency was measured in cultured cells after exposure to benzo[a]pyrene and at least one other
4 PAH (Table 4-14). A wide variety of cell types was used in these assays, including hamster
5 liver, lung, CHO, and V79 cells; rat liver epithelial cells; human teratocarcinoma epithelial cells;
6 rat and human mammary epithelial cells; mouse, rat, and human fibroblasts; human
7 lymphocytes; and guinea pig fetal cells. A number of the studies used a metabolic activation
8 system, typically either rat liver S9 or coculture with a cell type able to metabolize PAHs. While
9 laboratory methods varied widely, the general approach involved treating the cultured cells with
10 a solution of the test compound, either with or without metabolic activation. Usually,
11 bromodeoxyuridine was added to the growth medium to provide a means of staining metaphase
12 chromosomes, and colcemid was used to arrest mitotic cells. Chromosomes were examined
13 microscopically and aberrations or exchanges were scored visually. In most cases, the endpoint
14 examined was frequency of sister chromatid exchanges. Other endpoints included frequency of
15 micronuclei and scoring of chromosomal aberrations such as breaks, gaps, deletions, etc.

16 Only eight PAHs (anthracene, benz[a]anthracene, benzo[e]pyrene, cyclopenta-
17 [c,d]pyrene, fluoranthene, perylene, phenanthrene, and pyrene) have been tested for clastogenic
18 effects in vitro. In many cases, the available studies were aimed at evaluating the validity of a
19 given test system to predict carcinogenicity. In these studies, a range of compounds of known or
20 believed carcinogenicity were used. Often, benzo[a]pyrene was included as a known carcinogen,
21 and other PAHs were chosen because they were known or believed to be noncarcinogenic or
22 weakly carcinogenic.

23 Among the tested compounds, four gave positive results in at least one study. With few
24 exceptions, PAHs administered without metabolic activation gave nonpositive responses in these
25 assays. Cyclopenta[c,d]pyrene was reported to increase the frequency of sister chromatid
26 exchanges in two assays, one with and one without metabolic activation (Murison, 1988;
27 Krolewski et al., 1986). Benz[a]anthracene gave positive results in three studies of sister
28 chromatid exchange induction (Mane et al., 1990; Tong et al., 1983, 1981a) and nonpositive
29 results in a fourth (Warshawsky et al., 1995). Kochhar (1982) reported a dose-dependent
30 increase in chromosomal aberrations in V79 cells treated with benz[a]anthracene in the absence
31 of metabolic activation. Perylene increased aberrations in one system (Popescu et al., 1977), but
32 did not increase sister chromatid exchanges in another (Sirianni and Huang, 1978). Likewise,
33 pyrene gave positive results in a number of studies that included metabolic activation (Evans and
34 Mitchell, 1981; Perry and Thomson, 1981; Popescu et al., 1977) and nonpositive results in
35 several that did not include activation (DeSalvia et al., 1988; Tong et al., 1983, 1981a; Dean,
36 1981; Abe and Sasaki, 1977).

37 The clastogenicity and sister chromatid exchange data for PAHs are variable with respect
38 to cell type and use of extrinsic metabolic activation. Some cells have intrinsic metabolic

1 activity, while others require activation from an external source. The degree to which metabolic
2 activation is required for PAHs to exert a clastogenic effect in cell cultures is not well
3 established. Another limitation of these data stems from the fact that a small number of PAHs,
4 many traditionally believed to be noncarcinogenic or weakly carcinogenic, have been tested for
5 clastogenic effects in vitro.

6 Among the in vitro clastogenicity/sister chromatid exchange studies shown in Table 4-14,
7 10 studies met the selection criteria for use in this analysis.

8 9 **4.4. SUMMARY OF INFORMATION AVAILABLE TO DEVELOP RPFs FOR** 10 **INDIVIDUAL PAHs**

11 The PAH database contains several different types of data that may be used to estimate
12 relative potencies of individual PAHs. The data were summarized in Section 4.3 and include in
13 vivo tumor bioassays using various routes of exposure and data for cancer-related endpoints
14 from both in vivo and in vitro studies. As discussed above, the concurrent testing of
15 benzo[a]pyrene as a reference compound was considered essential to allow for RPF calculation.
16 The introduction to Section 4.3 lists criteria for selecting studies or data sets for use in the
17 analysis. Studies that met these criteria were used in the development of the RPF approach.
18 Chapter 5 discusses methods used for dose-response assessment and RPF calculation from each
19 study or dataset, and Chapter 6 discusses the selection of PAHs to be included in the RPF
20 approach using a weight of evidence evaluation of the available data. Chapter 7 describes the
21 derivation of final RPFs for each PAH included in the analysis.

5. METHODS FOR DOSE-RESPONSE ASSESSMENT AND RPF CALCULATION

A discussion of the available data on PAH carcinogenicity and cancer-related endpoints and criteria for selection of studies was presented in Chapter 4. This section describes the selection of dose-response data and methods for dose-response assessment and RPF calculation from the selected datasets. The dose-response data extracted from each study with positive results and the results of the statistical analyses are shown in Appendix C. Appendix C also contains information regarding the source of the dose-response data (i.e., the figure or table number from the study and the particular data points that were used in the dose-response assessment) and additional comments on the use of the data for dose-response assessment and RPF calculation. The results of the RPF calculations are shown in tables in Appendix E. These tables provide summary information for each study, including the PAHs that were tested, the data used to estimate the slopes (point estimate⁴ or BMD model result), the calculated RPF value, and any specific comments related to the data analysis.

5.1. CHOICE OF DOSE-RESPONSE DATA

For each of the endpoints evaluated in Chapter 4 (dermal, intraperitoneal, subcutaneous, oral, and other route bioassays; in vivo DNA adducts; in vivo clastogenicity or sister chromatid exchange frequency; in vitro bacterial and mammalian mutagenicity; in vitro morphological/malignant transformation; in vitro clastogenicity or sister chromatid exchange frequency; and other in vitro endpoints [DNA adducts, unscheduled DNA synthesis, DNA damage, etc.]), there was at least one study that met selection criteria. For those studies with positive findings, dose-response data were extracted for dose-response assessment and calculation of RPFs.

5.1.1. Dose-Response Data for Tumor Bioassays

Data on both benign and malignant tumors were included in the dose-response assessment. In cases where the combined incidence of benign and malignant tumors was reported, these data were selected; however, in some cases, only benign or only malignant tumor incidence was reported. These data were also considered appropriate for derivation of RPFs. There is evidence for progression from benign to malignant tumors (e.g., dermal papillomas progressing to carcinomas) in studies of benzo[a]pyrene (for example, see Albert et al., 1991), and other PAHs are assumed to be toxicologically similar to benzo[a]pyrene. Thus, even when a study reported only the incidence of benign tumors, these data were used in the dose-response assessment.

⁴For the purpose of this report, the term “point estimate RPF” is used to describe an RPF calculated from a single point on the dose-response curve for both the PAH of interest and benzo[a]pyrene. This term distinguishes the RPF from one calculating using a BMD modeling result from multidose data.

1 While tumor multiplicity data from tumor bioassays are not generally used to estimate
2 *cancer potency*, these data were included in the dose-response assessment in order to determine
3 whether they could serve as a reliable measure of *relative cancer potency*. Several bioassays
4 reported data on both tumor incidence and tumor number, providing information that could later
5 be used to compare relative potencies estimated from these two endpoints.

6 As discussed in Section 4.3, statistics were used for tumor bioassay data to determine
7 whether the tumor incidence or multiplicity observed at a particular dose represented a
8 statistically significant increase over controls. If statistical analyses were not described in the
9 original report, incidence data were analyzed using Fisher's exact test and the Cochran-Armitage
10 trend test. Positive findings were indicated by a significant ($p < 0.05$) difference for at least one
11 dose group by comparison to control (in Fisher's exact or an equivalent test) or a significant
12 dose-response trend (Cochran-Armitage or equivalent) for multidose studies. For tumor bioassay
13 data reported as tumor count, a t-test was conducted (when variance data were available) to
14 determine whether the count was significantly different from control ($p < 0.05$). The results of
15 the statistical analyses are shown with the dose-response data in Appendix C.

16 The tumor bioassays that reported both incidence and tumor count were unique in
17 offering two different datasets for the same study. For each dose of each PAH in the tumor
18 bioassays, the decision to calculate an RPF, and in some instances, the selection of the point of
19 departure, was based on whether the tumor incidence or count was statistically significantly
20 increased over the control; if there was a significant increase, an RPF was calculated. There was
21 a single instance where the tumor count was statistically significantly increased, but the
22 incidence of tumors was not. In female mice exposed at the high dose of fluoranthene in the
23 study by Busby et al. (1984), the lung tumor count was significantly increased (albeit borderline,
24 $p = 0.0343$) while the incidence was not, and neither was statistically significantly increased at
25 the lower dose. As there were no higher doses in this study, it is possible that the two measures
26 might have produced consistent findings at higher doses. For the purpose of this analysis, the
27 multiplicity data from this study were treated as an independent measure of carcinogenic
28 potency, and an RPF was calculated for the statistically increased tumor count irrespective of the
29 analysis of incidence. It should be noted that average tumor count can be skewed by an unusual
30 response in a single animal, and no information was available to determine whether such
31 response represented an anomaly unrelated to exposure or an unusual susceptibility to the
32 exposure. Thus, reliance on statistical analysis of mean tumor count alone as a measure of
33 carcinogenic response may be subject to additional uncertainty.

34 35 **5.1.2. Dose-Response Data for Cancer-Related Endpoint Studies**

36 For cancer-related endpoint data, each study authors' conclusions regarding a positive or
37 nonpositive response for each PAH were accepted, and RPFs were calculated when positive
38 results were reported. Data that were reported in graphical format in published studies of cancer-

1 related endpoints were digitized (Grab It!TM Graph Digitizer, Datatrend Software) to identify the
2 dose-response data points. In a few cases, the only cancer-related endpoint data in a given
3 publication were reported as relative potency (relative to benzo[a]pyrene). For these
4 publications, which included only in vitro cancer-related endpoint data (primarily mutagenicity),
5 the relative potency estimates calculated by the authors were used without modification (except
6 for dose adjustment where appropriate; see Section 5.5).

7 8 **5.2. OVERALL FORM OF RPF ESTIMATE**

9 The overall goal of the dose-response analysis was to calculate ratios representing the
10 relative potency of a given PAH compared with benzo[a]pyrene (i.e., RPFs). For all datasets, the
11 RPF was defined as the ratio (PAH_i:BaP) of the slopes of the dose-response curves in the low-
12 dose region, following Equation 5-1 below:

$$13 \qquad \qquad \qquad \text{RPF} = \text{slope PAH}_i \div \text{slope BaP} \qquad \qquad \qquad (5-1)$$

14
15
16 Data available for calculation of RPFs consisted of both quantal and continuous
17 endpoints. Quantal endpoints included tumor incidence or incidence of cancer-related endpoints
18 (including frequency of mutations). Continuous endpoint datasets included tumor counts
19 (number of tumors per animal) or cancer-related endpoints of a continuous-variable nature (e.g.,
20 number of sister chromatid exchanges, number of morphologically transformed colonies). Dose-
21 response assessment methods were specific to each type of endpoint (quantal or continuous) and
22 differed depending on whether there were multiple dose groups or a single dose group in the
23 dataset. Methods for multidose and single dose quantal and continuous data are described below.

24 25 **5.3. RPF CALCULATION FOR MULTIDOSE DATASETS**

26 Dose-response modeling using U.S. EPA's Benchmark Dose Software (Version 2.1.1 or
27 1.3.2) was conducted on multiple-dose data sets to estimate potency for both the target PAHs and
28 benzo[a]pyrene. Modeled estimates consider information about the shape of the dose-response
29 curve and are thus preferred over using a single dose group as the point of departure.

30 *Dose-response modeling.* For multidose quantal data, the multistage model was used and
31 the degree of the polynomial was assumed to equal the number of dose groups minus 2. The
32 multistage model was selected because it is the preferred model for cancer risk assessment of
33 animal bioassay data, and it provided a consistent model form for all of the datasets. For tumor
34 bioassay data, the multistage-cancer model was selected, while other quantal data were modeled
35 using the multistage model (both have the same model form and yield the same result). For
36 multidose continuous data, the linear model was selected for all datasets, as it is the simplest
37 model form for continuous data. For both quantal and continuous datasets, the goodness-of-fit
38 criteria were used to evaluate model fit. If the model did not provide adequate fit to the data,

1 high-dose groups were sequentially eliminated in an effort to achieve adequate fit, except when
2 truncating the data would result in the loss of datapoints at response levels in the range of the
3 benzo[a]pyrene response. The focus of the modeling effort is on the low dose and response
4 region, so doses and responses much higher than the benchmark response (BMR) are not as
5 informative and can be eliminated to improve model fit. If dose-group elimination did not
6 improve the model fit, a point-estimate ratio approach was used (see Section 5.4). The BMD
7 modeling outputs for all datasets that were successfully modeled are shown in Appendix D.

8 *Selection of BMR: Multidose data for both PAH and benzo[a]pyrene.* For tumor
9 incidence data, the BMR used in estimating the point of departure was a 10% increase in tumor
10 incidence over controls (extra risk form). For cancer-related endpoints such as frequency of
11 mutations, endpoint-specific points of departure were selected based on the background/control
12 frequency of the endpoint and the detection limit of the assay. For example, a 1% frequency was
13 selected for a control mutation frequency of 1/10,000 and a detection limit of two- to threefold
14 above background.

15 For multidose continuous data, the BMR used in estimating the point of departure was a
16 change of 1 standard deviation (1 SD) from the control mean. In the event that multiple-dose
17 continuous data were reported in the absence of SD values, a point estimate ratio approach was
18 employed to calculate the slope (see Section 5.4).

19 *Selection of BMR: Multidose data for PAH, single dose benzo[a]pyrene.* Some studies
20 included only one dose of benzo[a]pyrene as a positive control, while providing multiple-dose
21 data for a selected PAH. In these cases, dose-response modeling was performed for the selected
22 PAH and the BMR used for modeling was the observed response for benzo[a]pyrene adjusted for
23 background response. For tumor incidence data, for example, if the benzo[a]pyrene dose was
24 associated with a 60% extra risk for tumors, the BMR chosen for modeling the data for the PAH
25 was 60% extra risk. RPFs were then calculated using a ratio of the slope factors calculated with
26 equivalent points of departure (e.g., BMD₆₀). The goal of this approach was to compare PAH
27 potencies at similar response locations on the dose-response curve. There is uncertainty
28 associated with relative potency estimates calculated at the high end of the dose-response curves
29 and using the resultant RPF for low-exposure scenarios, because the relative potency relationship
30 between any two PAHs may be different at the low end, compared with the high end, of the
31 dose-response curves. The uncertainties and limitations associated with the use of high-dose
32 data to estimate relative potency are further discussed in Chapter 7. Data sets for which tumor
33 incidence was $\geq 90\%$ in the lowest dose group were not used to calculate potency estimates and
34 RPFs, because the response is near plateau and such data provide insufficient information on the
35 slope of the dose-response relationship.

36 For continuous data, when a point estimate was used to estimate the slope for
37 benzo[a]pyrene and modeling was used to estimate the slope for a given PAH, the BMR used for
38 BMD modeling was a point value set at the response (e.g., mean number of tumors per animal

1 for tumor multiplicity data) observed in the benzo[a]pyrene group, adjusted for response in the
2 control group. This approach is consistent with the BMR used for quantal data when only a
3 single benzo[a]pyrene dose group was available. Provided that a linear model is fit to continuous
4 data, the choice of a higher BMR would not appreciably change the RPF.

5 *Selection of point of departure.* The point of departure selected for slope estimation was
6 the BMD estimate rather than the lower confidence limit on the BMD. The BMD, as the central
7 or “best” estimate of the dose associated with the selected BMR, was considered a more stable
8 basis for comparison between the potency of the selected PAH and benzo[a]pyrene, and thus for
9 calculation of relative potency, than the lower confidence limit.

10 *Extrapolation from point of departure.* The slopes of the dose-response curves in the
11 low-dose regions were calculated by linear extrapolation to the origin from the model-predicted
12 points of departure. Equation 5-2 below shows the calculation of slope from multidose quantal
13 data.

$$14 \text{ Slope} = [0.1/\text{BMD}_{10}] \quad (5-2)$$

15
16
17 Equation 5-3 below shows the calculation of slope from multidose continuous data.

$$18 \text{ Slope} = [1\text{SD change}]/[\text{BMD}_{1\text{SD}}] \quad (5-3)$$

21 **5.4. RPF CALCULATION FOR SINGLE DOSE DATASETS**

22 A number of studies reported data for only single doses of benzo[a]pyrene and other
23 PAHs; for these studies, a point estimate approach was used to calculate the RPF. A point
24 estimate approach was also used to calculate RPFs for multidose datasets when model fit was not
25 achieved, when variance data were not available for continuous data, or when problems with
26 model implementation were encountered.

27 *Selection of point of departure.* When only one dose of each compound was used, there
28 was only one choice for the point of departure. However, when multidose data were available,
29 but a point estimate approach was used, the point of departure was chosen as follows. For tumor
30 bioassay data, the lowest dose associated with a statistically significant increase in tumor
31 incidence or multiplicity over control values was selected as the point of departure. Variance
32 was not reported for tumor multiplicity data in any of the dermal studies and for some of the
33 intraperitoneal studies, so the corresponding incidence data were used to determine the dose at
34 which a significant difference from control was observed.

35 The benzo[a]pyrene dose chosen in most instances was the lowest dose associated with a
36 significant increase in tumor count or incidence. For tumor multiplicity data, the PAH dose
37 chosen for the point estimate RPF calculation was the lowest dose associated with a tumor count
38 similar to that observed at the selected benzo[a]pyrene dose (similar to selecting a BMR similar

1 to the benzo[a]pyrene incidence). In the case of two dermal initiation studies conducted by
2 Cavalieri et al. (1991), however, the tumor count at the lowest dose of dibenzo[a,l]pyrene was
3 much higher than the tumor count at the lowest benzo[a]pyrene dose associated with statistical
4 significance. In order to compare the doses associated with similar tumor counts (i.e., at a
5 similar place on the dose-response curve), a higher benzo[a]pyrene dose was chosen for the RPF
6 calculation. A comparison of the RPFs calculated using this approach with RPFs calculated
7 using the lowest dose associated with a statistically significant increase over controls for both
8 dibenzo[a,l]pyrene and benzo[a]pyrene showed only small differences in the RPF values
9 (9 versus 10 in the 16-week study and 39 versus 42 in the 27-week study). A similar approach
10 was used to calculate the RPF for B_jAC using the intraperitoneal multiplicity data from Mass et
11 al. (1993).

12 For cancer-related endpoint data, statistical analysis was not always available for each
13 dose group. For these data, the lowest dose that produced a near maximal change in the assay of
14 concern was selected as the point of departure. That is, the highest dose in the linear portion of
15 the dose-response curve (identified by visual display of the data) was selected in these cases.

16 *Extrapolation from point of departure.* As with multiple dose slope estimations, point
17 estimate slope calculations also used the extra risk form. Thus, for single dose quantal data, the
18 slope was calculated by linear extrapolation to the origin after an extra risk adjustment of the
19 observed response (Equation 5-4):

$$20 \text{ Slope} = [(\text{response at dose} - \text{control response}) \div (1 - \text{control response})] \div \text{dose} \quad (5-4)$$

21
22 For single dose continuous data, the slope was calculated by linear extrapolation to the
23 origin after adjustment of the observed response in the PAH-treated animals for the control
24 response (Equation 5-5).

$$25 \text{ Slope} = [(\text{value of variable at dose}) - (\text{value of variable})_{\text{control}}] \div \text{dose} \quad (5-5)$$

26 27 28 **5.5. DOSE CONVERSION FOR RPF CALCULATION**

29 Some of the studies used to calculate RPFs reported doses or test concentrations on a
30 molar basis (e.g., μmol per mouse, $\mu\text{mol/L}$), rather than a mass basis (mg or μg). The molar
31 ratio differs from the mass ratio for any PAH with a molecular weight that differs from that of
32 benzo[a]pyrene; thus, for these compounds, an RPF expressed on a mass basis will differ from
33 that expressed on a molar basis. Table 5-1 shows a hypothetical example for fluoranthene, a
34 PAH with a molecular weight that differs from benzo[a]pyrene by 20%. As the table shows, the
35 RPF differs depending on which dose units are used.
36
37

Table 5-1. Comparison between molar and mass-based RPF

	Response	Dose in mol	Molecular weight (g/mol)	Dose in g	Molar RPF	Mass RPF
FA	0.1	5	202.26	1,011	0.20	0.25
BaP	0.1	1	252.32	252	1	1

1
2 In order to ensure that comparisons across endpoints used consistent units, the doses used
3 to calculate RPFs were converted to mass-based units using the molecular weight of the relevant
4 PAH prior to estimating the RPF. While the RPF ratio is nominally unitless, it should be
5 interpreted as the ratio of the dose of PAH to the dose of benzo[a]pyrene. Since RPFs will be
6 used in conjunction with a PAH dose and benzo[a]pyrene cancer potency in mass units (oral
7 slope factors and inhalation unit risks reported in units of $[\text{mg}/\text{kg}\cdot\text{day}]^{-1}$ and $[\mu\text{g}/\text{m}^3]^{-1}$,
8 respectively); it is important to use mass-based RPFs. Alternatively, if a molar RPF ratio were to
9 be used, it would be applied with PAH doses and benzo[a]pyrene cancer potency values
10 estimated on a molar basis; this would require a significant shift in the way PAH risks are
11 calculated compared to other carcinogens. Therefore, the mass-based RPF was selected to be
12 consistent with dose metrics used to calculate cancer risk.

13 14 **5.6. SPECIAL CONSIDERATIONS FOR RPF CALCULATION USING TUMOR** 15 **BIOASSAY DATA**

16 Several dermal bioassays reported significant mortality prior to the appearance of the first
17 skin tumor. For these data sets, an assumption was made that the number of animals at risk for
18 tumor development was equal to the total number of animals alive at the time of the appearance
19 of the first tumor. Benign and malignant tumor types within the same target organ were
20 combined for calculation of the RPF. The total incidence of animals with either a benign or
21 malignant lesion was directly reported in each study (i.e., the number of animals with adenoma
22 or carcinoma).

23 Tumor incidence data reported for different target organs within the same group of
24 animals were analyzed separately unless the joint incidence (incidence of either tumor type in
25 each dose group) was reported in the publication. Liver and lung tumors were reported in
26 newborn mice exposed to PAHs by intraperitoneal injection (LaVoie et al., 1994, 1987; Busby et
27 al., 1989, 1984; Weyand and LaVoie, 1988; Wislocki et al., 1986). In most studies, tumor
28 incidence was reported separately for the different target organs and could not be combined as
29 the joint incidence was unknown. A gender difference was observed in the newborn mouse
30 studies, with liver tumors observed in male mice only, and lung tumors reported for both male
31 and female mice. The tumor incidence data were, therefore, evaluated separately for male and

1 female mice. RPF values were calculated separately for male and female mice and for lung
2 tumor incidence and liver tumor incidence in these studies.

3 4 **5.7. SPECIAL CONSIDERATIONS FOR RPF CALCULATION USING CANCER- 5 RELATED ENDPOINT DATA**

6 The in vitro studies of cancer-related endpoints included measurements of bacterial
7 mutagenicity, mammalian mutagenicity, morphological/malignant cell transformation, DNA
8 adduct formation, DNA damage or repair, and clastogenicity or sister chromatid exchange
9 frequency. Many of the studies describing in vitro cancer-related endpoints provide dose-
10 response data under varying study conditions. For example, bacterial mutagenesis studies used
11 multiple strains, different metabolic activation processes, and/or varying assay systems. In order
12 to limit the number of datasets used for dose-response analysis of in vitro mutagenicity studies,
13 and to provide a consistent basis for comparing RPFs for different PAHs, data associated with
14 the conditions that maximized the benzo[a]pyrene response within a particular study were used
15 for the dose-response assessment of PAHs. It should be noted that in several studies, test
16 conditions that were optimal for benzo[a]pyrene were not necessarily optimal for the selected
17 PAH (see Appendix C for specific studies). The uncertainties and limitations associated with
18 this approach are discussed further in Chapter 8.

19 For time-course studies of DNA adducts, results were reported as either AUC or peak
20 formation of adducts. AUC was considered preferable for dose-response assessment, because
21 this measure considers both adduct formation and repair. Adducts measured in more than one
22 organ were summed to derive a total measure of adduct formation (standardized per unit amount
23 of DNA).

24 The data for bacterial and mammalian cell mutagenicity and malignant cell
25 transformation were sometimes expressed as a mutation or transformation frequency (i.e.,
26 mutants/total cell count or transformed cells/total cells). For multiple-dose studies, these quantal
27 variables were evaluated using the multistage model as described above. Problems were
28 sometimes encountered when using the multistage model for incidence data of this type. In some
29 cases, modifying the initial parameters in the multistage algorithm facilitated convergence. In a
30 select few cases, the quantal linear model was used when the multistage model would not
31 converge. If neither the multistage nor quantal linear models provided adequate fit, a point
32 estimate approach was used. If possible, the point estimates for both benzo[a]pyrene and the
33 target PAH were chosen at a comparable response level (e.g., the doses of benzo[a]pyrene and
34 the target PAH that both gave two mutants in 10^5 cells). However, in many cases, a comparable
35 response rate was not available. In these instances, the RPF was derived from slopes calculated
36 by linear extrapolation from the peak response.

37 As noted earlier, for studies that included only one dose of benzo[a]pyrene and multiple
38 dose data for a selected PAH, the BMR selected for dose-response modeling for the selected

1 PAH was the benzo[a]pyrene response with the background or control response subtracted. In
2 some instances, when the benzo[a]pyrene response level greatly exceeded the response at the
3 highest dose of the selected PAH, the software would fail to calculate the BMD at the
4 benzo[a]pyrene response level. In these instances, a point estimate approach using the peak
5 response for the selected PAH was used.

6 The individual study RPFs calculated for each PAH were used in a weight of evidence
7 evaluation to select PAHs for inclusion in the RPF approach (see Chapter 6) and in the derivation
8 of a final RPF for each compound (Chapter 7).

9
10

6. SELECTION OF PAHs FOR INCLUSION IN RELATIVE POTENCY APPROACH

The selection of PAHs to be included in the RPF approach began with an evaluation of whether the available data were adequate to assess the carcinogenicity of each compound. At least one RPF value was calculated for each of 51 PAHs. For 16 of these compounds, only a single RPF value derived from an in vitro cancer-related endpoint (primarily mutagenicity assays) was available. These PAHs are shown in Table 6-1. Due to the limited data available for these 16 compounds, no further evaluation of these PAHs was conducted, and they were not selected for inclusion in the RPF approach.

Table 6-1. PAHs with only one RPF from a single in vitro cancer-related endpoint study and excluded from RPF approach

PAH	CASRN	Abbreviation
Aceanthrylene	202-03-09	ACEA
Acenaphthene	83-32-9	AN
Acenaphthylene	208-96-8	ANL
Acephenanthrylene	201-06-9	APA
Benzo[a]perylene	191-85-5	BaPery
Benz[b]anthracene	92-24-9	BbA
Benzo[b]perylene	197-70-6	BbPery
Benzo[c]phenanthrene	195-19-7	BcPH
Cyclopent[h,i]aceanthrylene	131581-33-4	CPhiACEA
Cyclopent[h,i]acephenanthrylene	114959-37-4	CPhiAPA
Dibenzo[a,f]fluoranthene	203-11-2	DBaF
Dibenz[a,j]anthracene	224-41-9	DBajA
Dibenzo[b,e]fluoranthene	2997-45-7	DBbeF
Dibenzo[e,l]pyrene	192-51-8	DBelP
Dibenz[k,mno]acephenanthrylene	153043-81-3	DBkmnoAPH
Naphtho[2,3-a]pyrene	196-42-9	N23aP

The remaining 35 PAHs had RPF values calculated from at least one in vivo dataset or at least two in vitro cancer-related endpoint datasets. For these compounds, a weight of evidence approach was used to determine whether the available data (including the calculated RPFs as well as nonpositive studies that met selection criteria) were adequate to include each compound in the RPF approach. Using the calculated RPFs in the weight of evidence evaluation allowed consideration of the magnitude of calculated RPFs in assessing carcinogenicity. When data were not considered adequate, the PAH was excluded from the RPF approach. When data were considered adequate for a given PAH, it was selected for inclusion.

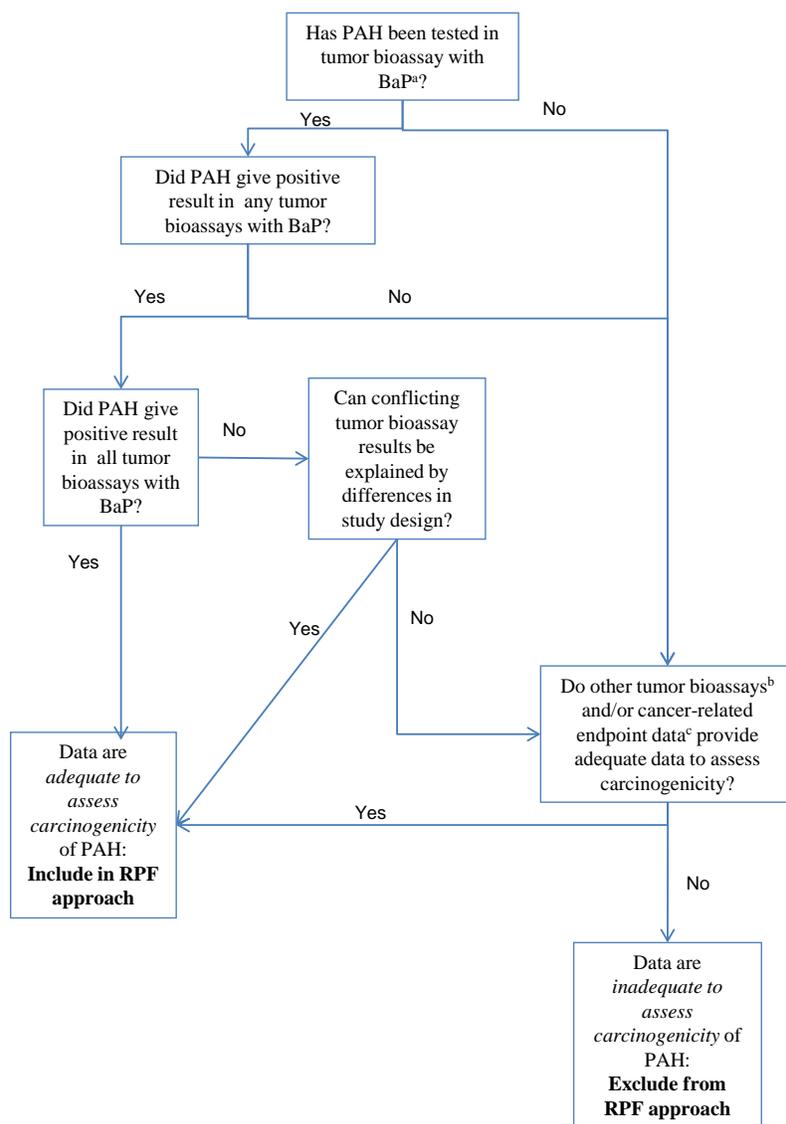
A PAH with adequate evidence to suggest no carcinogenicity was selected for inclusion in the RPF approach and assigned an RPF of zero. While there is little quantitative difference

1 between selecting a final RPF of zero for a given PAH and excluding that PAH from the RPF
2 approach, this is an important distinction for uncertainty analysis. There is substantial
3 uncertainty in the risk associated with a PAH that is excluded from the RPF approach due to
4 inadequate data; this compound could be of low or high potency. However, for a PAH with an
5 RPF of zero, there is evidence to suggest that this compound is not carcinogenic, and the
6 uncertainty associated with the cancer risk is markedly reduced. For anthracene, phenanthrene,
7 and pyrene, it has been determined that the available data support a practical RPF of zero. The
8 weight of evidence analysis is outlined in Section 6.1 and the results are described in narratives
9 for each of the 35 individual PAHs (Section 6.2). Chapter 7 describes how the RPFs from
10 multiple datasets were used to derive final RPFs for those PAHs selected for inclusion in the
11 approach, and reports the final RPF information for each PAH.

12 13 **6.1. METHOD FOR SELECTING PAHs FOR INCLUSION IN RELATIVE POTENCY** 14 **APPROACH**

15 For each of the 35 PAHs, a weight of evidence evaluation was conducted to assess the
16 evidence that each PAH could induce a carcinogenic response. For the purposes of this analysis,
17 PAHs were assumed to be carcinogenic by inferring toxicological similarity to the indicator
18 compound, benzo[a]pyrene. The weight of evidence approach was developed to determine
19 whether the available information for each PAH was adequate for inclusion of the PAH in the
20 RPF approach. Figure 6-1 shows the decision tree that was used to evaluate the data for each
21 PAH and to determine whether it should be included in the RPF approach. The weight of
22 evidence evaluation concluded with one of two possible outcomes:

- 23
24 (1) The data reviewed are adequate to evaluate carcinogenicity and the PAH should be
25 included in the RPF analysis, or
26
27 (2) The data reviewed are inadequate to assess carcinogenicity and the PAH should be
28 excluded from the RPF analysis.
29



1
2
3
4
5
6
7
8
9
10
11
12
13
14

^aBioassays with benzo[a]pyrene that met study quality criteria (includes studies with nonpositive results).

^bOther bioassays include those that did not test benzo[a]pyrene and/or those that were not suitable for RPF derivation (e.g., incidence at lowest dose exceeded 90%).

^cCancer-related endpoint data examined in this process included studies of DNA adducts, clastogenicity or sister chromatid exchange, mutagenicity, morphological transformation, DNA damage, unscheduled DNA synthesis, etc. that included the selected PAH and benzo[a]pyrene.

Figure 6-1. Weight of evidence analysis of for selection of PAHs to be included in the RPF approach.

1 In vivo tumor bioassays that included benzo[a]pyrene were given the greatest weight in
2 assessing the carcinogenicity of a given PAH; data from other bioassays and cancer-related
3 endpoint studies were used to supplement the weight of evidence when the bioassay data that
4 included benzo[a]pyrene were conflicting or nonpositive. Structural alerts for PAH
5 carcinogenicity or mutagenicity (specifically, at least four aromatic rings, or the presence of a
6 classic bay or fjord region formed entirely by aromatic rings) were noted in the evaluation for
7 each PAH, but were not used explicitly in the weight of evidence evaluation.

8 When there were bioassays including benzo[a]pyrene with positive findings, and none
9 with nonpositive findings for a given PAH, that compound was selected for inclusion in the RPF
10 approach, and no further evaluation of cancer-related endpoint data was conducted. However,
11 the cancer-related endpoint findings for these compounds were noted in the individual PAH
12 narratives (Section 6.2). Among the PAHs included in this analysis, there were none with
13 positive bioassay data and robust nonpositive cancer-related endpoint data. Were this instance to
14 arise, it would require special consideration, as it might imply a different mode of carcinogenic
15 action than the PAHs addressed herein.

16 Bioassays that met selection criteria (see Section 4.3) were included in the weight of
17 evidence analysis, regardless of whether positive or nonpositive results were found. However,
18 the weight of evidence evaluation assumed that a given compound may be active in one system
19 (e.g., newborn mouse) and inactive or weakly active in another (e.g., dermal initiation). Thus,
20 when conflicting results were observed in different test systems, different species, or different
21 genders, the PAH was assumed to be carcinogenic based on the positive findings and was
22 included in the RPF approach.

23 In order to evaluate the results of bioassays with positive and nonpositive results in the
24 same test system, an “RPF detection limit” was conceptualized as a means of approximating the
25 minimum RPF that could be determined with respect to the design of the study. The “RPF
26 detection limit” was defined as the RPF determined by the lowest response that would have been
27 statistically significant for the subject PAH and the actual benzo[a]pyrene response. The lowest
28 statistically significant response was calculated using the incidence of tumors in the control
29 group, number of animals in the group treated with the subject PAH, and Fisher’s exact test⁵
30 (employing a one-sided p -value ≤ 0.05). Appendix F provides an example calculation of an
31 “RPF detection limit.” The utility of this concept is in weighing positive and nonpositive
32 bioassay results. If all of the nonpositive studies for a subject PAH had “RPF detection limits” in
33 excess of or in the range of what is observed in the positive studies, then it is plausible that the
34 nonpositive studies may not have been sufficiently sensitive to estimate the RPF appropriate to
35 the subject PAH. In this event, the PAH was considered carcinogenic and was included in the
36 RPF approach.

⁵This calculation was implemented using trial and error within the Fisher’s exact test in the online statistical calculator, GraphPad®.

1 If there were no bioassays with benzo[a]pyrene for a given compound, all of the selected
2 bioassays gave nonpositive results, or inconsistent results could not be explained by test system
3 or “RPF detection limit”, then the results of other bioassays (those without benzo[a]pyrene, or
4 those rejected from dose-response assessment exclusively because of concerns associated with
5 benzo[a]pyrene) and cancer-related endpoint data were evaluated. The weight of evidence
6 analysis then considered all of the following information: bioassays with benzo[a]pyrene, other
7 bioassays, and cancer-related endpoint data. If these data were determined to be inadequate to
8 assess the carcinogenicity for a given PAH, then that compound was excluded from the RPF
9 approach. If the data were considered adequate to assess the carcinogenicity, the compound was
10 retained and a final RPF was derived. Section 6.2 below describes the weight of evidence
11 evaluation for each of the 35 PAHs. Section 7.1 describes how final RPFs were derived for the
12 27 PAHs selected for inclusion in the RPF approach.

13 14 **6.2. WEIGHT OF EVIDENCE EVALUATION FOR 35 INDIVIDUAL PAHs**

15 For each PAH, the structure is shown along with a brief reference to any structural alerts
16 for carcinogenicity (specifically, more than three aromatic rings and/or bay or fjord region in
17 alternant PAH). Next, a brief narrative describing the weight of evidence evaluation is given,
18 with a graphical representation of the data that were available for RPF calculation (Figures 6-2 to
19 6-35). The graph for each compound provides a visual representation of the database of studies
20 that included both the subject PAH and benzo[a]pyrene. The solid bars show the values of the
21 RPFs calculated from all studies with positive findings. The x-axis label shows the reference for
22 the pertinent study. The RPFs are color-coded to distinguish among in vivo tumor bioassays
23 based on incidence data, in vivo tumor bioassays based on multiplicity data, in vivo cancer-
24 related endpoint studies, and in vitro cancer-related endpoint studies. Within these categories,
25 the RPFs are ordered (left to right in the graph) from highest to lowest, with positive results
26 shown before nonpositive results.

27 For each nonpositive bioassay, an empty, dotted bar shows what is termed the “RPF
28 detection limit” (see Section 6.1 for description). Missing bars designate cancer-related studies
29 that resulted in nonpositive findings. An RPF detection limit for nonpositive cancer-related
30 studies was not included, because comparisons between nonpositive and positive studies were
31 complicated by the wide variety of study conditions (e.g., test species and strains, metabolic
32 activation sources, assay systems).

33 Each narrative concludes with a statement as to whether the subject PAH was selected for
34 inclusion in the PAH RPF approach. The weight of evidence evaluation for the 35 PAHs with at
35 least one in vivo RPF or at least two in vitro cancer-related endpoint RPFs resulted in the
36 selection of 27 PAHs for inclusion in the RPF approach (see Table 6-2) and the exclusion of
37 8 PAHs from the approach.

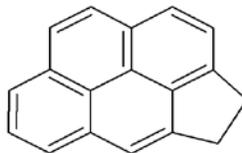
Table 6-2. Results of weight of evidence evaluation for 27 PAHs selected for inclusion in the RPF approach

Adequate data: selected for inclusion in RPF approach					
PAH	CASRN	Abbreviation	PAH	CASRN	Abbreviation
Benzo[a]pyrene	50-32-8	BaP	Cyclopenta[c,d]pyrene	27208-37-3	CPcdP
Anthanthrene	191-26-4	AA	Cyclopenta[d,e,f]chrysene, 4H-	202-98-2	CPdefC
Anthracene	120-12-7	AC	Dibenz[a,c]anthracene	215-58-7	DBacA
Benz[a]anthracene	56-55-3	BaA	Dibenzo[a,e]fluoranthene	5385-75-1	DBaeF
Benz[b,c]aceanthrylene, 11H-	202-94-8	BbcAC	Dibenzo[a,e]pyrene	192-65-4	DBaeP
Benzo[b]fluoranthene	205-99-2	BbF	Dibenz[a,h]anthracene	53-70-3	DBahA
Benzo[c]fluorene	205-12-9	BcFE	Dibenzo[a,h]pyrene	189-64-0	DBahP
Benzo[e]aceanthrylene	199-54-2	BeAC	Dibenzo[a,i]pyrene	189-55-9	DBaiP
Benzo[g,h,i]perylene	191-24-2	BghiP	Dibenzo[a,l]pyrene	191-30-0	DBalP
Benzo[j]aceanthrylene	202-33-5	BjAC	Fluoranthene	206-44-0	FA
Benzo[j]fluoranthene	205-82-3	BjF	Indeno[1,2,3-c,d]pyrene	193-39-5	IP
Benzo[k]fluoranthene	207-08-9	BkF	Naphtho[2,3-e]pyrene	193-09-9	N23eP
Benzo[l]aceanthrylene	211-91-6	BlAC	Phenanthrene	85-01-8	PH
Chrysene	218-01-9	CH	Pyrene	129-00-0	Pyr
Inadequate data					
PAH	CASRN	Abbreviation	PAH	CASRN	Abbreviation
Acepyrene, 2,3-	25732-74-5	ACEP	Coronene	191-07-1	CO
Benzo[b]fluorene, 11H-	243-17-4	BbFE	Fluorene	86-73-7	FE
Benzo[e]pyrene	192-97-2	BeP	Perylene	198-55-0	Pery
Benzo[g,h,i]fluoranthene	203-12-3	BghiF	Triphenylene	217-59-4	Tphen

1
2

1

2,3-Acepyrene (ACEP)



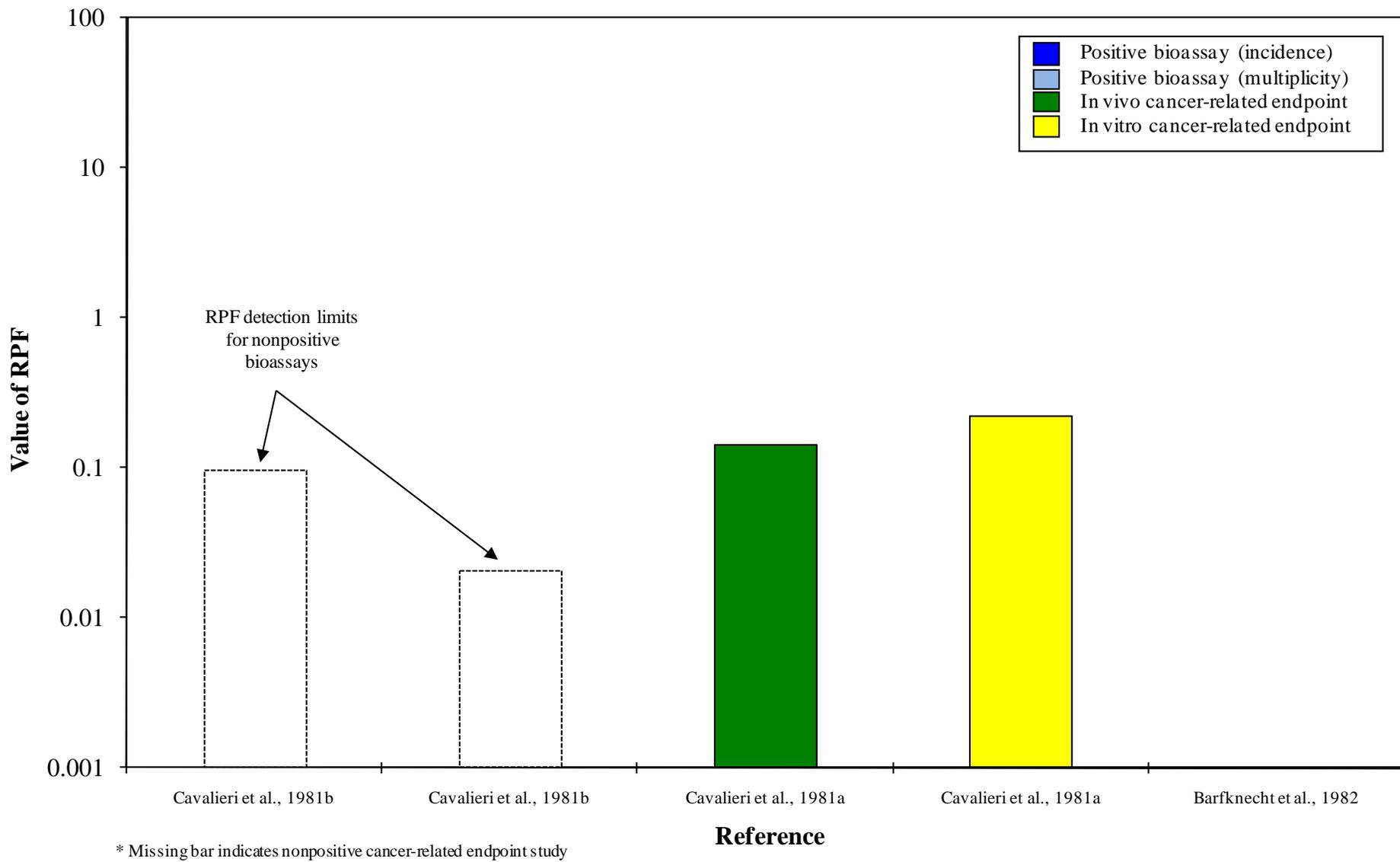
2

3

4 2,3-Acepyrene (CASRN 25732-74-5) is a nonalternant PAH comprised of four aromatic
5 rings and one five-membered ring. 2,3-Acepyrene does not contain a classic bay or fjord region
6 in its structure.

7 Five datasets for 2,3-acepyrene met selection criteria and included benzo[a]pyrene
8 (shown in Figure 6-2). Dermal initiation and complete carcinogenicity bioassays in mice
9 resulted in nonpositive findings (both published by Cavalieri et al., 1981b). RPF detection limits
10 for these studies were 0.09 and 0.02, respectively. The limited cancer-related data are mixed,
11 with one positive dataset for in vivo DNA adduct formation, one positive bacterial mutagenicity
12 dataset (both published by Cavalieri et al., 1981a), and one nonpositive mammalian mutagenicity
13 dataset (Barfknecht et al., 1982). There are no bioassays of 2,3-acepyrene without
14 benzo[a]pyrene. Overall, the database for 2,3-acepyrene is both limited and inconsistent. The
15 database for 2,3-acepyrene does not provide adequate information with which to assess
16 carcinogenicity; this PAH was not selected for inclusion in the RPF approach.

17



1
2

Figure 6-2. 2,3-Acepyrene (ACEP) RPFs*.

1

Anthanthrene (AA)



2

3

4

Anthanthrene (CASRN 191-26-4) is an alternant PAH comprised of six fused aromatic rings. Anthanthrene does not have a bay or fjord region in its structure.

6

7

8

9

10

11

12

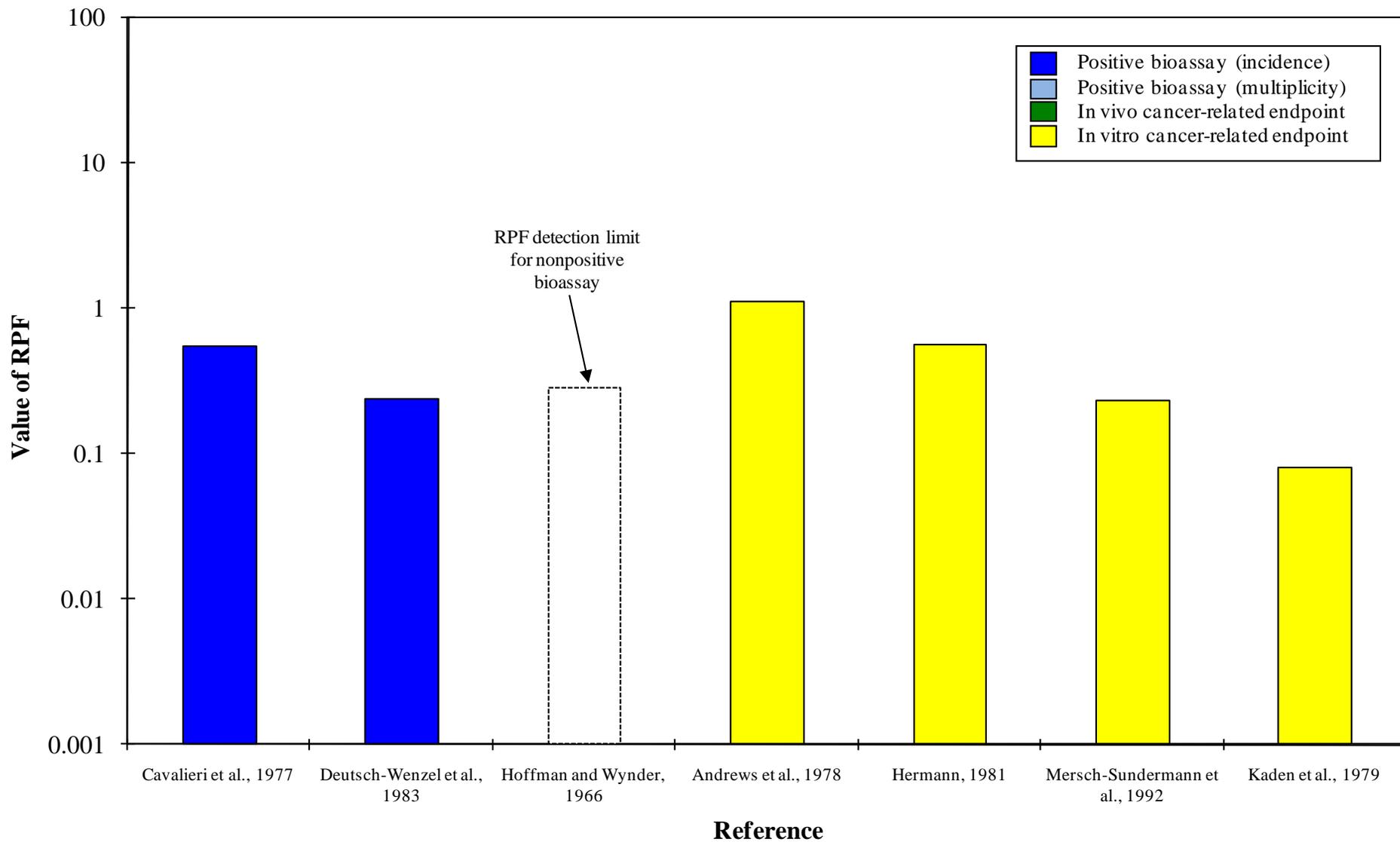
13

14

15

16

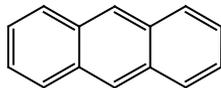
There are seven datasets for anthanthrene that met selection criteria and included benzo[a]pyrene (Figure 6-3). The database includes three in vivo tumor bioassays, three bacterial mutagenicity datasets, and one in vitro DNA damage dataset. Statistically increased tumor incidences were reported in both a rat lung implantation bioassay (Deutsch-Wenzel et al., 1983) and a dermal complete carcinogenicity bioassay in mice (Cavalieri et al., 1977). No increase over control tumor incidence was reported in a dermal initiation study (Hoffmann and Wynder, 1966), but the RPF detection limit for this study was 0.3. All of the cancer-related endpoint studies gave positive results. Because conflicting bioassay data can be explained by differences in study design (initiation versus complete dermal carcinogenicity), anthanthrene was considered carcinogenic and selected for inclusion in the RPF approach.



1
2

Figure 6-3. Anthanthrene (AA) RPFs.

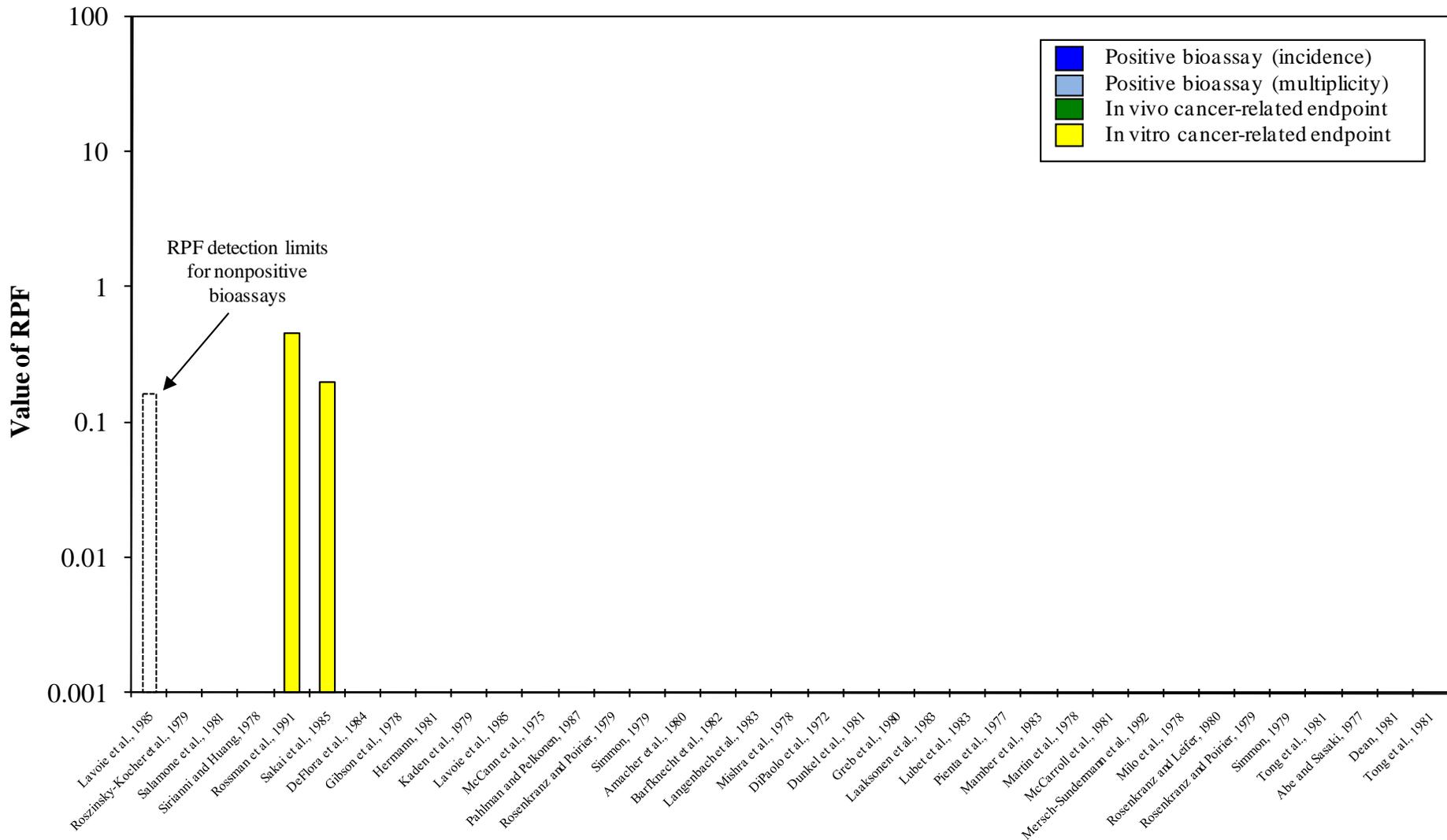
1 *Anthracene (AC)*



4 Anthracene (CASRN 120-12-7) is an alternant PAH comprised of three fused aromatic
5 rings. Anthracene does not have a bay or fjord region in its structure, and contains less than four
6 aromatic rings.

7 Thirty-seven datasets for anthracene met selection criteria and included benzo[a]pyrene,
8 including 1 dermal initiation tumor bioassay, 3 in vivo clastogenicity or sister chromatid
9 exchange datasets, 10 bacterial mutagenicity datasets, 4 mammalian mutagenicity datasets,
10 6 morphological/malignant cell transformation datasets, and 13 in vitro DNA adduct, DNA
11 damage, or clastogenicity datasets (Figure 6-4). The single dermal initiation bioassay gave a
12 nonpositive result, with an RPF detection limit of 0.2 (LaVoie et al., 1985). Only two datasets
13 gave positive results: an in vitro bacterial mutagenicity assay and an in vitro study of DNA
14 damage. The remaining 35 datasets reported nonpositive findings. To confirm the nonpositive
15 findings in the one tumor bioassay that included benzo[a]pyrene, other bioassays and cancer-
16 related endpoint data for anthracene were considered in the weight of evidence evaluation. In
17 bioassays without benzo[a]pyrene, anthracene did not induce a statistically significant increase in
18 tumor incidence in two dermal initiation studies (LaVoie et al., 1983; Salaman and Roe, 1956)
19 and a lung implantation bioassay (Stanton, 1972). Scribner (1973) reported a weak tumorigenic
20 response in a dermal initiation study in mice (4/28 mice developed papillomas by week 35 after
21 dermal treatment with 10 μ mol anthracene in benzene followed by twice weekly treatment with
22 TPA, as compared with 0/30 control mice, $p = 0.048$).

23 In vitro assays of mutagenicity (both bacterial and mammalian) are nearly all nonpositive
24 for anthracene (13/14 studies). Studies of morphological/malignant cell transformation were all
25 nonpositive. Finally, in numerous in vitro studies of DNA damage or clastogenicity, anthracene
26 has given nonpositive results (12/13). Sakai et al. (1985) reported a mutagenic response in
27 bacteria treated with anthracene, and Rossman et al. (1991) observed evidence of unscheduled
28 DNA synthesis in *Escherichia coli* treated with anthracene. Overall, the weight of evidence
29 suggests that anthracene is not carcinogenic. In addition, anthracene lacks all three known
30 structural alerts (at least four rings, bay or fjord region) for PAH carcinogenicity and/or
31 mutagenicity. Because the weight of evidence evaluation suggests that the data are adequate to
32 assess the carcinogenicity of anthracene, this compound was selected for inclusion in the RPF
33 approach and assigned an RPF of zero.



* Missing bar indicates nonpositive cancer-related endpoint study

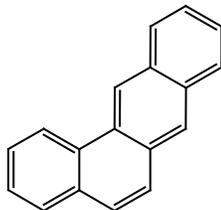
Reference

1
2

Figure 6-4. Anthracene (AC) RPFs*.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

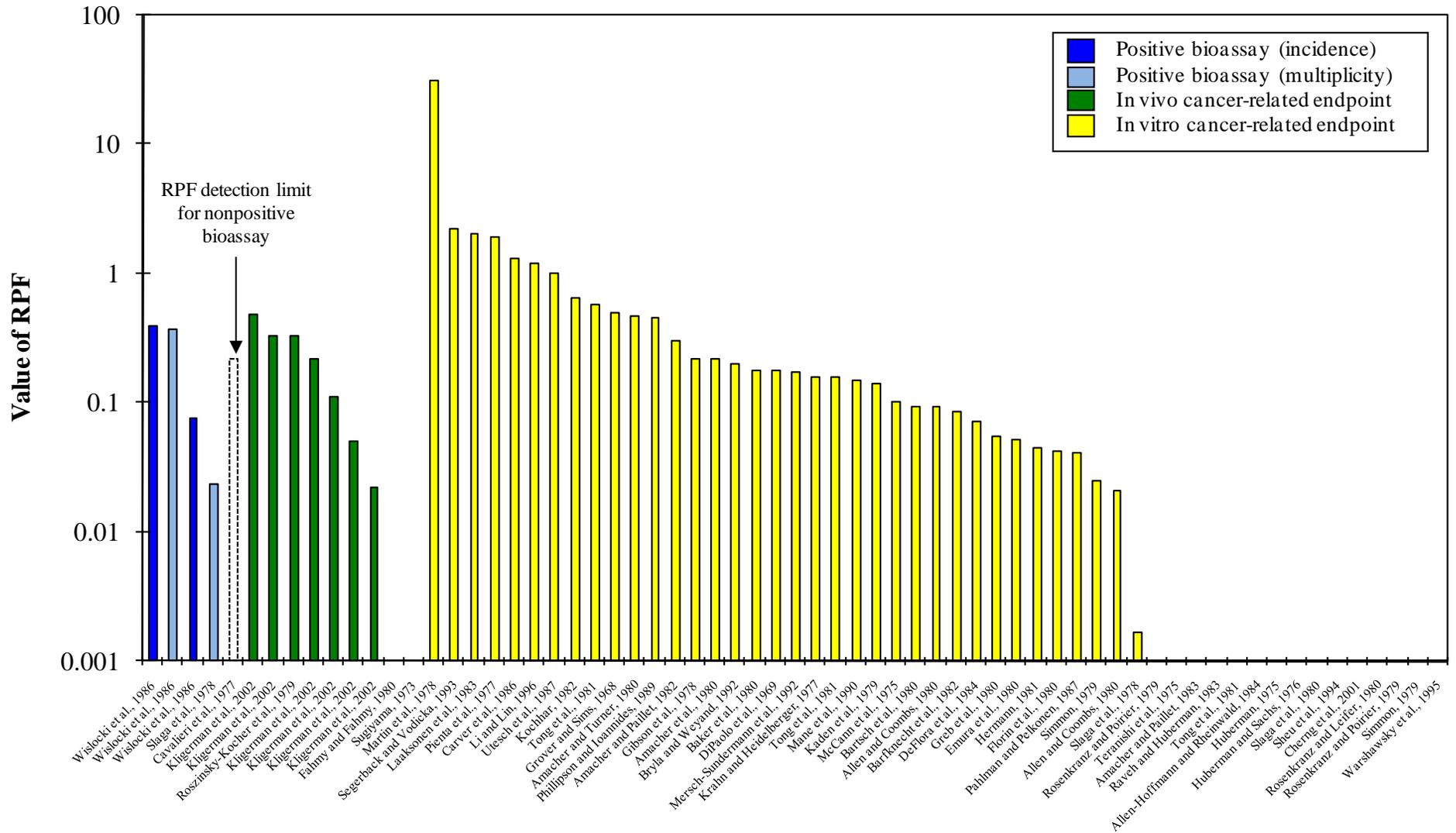
Benz[a]anthracene (BaA)



Benz[a]anthracene (CASRN 56-55-3) is an alternant PAH comprised of four fused aromatic rings. Benz[a]anthracene contains a bay region but no fjord region in its structure.

There are 65 datasets for benz[a]anthracene that met selection criteria and included benzo[a]pyrene (Figure 6-5). Included in the database are tumor bioassays (5), in vivo DNA adduct studies (4), in vivo clastogenicity studies (4), an in vivo mutagenicity study (1), bacterial mutagenicity (15), mammalian mutagenicity (14), morphological/malignant cell transformation assays (6), and in vitro studies of DNA damage, adducts, or clastogenicity (16). There are five tumor bioassay datasets of benz[a]anthracene that included benzo[a]pyrene; four gave positive results and one gave a nonpositive result. The positive findings were in different genders tested in a newborn mouse study using intraperitoneal injection (Wislocki et al., 1986); the datasets included both tumor incidence and multiplicity data for both sexes. Positive results were also reported in a dermal initiation study (Slaga et al., 1978). The one nonpositive bioassay (Cavalieri et al., 1977) was a dermal complete carcinogenicity study with an RPF detection limit of 0.2. Benz[a]anthracene was shown to form DNA adducts when administered in vivo in both rats and mice via injection and gavage (Kligerman et al., 2002). Mutagenicity and morphological/malignant cell transformation assays of benz[a]anthracene were predominantly positive, as were studies of other cancer-related endpoints.

Given that the differing bioassay results can be attributed to different test systems and study design, benz[a]anthracene was considered carcinogenic and was selected for inclusion in the RPF approach.



* Missing bar indicates nonpositive cancer-related endpoint study

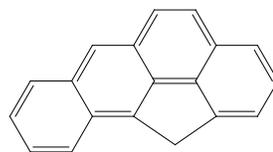
Reference

1
2

Figure 6-5. Benz[a]anthracene (BaA) RPFs*.

1

11H-Benz[b,c]aceanthrylene (BbcAC)



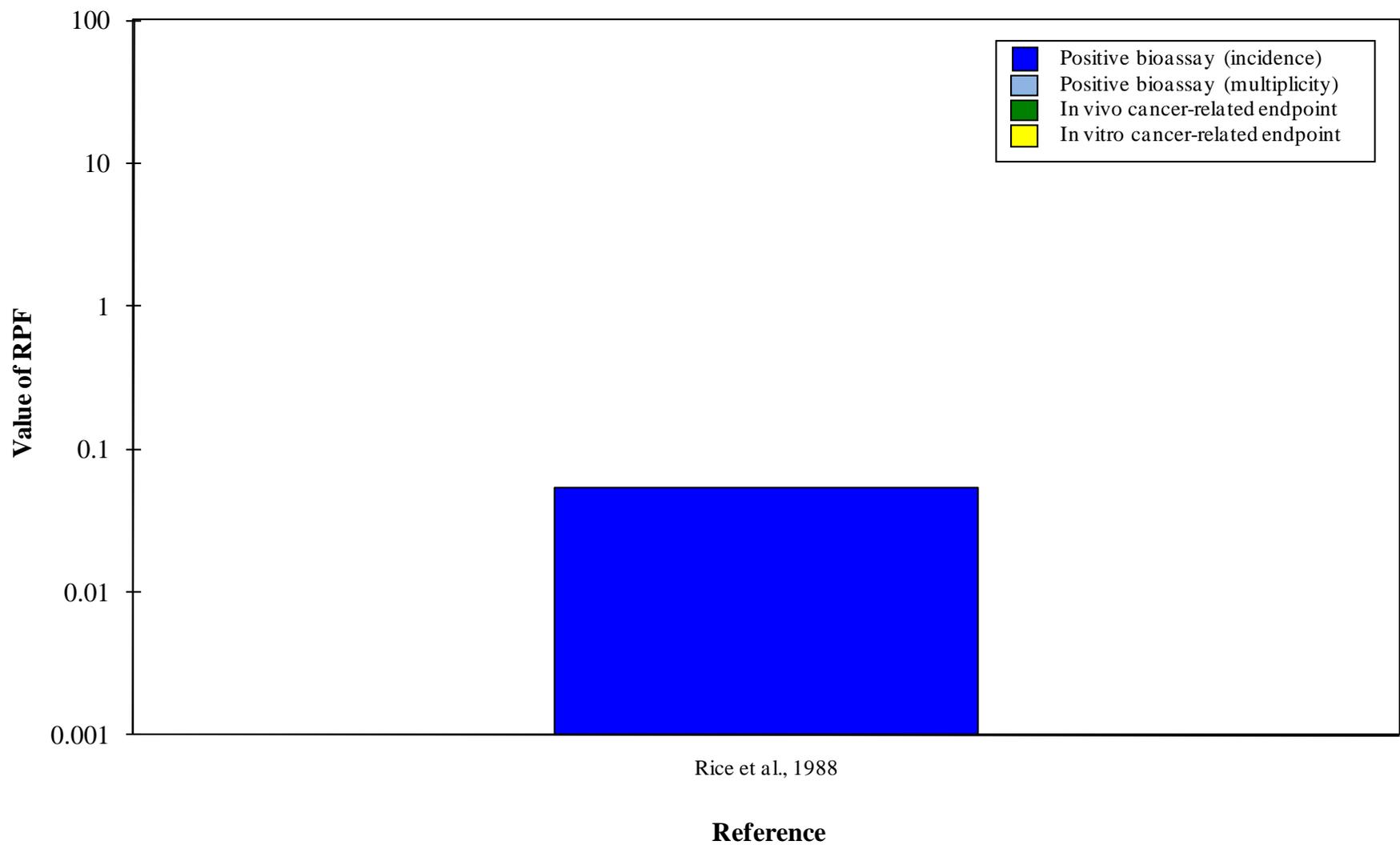
2

3

4 11H-Benz[b,c]aceanthrylene (CASRN 202-94-8) is a nonalternant PAH comprised of
5 four aromatic rings and one five-membered ring. 11H-Benz[b,c]aceanthrylene does not contain
6 a classic bay or fjord region in its structure.

7 There was only one dataset for benz[b,c]aceanthrylene that met selection criteria and
8 included benzo[a]pyrene (Figure 6-6). This multidose dermal initiation study resulted in an RPF
9 estimate of 0.05 (Rice et al., 1988). Benz[b,c]aceanthrylene has not been tested in any bioassay
10 without benzo[a]pyrene. There are no cancer-related endpoint data for benz[b,c]aceanthrylene.
11 As the only available bioassay of this PAH was positive, benz[b,c]aceanthrylene was considered
12 carcinogenic and was selected for inclusion in the RPF approach.

13

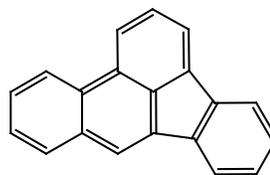


1
2

Figure 6-6. 11H-Benz[b,c]aceanthrylene (BbcAC) RPFs.

1

Benzo[b]fluoranthene (BbF)

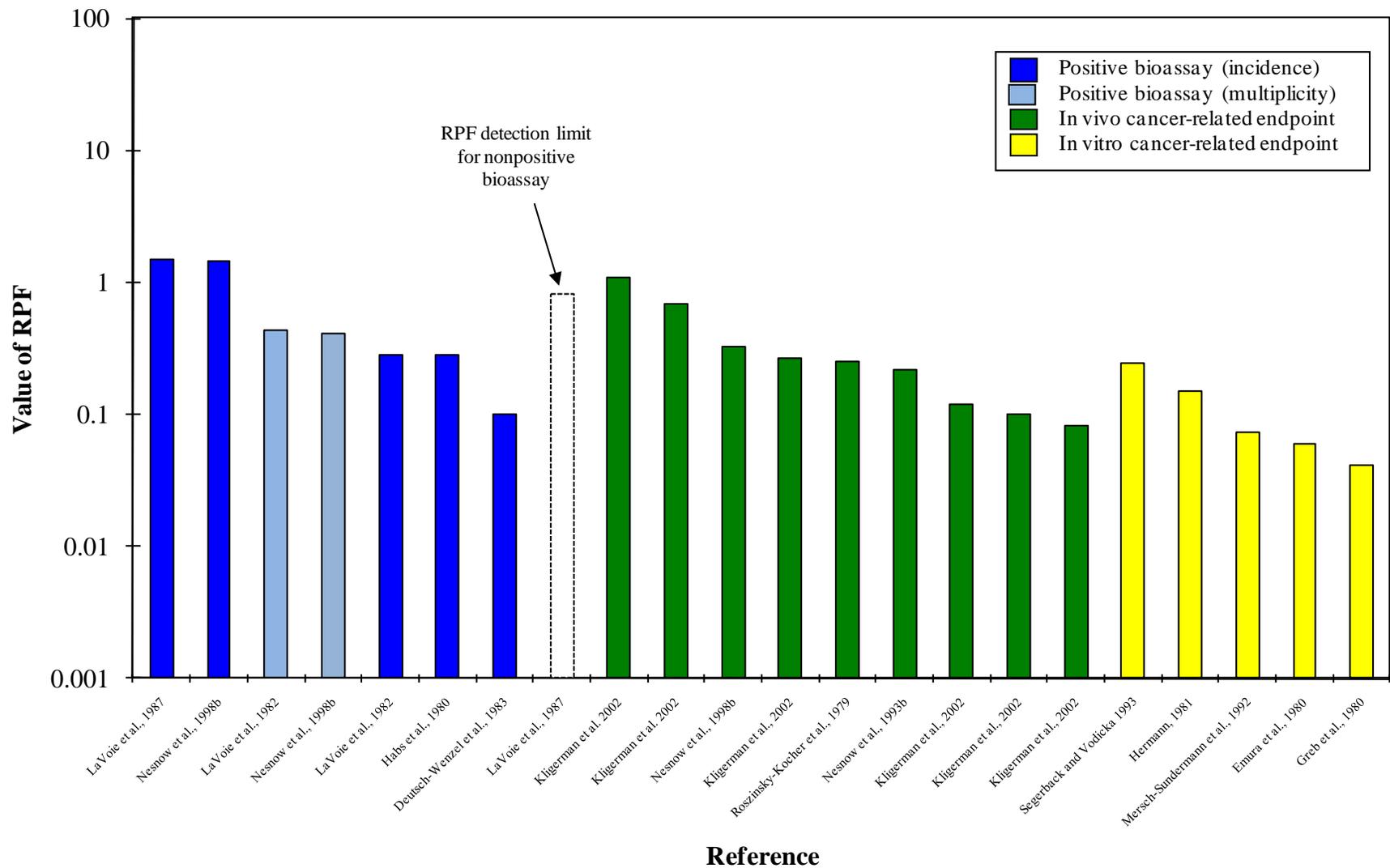


2

3

4 Benzo[b]fluoranthene (CASRN 205-99-2) is a nonalternant PAH comprised of four
5 aromatic rings and one five-membered ring. Benzo[b]fluoranthene contains one classic bay
6 region but no fjord region in its structure.

7 There were 22 datasets of benzo[b]fluoranthene that met selection criteria and included
8 benzo[a]pyrene (Figure 6-7). Included in the database are in vivo tumor bioassay datasets (8), in
9 vivo DNA adduct datasets (7), in vivo clastogenicity datasets (3), mutagenicity and
10 morphological/malignant cell transformation datasets (3), and an in vitro DNA damage dataset
11 (1). Statistically significant increases in tumor incidence and/or multiplicity were reported in
12 male mice tested in two newborn mouse bioassays using intraperitoneal injection (Nesnow et al.,
13 1998b; LaVoie et al., 1987), in dermal initiation (LaVoie et al., 1982) and dermal complete
14 carcinogenicity (Habs et al., 1980) bioassays, and in a rat lung implantation bioassay (Deutsch-
15 Wenzel et al., 1983). The one nonpositive result was in female mice tested in the newborn
16 mouse bioassay; the RPF detection limit was 0.8 (LaVoie et al., 1987). A number of studies
17 showed that benzo[b]fluoranthene forms DNA adducts when administered in vivo to rats or mice
18 via injection or gavage (Kligerman et al., 2002; Nesnow et al., 1998b, 1993b). One mutagenicity
19 assay and two morphological/malignant cell transformation assays of benzo[b]fluoranthene were
20 positive, as were studies of other cancer-related endpoints; there were no nonpositive studies of
21 cancer-related endpoints. Given that the differing bioassay results can be attributed to different
22 genders, benz[a]anthracene was considered carcinogenic and was selected for inclusion in the
23 RPF approach.

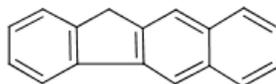


1
2

Figure 6-7. Benzo[b]fluoranthene (BbF) RPFs.

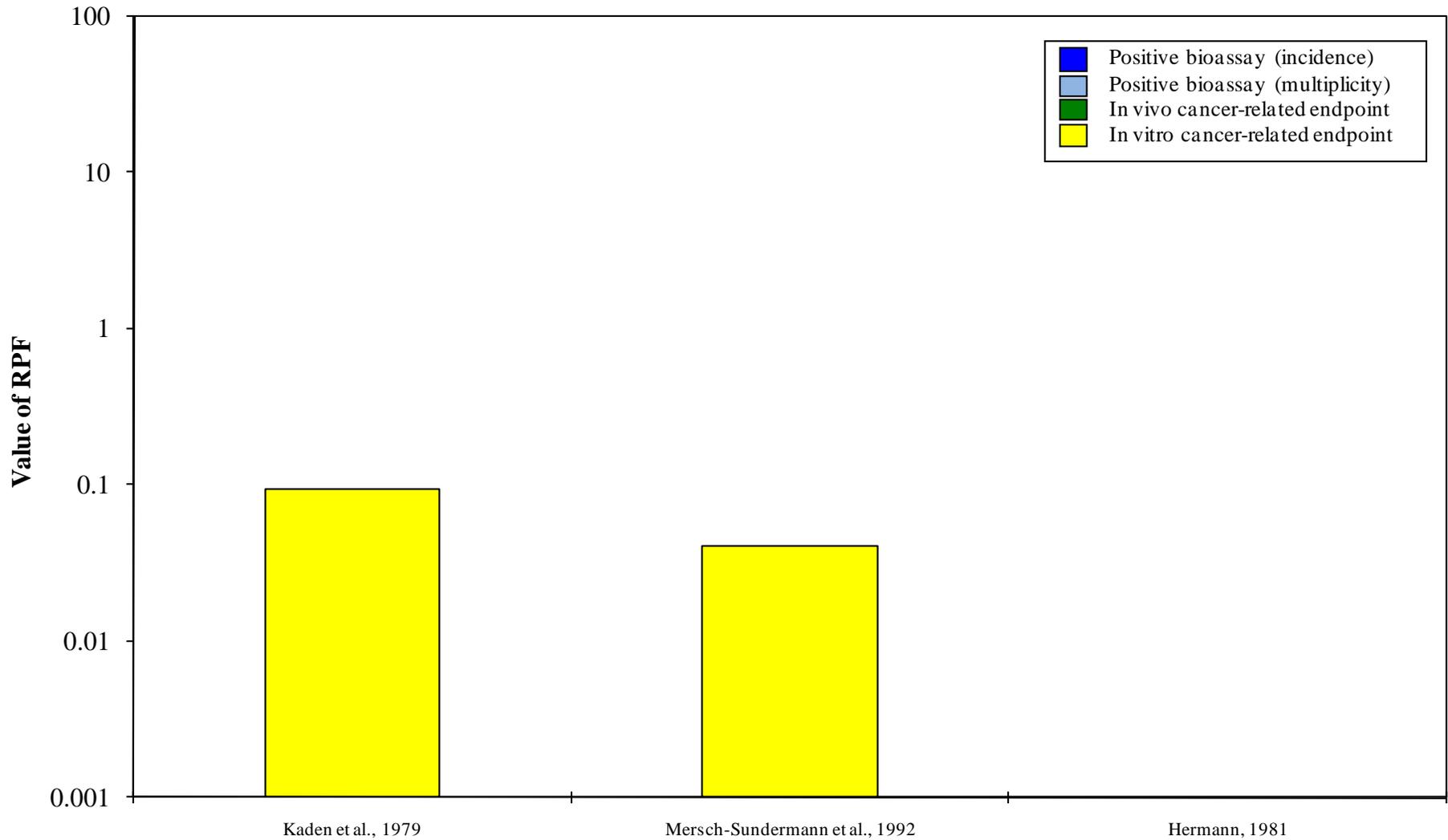
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

11H-Benzo[b]fluorene (BbFE)



11H-Benzo[b]fluorene (CASRN 243-17-4) is a nonalternant PAH comprised of three aromatic rings and one five-membered ring. 11H-Benzo[b]fluorene does not contain a classic bay or fjord region in its structure.

There were three datasets for 11H-benzo[b]fluorene that met selection criteria and included benzo[a]pyrene (Figure 6-8): two mutagenicity datasets and an in vitro DNA damage dataset. There are no bioassays of 11H-benzo[b]fluorene that included benzo[a]pyrene, so bioassays without benzo[a]pyrene and cancer-related endpoint data were considered. LaVoie et al. (1981) conducted a study of skin tumor initiation in mice treated with 1 mg 11H-benzo[b]fluorene followed by 20 weeks of treatment with TPA. The incidence of tumor-bearing animals (4/20) was not significantly increased over controls (1/20) (LaVoie et al., 1981). The limited cancer-related endpoint data were mixed, with one positive mutagenicity study (Kaden et al., 1979), one nonpositive mutagenicity study (Hermann, 1981), and one positive in vitro study of DNA damage (Mersch-Sundermann et al., 1992). Overall, the database for 11H-benzo[b]fluorene is both limited and inconsistent. Because the database for 11H-benzo[b]fluorene does not provide adequate information with which to assess carcinogenicity, this PAH was not selected for inclusion in the RPF approach.



* Missing bar indicates nonpositive cancer-related endpoint study

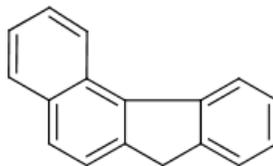
Reference

1
2

Figure 6-8. 11H-Benzo[b]fluorene (BbFE) RPFs*.

1

Benzo[c]fluorene (BcFE).



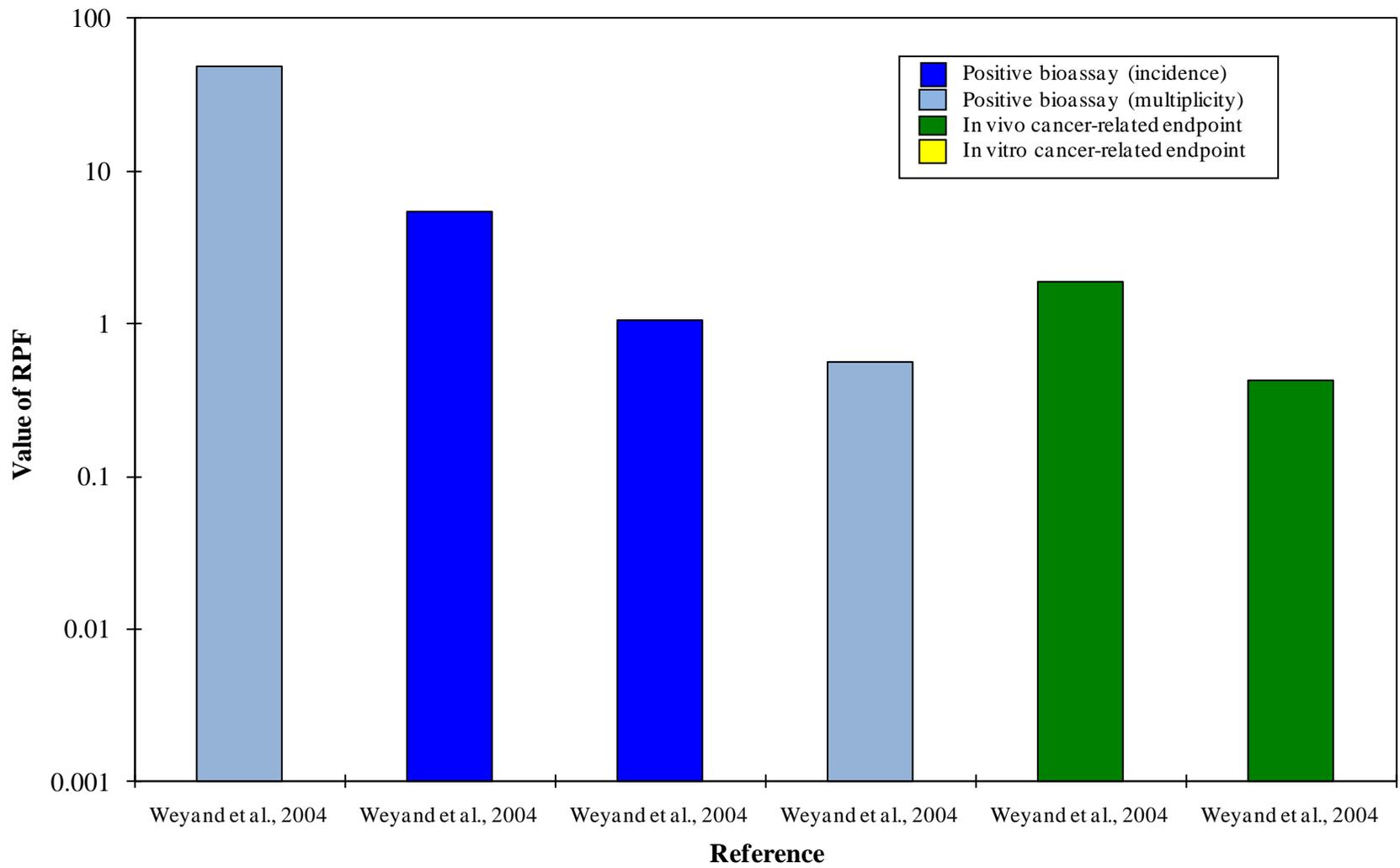
2

3

4 Benzo[c]fluorene (CASRN 205-12-9) is a nonalternant PAH comprised of three aromatic
5 rings and one five-membered ring. Benzo[c]fluorene does not contain a classic bay or fjord
6 region in its structure.

7 There were six datasets for benzo[c]fluorene that met selection criteria and included
8 benzo[a]pyrene (Figure 6-9); all gave positive results. The database includes oral and
9 intraperitoneal in vivo tumor bioassays (each reporting both incidence and multiplicity) and in
10 vivo DNA adduct data. Significantly increased lung tumor incidence and tumor multiplicity
11 were reported after both oral and intraperitoneal exposure (Weyand et al., 2004). As the
12 available bioassays that included benzo[a]pyrene were positive, benzo[c]fluorene was considered
13 carcinogenic and was selected for inclusion in the RPF approach.

14

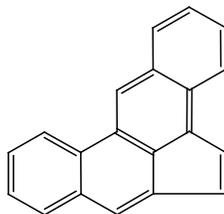


1
2
3

Figure 6-9. Benzo[c]fluorene (BcFE) RPFs.

1

Benz[e]aceanthrylene (BeAC).



2

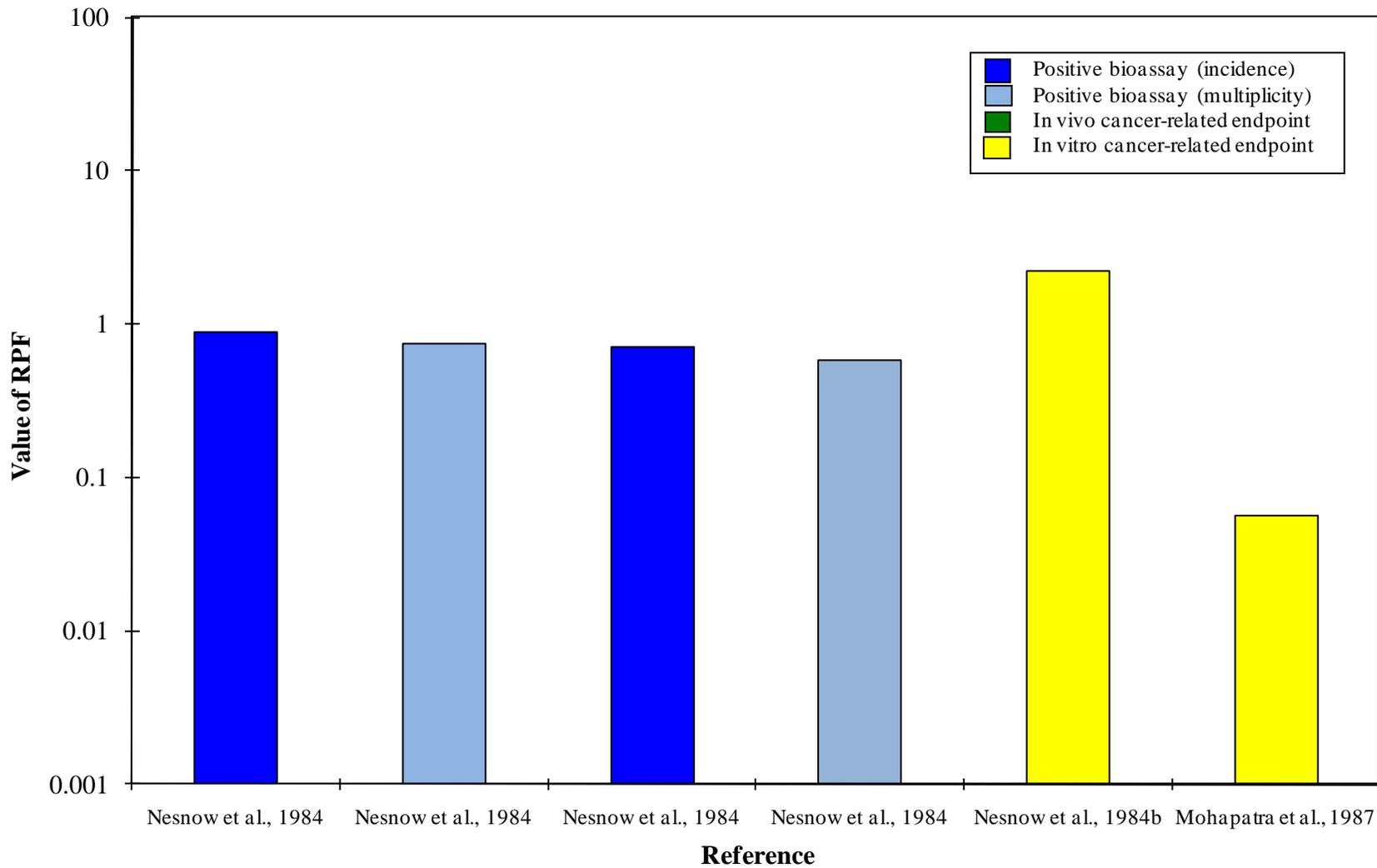
3

4 Benz[e]aceanthrylene (CASRN 199-54-2) is a nonalternant PAH comprised of four
5 aromatic rings and one five-membered ring. Benz[e]aceanthrylene contains a classic bay region
6 but no fjord region in its structure.

7 There were six datasets for benz[e]aceanthrylene that met selection criteria and included
8 benzo[a]pyrene (Figure 6-10); all gave positive results. The database includes an in vivo tumor
9 bioassay in two sexes (each reporting both incidence and multiplicity), a mammalian

10 mutagenicity study, and a morphological/malignant cell transformation study. Significantly
11 increased tumor incidence and tumor multiplicity were reported for both male and female mice
12 in a dermal initiation bioassay in mice (Nesnow et al., 1984). As the available bioassay that
13 included benzo[a]pyrene was positive, benz[e]aceanthrylene was considered carcinogenic and
14 was selected for inclusion in the RPF approach.

15

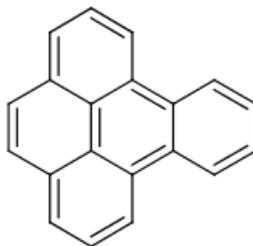


1
2

Figure 6-10. Benz[e]aceanthrylene (BeAC) RPFs.

1

Benzo[e]pyrene (BeP)



2

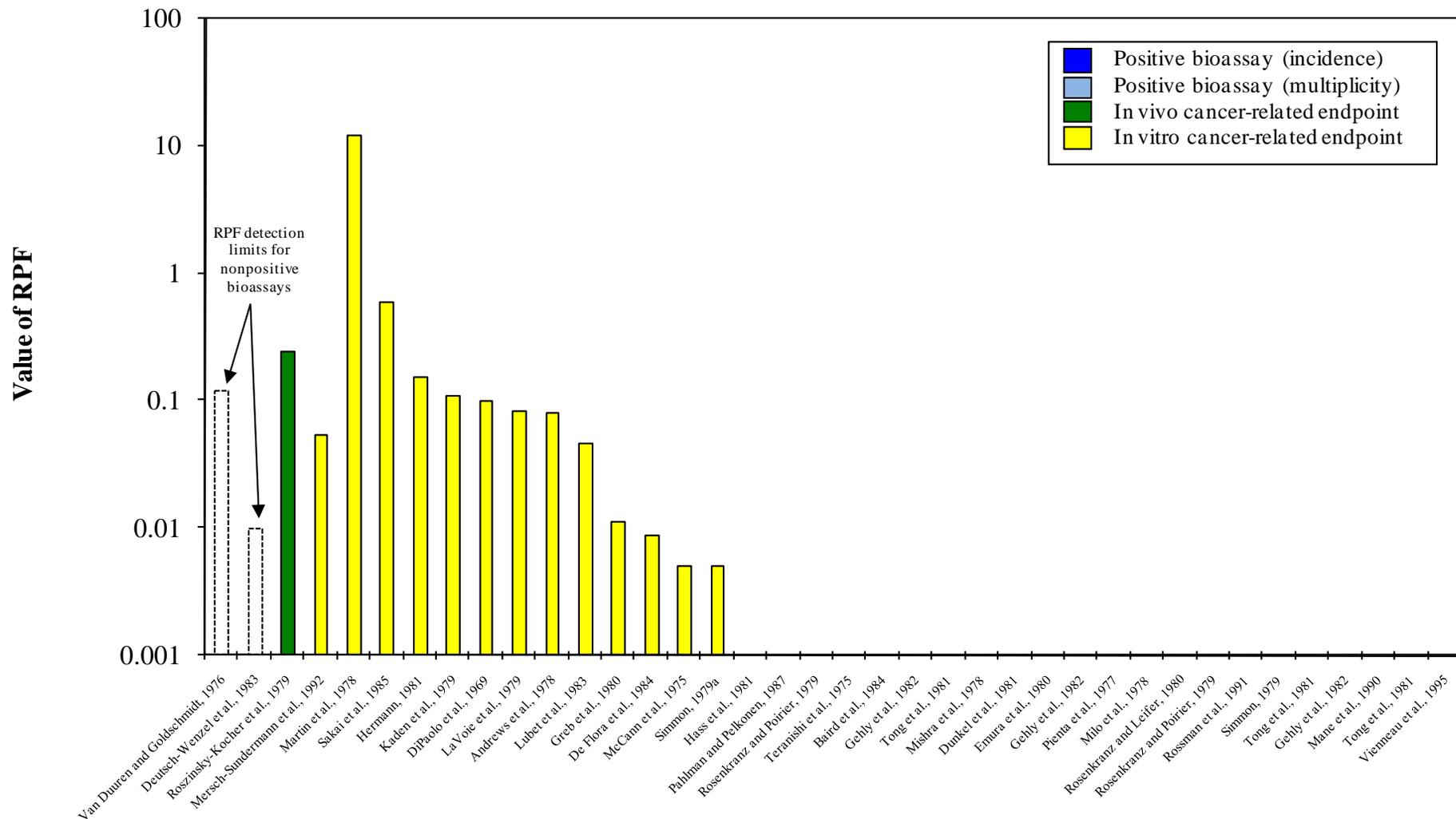
3

4 Benzo[e]pyrene (192-97-2) is an alternant PAH comprised of five fused aromatic rings.
5 Benzo[e]pyrene contains two bay regions but no fjord region in its structure.

6 Thirty-seven datasets for benzo[e]pyrene met selection criteria and included
7 benzo[a]pyrene: 2 tumor bioassays, 1 in vivo clastogenicity dataset, 12 bacterial mutagenicity
8 datasets, 4 mammalian mutagenicity datasets, 7 morphological/malignant cell transformation
9 datasets, and 11 in vitro DNA damage or clastogenicity datasets (Figure 6-11). No increase in
10 tumor incidence was observed when benzo[e]pyrene was tested alone as part of a dermal
11 cocarcinogenicity bioassay (Van Duuren and Goldschmidt, 1976). When tested in a lung
12 implantation bioassay in rats, benzo[e]pyrene exposure did not result in a significant increase in
13 tumor incidence (Deutsch-Wenzel et al., 1983). The RPF detection limits of these studies were
14 approximately 0.01 and 0.1. To confirm the nonpositive findings in the available tumor
15 bioassays that included benzo[a]pyrene, other bioassays and cancer-related endpoint data were
16 considered. In bioassays without benzo[a]pyrene, benzo[e]pyrene gave nonpositive results in a
17 dermal initiation bioassay (1 mg/mouse; Van Duuren et al., 1968) and a newborn mouse bioassay
18 (0.7 μmol ; Chang et al., 1981). A significant increase in tumor incidence was reported in a
19 single-concentration dermal initiation study in mice; 11/13 surviving mice (20 were treated) had
20 papillomas by week 35 after dermal treatment with 10 μmol benzo[e]pyrene in benzene
21 ($p < 0.0001$), followed by twice weekly treatment with TPA; no control mice had papillomas
22 (Scribner, 1973).

23 In vitro assays of mutagenicity (both bacterial and mammalian) and morphological/
24 malignant cell transformation give inconsistent results for benzo[e]pyrene; 11/23 studies were
25 positive and the rest were nonpositive. Positive studies include a mix of bacterial mutagenicity
26 and morphological/malignant cell transformation assays; four mammalian mutagenicity assays
27 were nonpositive. One study of in vivo clastogenicity and two studies of in vitro DNA damage
28 were positive, while nine studies of in vitro DNA damage or clastogenicity were nonpositive.

29 While the database for benzo[e]pyrene is quite large, the results are inconsistent; as a
30 result, no conclusion can be drawn as to carcinogenicity. This PAH was not selected for
31 inclusion in the RPF approach.



* Missing bar indicates nonpositive cancer-related endpoint study

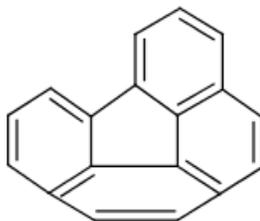
Reference

1
2

Figure 6-11. Benzo[e]pyrene (BeP) RPFs*.

1

Benzo[g,h,i]fluoranthene (BghiF)



2

3

4

Benzo[g,h,i]fluoranthene (CASRN 203-12-3) is a nonalternant PAH comprised of four aromatic rings and one five-membered ring. Benzo[g,h,i]fluoranthene does not contain a classic bay or fjord region in its structure.

5

6

7

There were six datasets for benzo[g,h,i]fluoranthene that met selection criteria and included benzo[a]pyrene (Figure 6-12). A dermal initiation bioassay in mice (Van Duuren et al., 1966) did not result in a statistically significant increase in tumor incidence; the RPF detection limit was 0.06. There were no other bioassays that met selection criteria. There were three positive bacterial mutagenicity studies (Chang et al., 2002; Lafleur et al., 1993; Carver et al., 1986), one positive study of in vitro DNA damage (Mersch-Sundermann et al., 1992), and a mammalian mutagenicity study with nonpositive results (Lafleur et al., 1993). The RPF values for the positive cancer-related endpoint datasets ranged from 0.6 to 1. Overall, the database for benzo[g,h,i]fluoroanthene is both limited and inconsistent. Because the database for benzo[g,h,i]fluoranthene does not provide adequate information with which to assess carcinogenicity, this PAH was not selected for inclusion in the RPF approach.

8

9

10

11

12

13

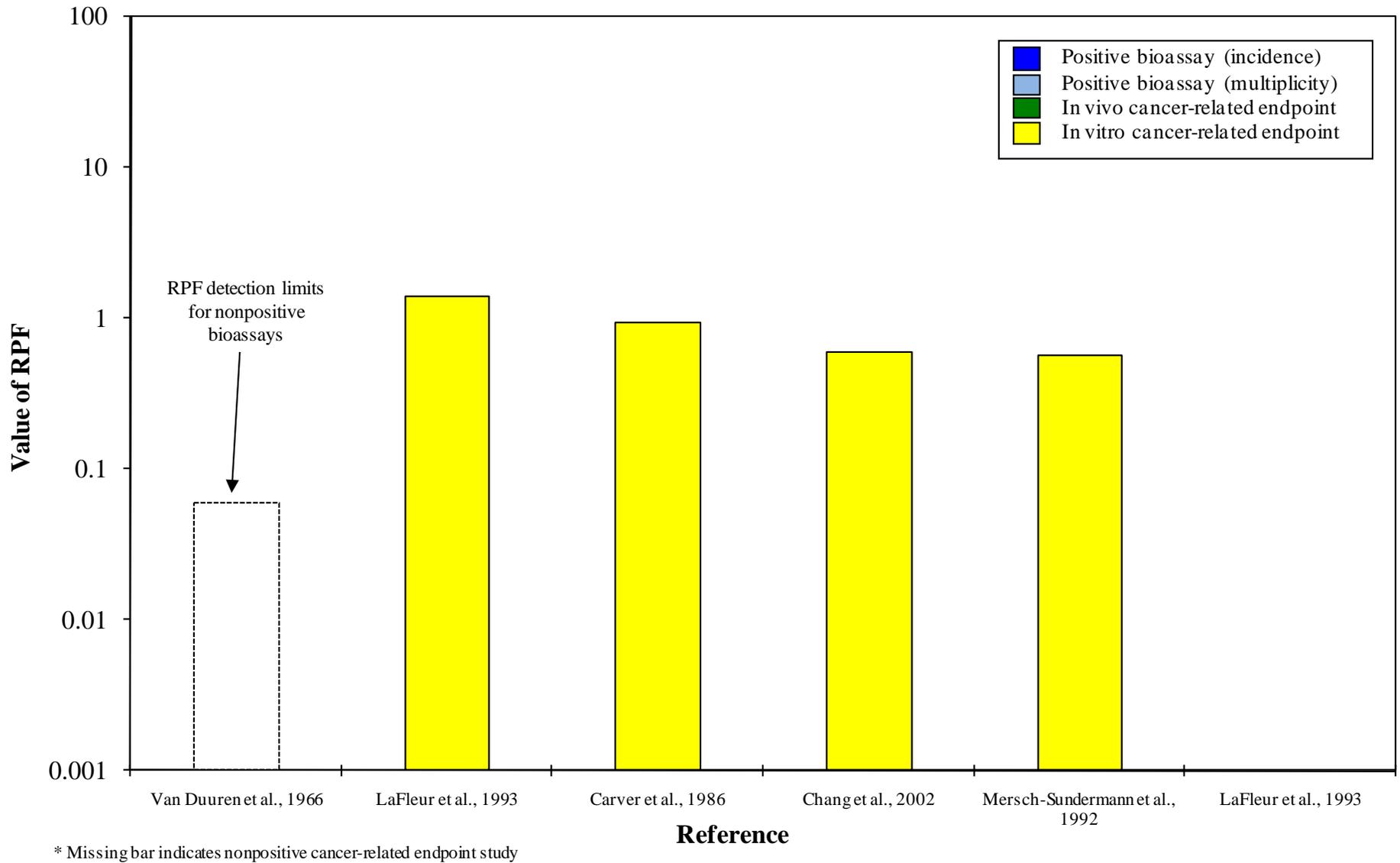
14

15

16

17

18

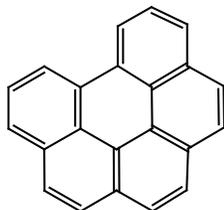


1
2

Figure 6-12. Benzo[g,h,i]fluoranthene (BghiF) RPFs*.

1

Benzo[g,h,i]perylene (BghiP)

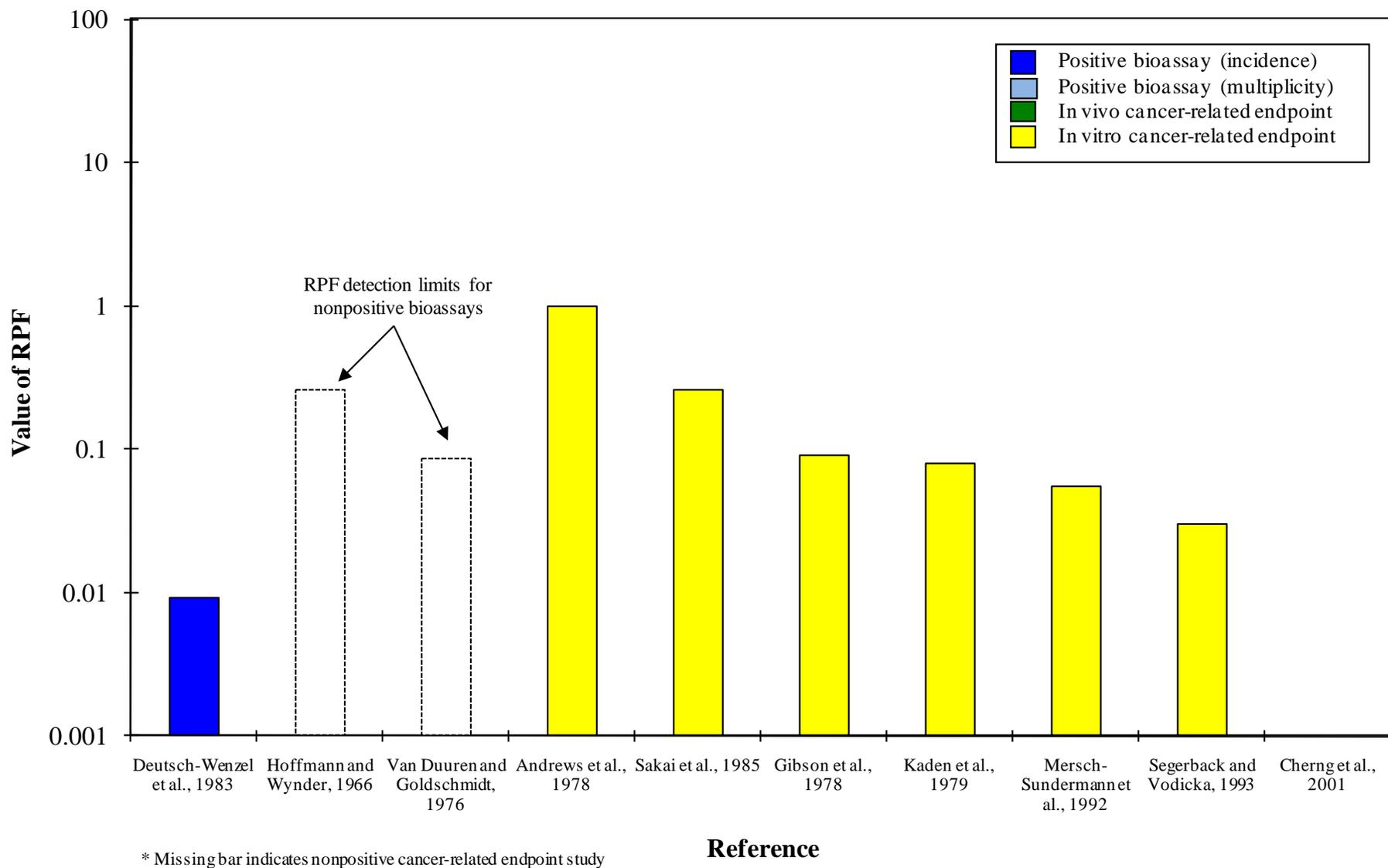


2

3

4 Benzo[g,h,i]perylene (CASRN 191-24-2) is an alternant PAH comprised of six fused
5 aromatic rings. Benzo[g,h,i]perylene contains a bay region but no fjord region in its structure.

6 There were 10 datasets for benzo[g,h,i]perylene that met selection criteria and included
7 benzo[a]pyrene (Figure 6-13). The database includes three in vivo tumor bioassays, four
8 bacterial mutagenicity datasets, an in vitro DNA damage dataset, and two in vitro DNA adduct
9 datasets. Of the three bioassays, positive findings were only reported in one: a rat lung
10 implantation bioassay (Deutsch-Wenzel et al., 1983) that resulted in an RPF estimate of 0.009.
11 In a dermal initiation bioassay (Hoffmann and Wynder, 1966) and a dermal cocarcinogenicity
12 bioassay (Van Duuren and Goldschmidt, 1976), there was no statistically significant increase in
13 tumor incidence, but these studies had relatively insensitive RPF detection limits (around 0.1)
14 compared with the positive study. There were four positive mutagenicity studies; all were
15 conducted in bacterial systems. Studies of in vitro DNA adducts and DNA damage were
16 positive. Because the inconsistent bioassay results can be attributed to different test systems
17 (different species and route), benzo[g,h,i]perylene was considered carcinogenic and was selected
18 for inclusion in the RPF approach.

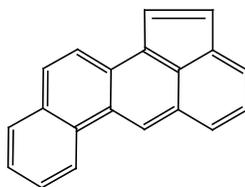


1
2

Figure 6-13. Benzo[g,h,i]perylene (BghiP) RPFs*.

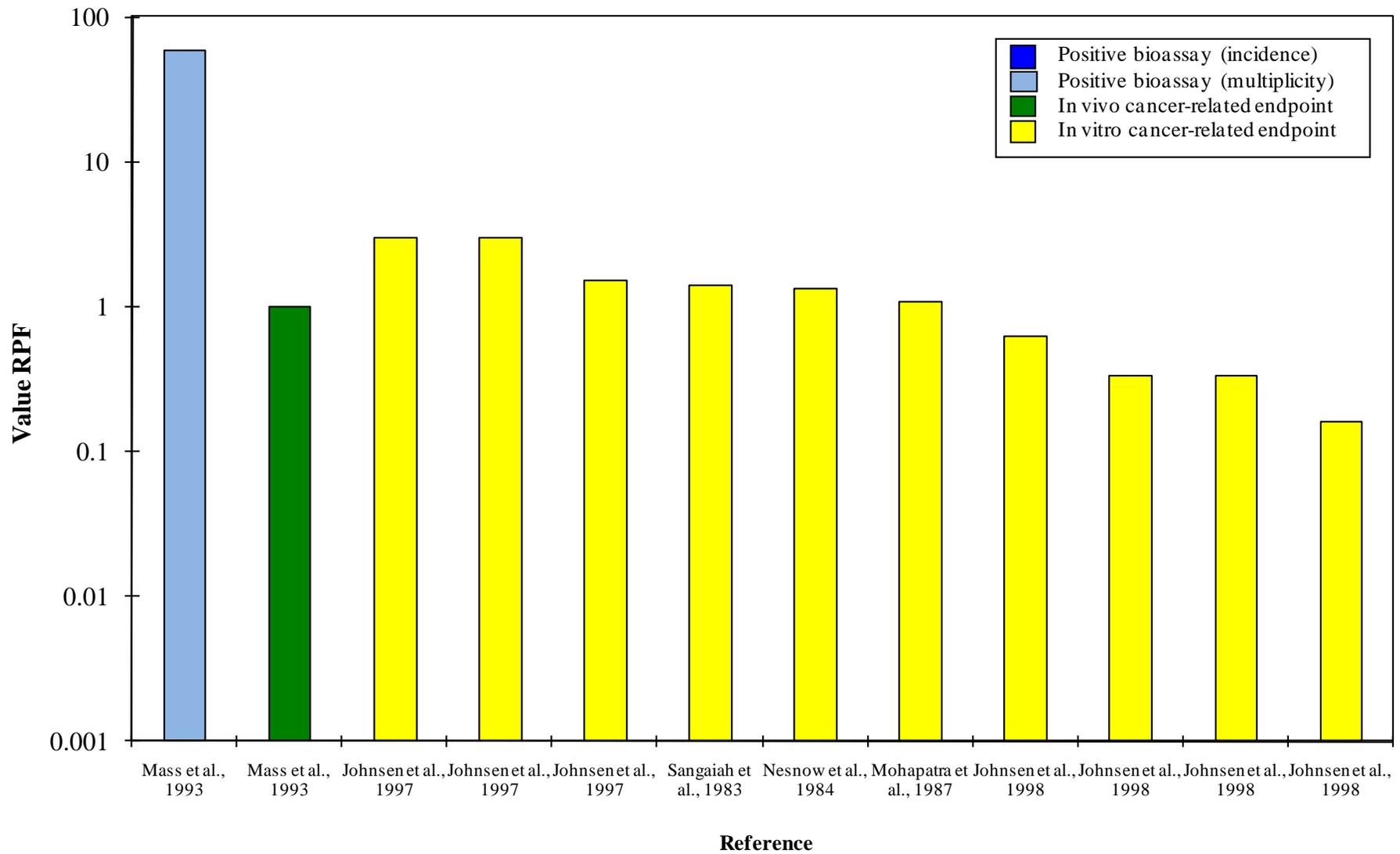
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25

Benz[j]aceanthrylene (BjAC)



Benz[j]aceanthrylene (CASRN 202-33-5) is a nonalternant PAH comprised of four aromatic rings and one five-membered ring. Benz[j]aceanthrylene contains a classic bay region but no fjord region in its structure.

There were 12 datasets for benz[j]aceanthrylene that met selection criteria and included benzo[a]pyrene (Figure 6-14); all of the studies gave positive results. The database includes one in vivo tumor bioassay dataset, one in vivo DNA adduct dataset, four mutagenicity or morphological/malignant cell transformation datasets, and six in vitro DNA damage or DNA adduct datasets. In a bioassay of benz[j]aceanthrylene that used intraperitoneal injection in an A/J mouse system (Mass et al., 1993), all mice treated with benz[j]aceanthrylene developed tumors (incidence of 100% at doses of 20–100 mg/kg; incidence for benzo[a]pyrene was 63–100% across the same dose range), precluding the derivation of an RPF using incidence data. However, tumor multiplicity (average number of tumors per animal) data were available for dose-response modeling and resulted in an RPF estimate of 60. Benz[j]aceanthrylene treatment resulted in a pronounced increase in the average number of tumors per animal (59.45 tumors per animal at 20 mg/kg), much higher than benzo[a]pyrene treatment (5.05 tumors per animal at 100 mg/kg), indicating that this compound is very potent in this test system. In a dermal initiation bioassay that did not include benzo[a]pyrene, benz[j]aceanthrylene induced papillomas in 90% of mice treated with an initiating dose of 40 μ g (compared with 5% incidence in controls). As the available bioassay that included benzo[a]pyrene was positive and suggested that this compound is very potent, benz[j]aceanthrylene was considered carcinogenic and was selected for inclusion in the RPF approach.

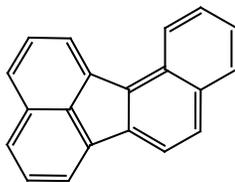


1
2

Figure 6-14. Benz[j]aceanthrylene (BjAC) RPFs.

1

Benzo[j]fluoranthene (BjF)



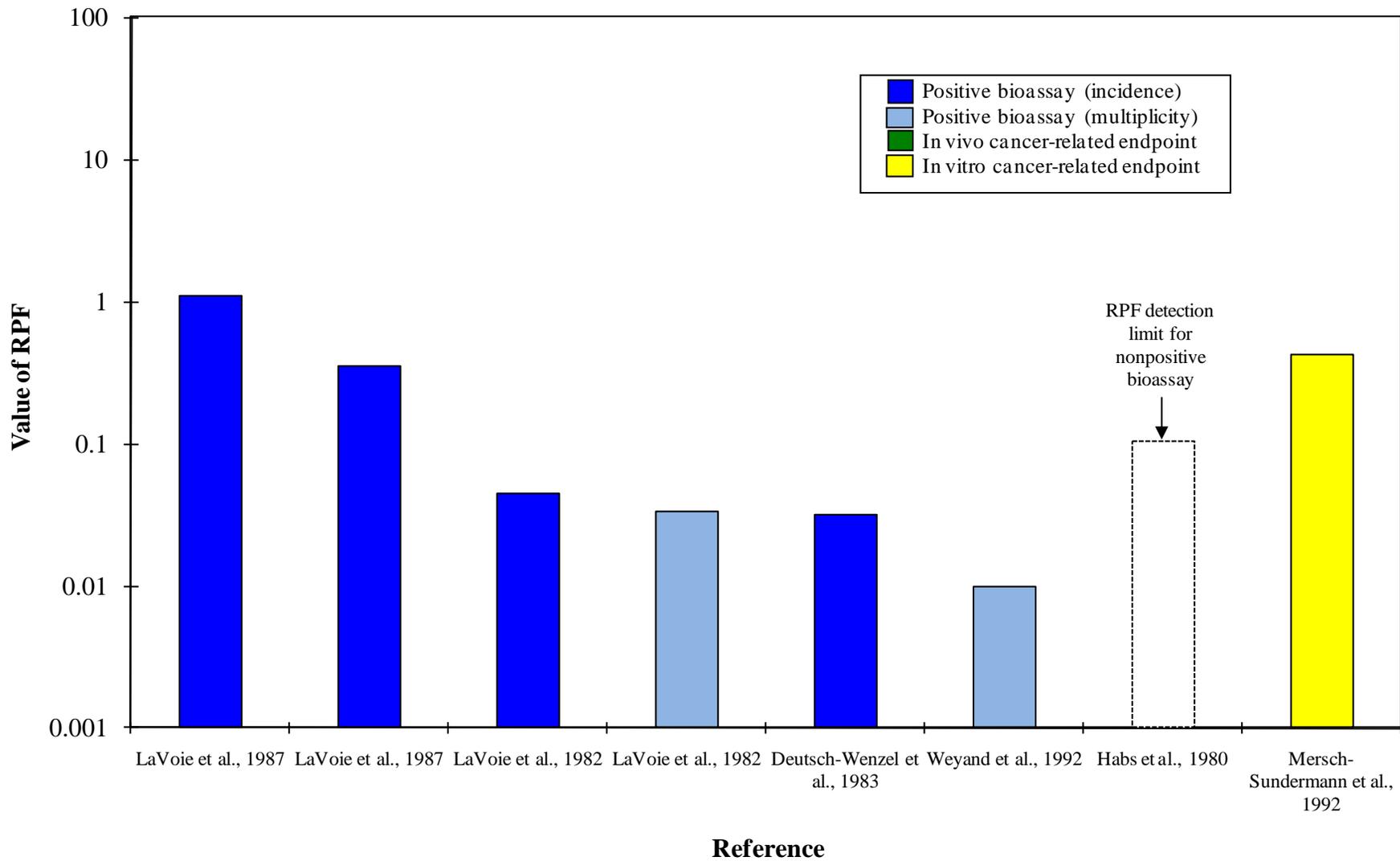
2

3

4 Benzo[j]fluoranthene (CASRN 205-82-3) is a nonalternant PAH comprised of four
5 aromatic rings and one five-membered ring. Benzo[j]fluoranthene does not contain a classic bay
6 or fjord region in its structure.

7 There were eight datasets for benzo[j]fluoranthene that met selection criteria and
8 included benzo[a]pyrene (Figure 6-15): seven in vivo tumor bioassay datasets and one in vitro
9 study of DNA damage. Of the seven bioassay datasets, significant increases in tumor incidence
10 or count were observed in all but one. Significant increases in tumor incidence were reported in
11 both male and female mice tested in a newborn mouse bioassay using intraperitoneal injection of
12 single doses (LaVoie et al., 1987), a mouse dermal initiation study (LaVoie et al., 1982), and a
13 rat lung implantation bioassay (Deutsch-Wenzel et al., 1983). Significant increases in tumor
14 multiplicity were reported in two mouse dermal initiation studies (Weyand et al., 1992; LaVoie
15 et al., 1982). The one nonpositive bioassay was a mouse dermal complete carcinogenicity
16 bioassay with an RPF detection limit of 0.1 (Habs et al., 1980). The in vitro study of DNA
17 damage gave positive results (Mersch-Sundermann et al., 1992). Because the inconsistent
18 bioassay results can be attributed to different test systems or study design, benzo[j]fluoroanthene
19 was considered carcinogenic and was selected for inclusion in the RPF approach.

20

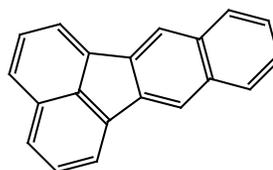


1
2

Figure 6-15. Benzo[j]fluoranthene (BjF) RPFs.

1

Benzo[k]fluoranthene (BkF)



2

3

4

Benzo[k]fluoranthene (CASRN 207-08-9) is a nonalternant PAH comprised of four aromatic rings and one five-membered ring. Benzo[j]fluoranthene does not contain a classic bay or fjord region in its structure.

6

7

8

9

10

11

12

13

14

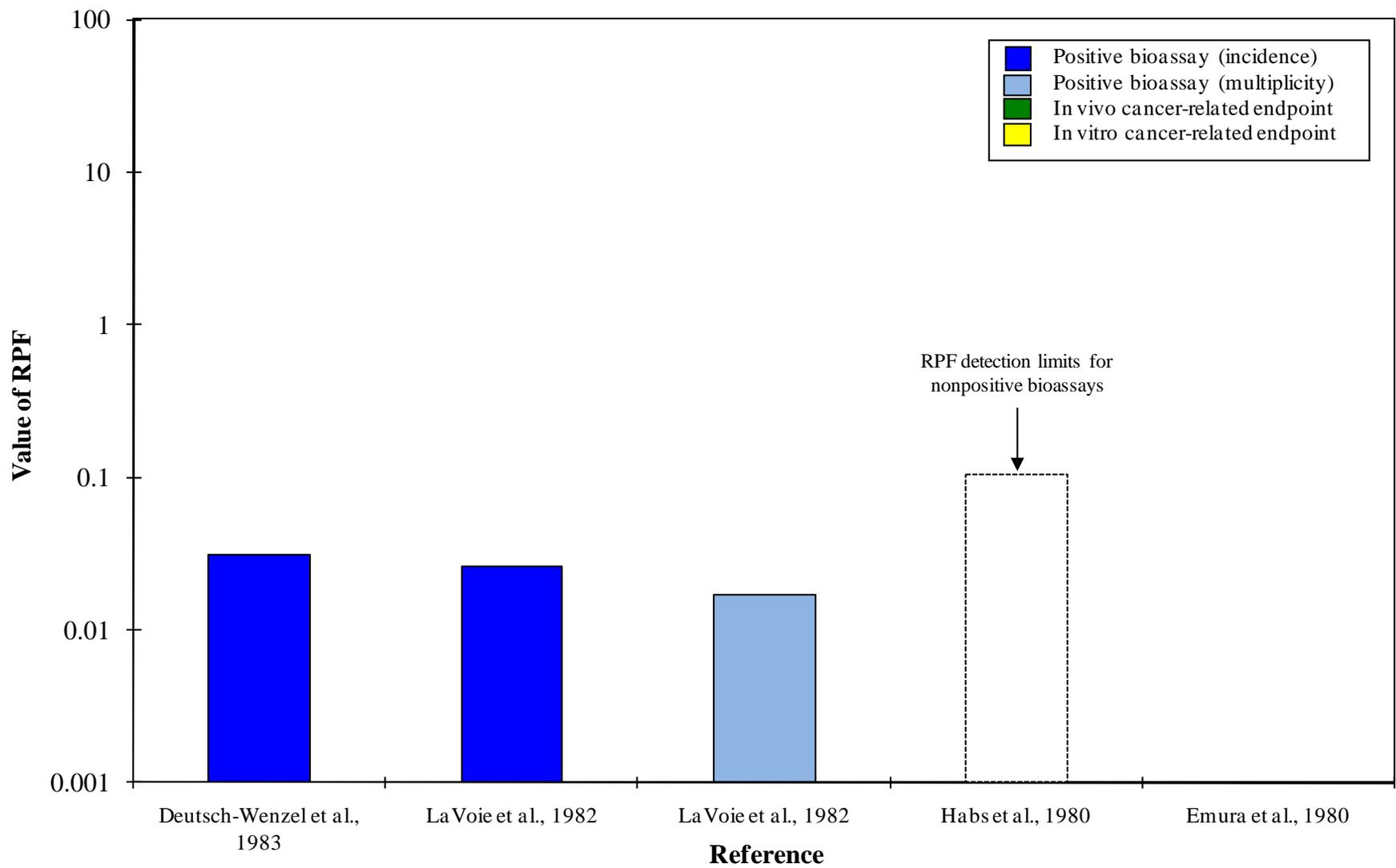
15

16

17

18

There were five datasets for benzo[k]fluoranthene that met selection criteria and included benzo[a]pyrene (Figure 6-16). The database includes four in vivo tumor bioassay datasets and one morphological/malignant cell transformation dataset. Statistically significant increases in tumor incidence and tumor count were reported in a mouse dermal initiation study (LaVoie et al., 1982) and increased tumor incidence was reported in a rat lung implantation bioassay (Deutsch-Wenzel et al., 1983). No significant increase in tumor incidence was observed in a dermal complete carcinogenicity study with an RPF detection limit of 0.1 (Habs et al., 1980). The morphological/malignant cell transformation study (Emura et al., 1980) was nonpositive. Because the inconsistent bioassay results can be attributed to different test systems or study design (dermal initiation versus dermal complete carcinogenicity), benzo[k]fluoranthene was considered carcinogenic and was selected for inclusion in the RPF approach.



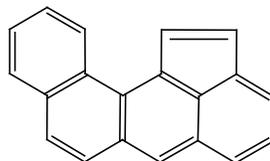
* Missing bar indicates nonpositive cancer-related endpoint study

1
2

Figure 6-16. Benzo[k]fluoranthene (BkF) RPFs*.

1

Benz[l]aceanthrylene (BLAC)

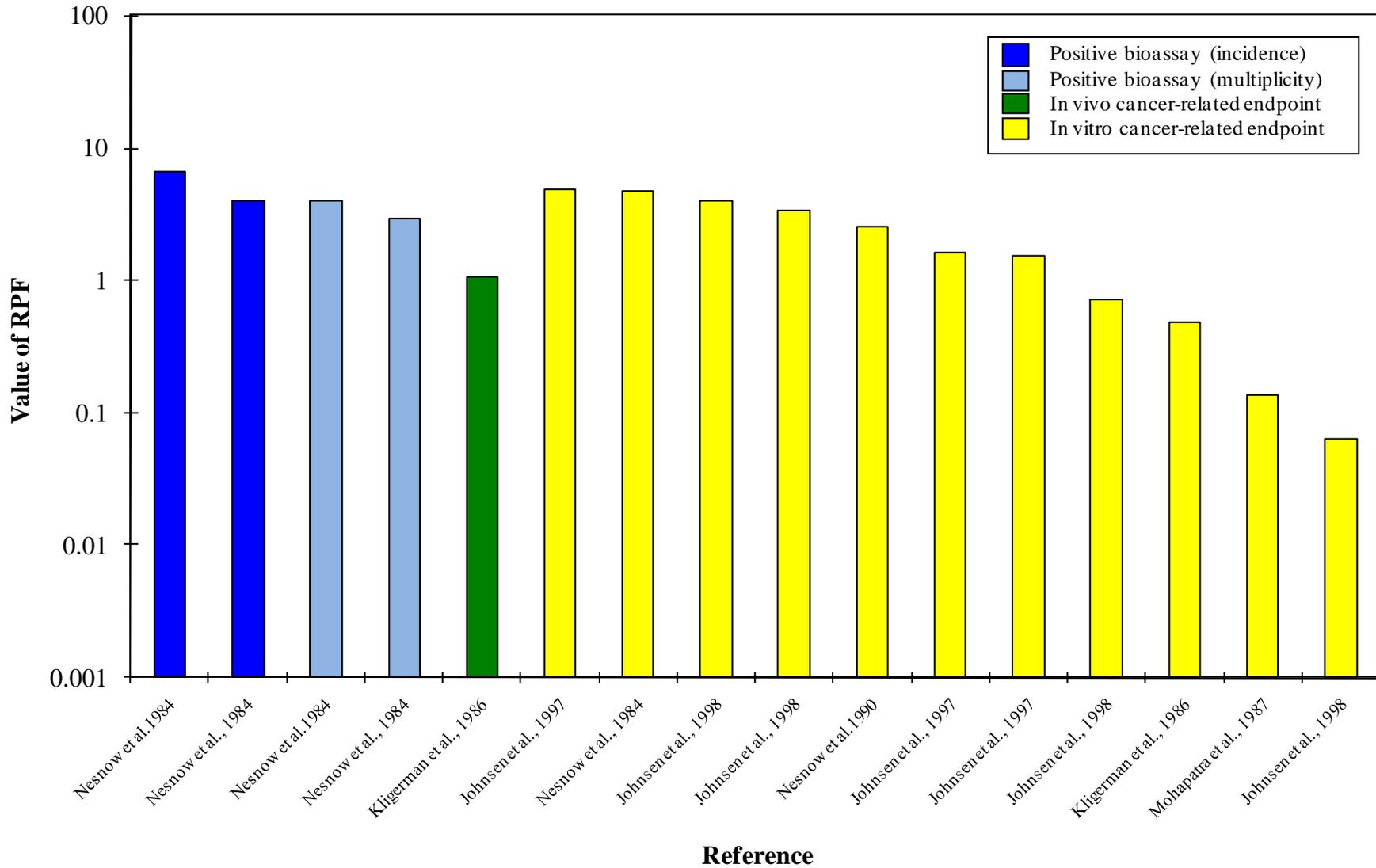


2

3

4 Benz[l]aceanthrylene (CASRN 211-91-6) is a nonalternant PAH comprised of four
5 aromatic rings and one five-membered ring. Benz[l]aceanthrylene does not contain a classic bay
6 or fjord region in its structure.

7 There were 16 datasets for benz[l]aceanthrylene that met selection criteria and included
8 benzo[a]pyrene (Figure 6-17); all of the studies gave positive results. The database includes four
9 in vivo tumor bioassay datasets, five mutagenicity or morphological/malignant cell
10 transformation datasets, one in vivo clastogenicity dataset, and six in vitro DNA adduct or DNA
11 damage datasets. Significant increases in tumor count and multiplicity were reported in both
12 male and female mice in a dermal initiation bioassay (Nesnow et al., 1984). All of the cancer-
13 related endpoint studies were positive as well. Relative potency estimates for most of the
14 available datasets were ≥ 1.0 , suggesting equivalent or greater potency than benzo[a]pyrene. As
15 the available bioassays that included benzo[a]pyrene were positive, benz[l]aceanthrylene was
16 considered carcinogenic and was selected for inclusion in the RPF approach.

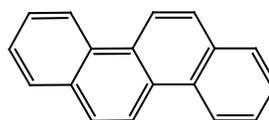


1
2

Figure 6-17. Benz[a]aceanthrylene (BIAC) RPFs.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33

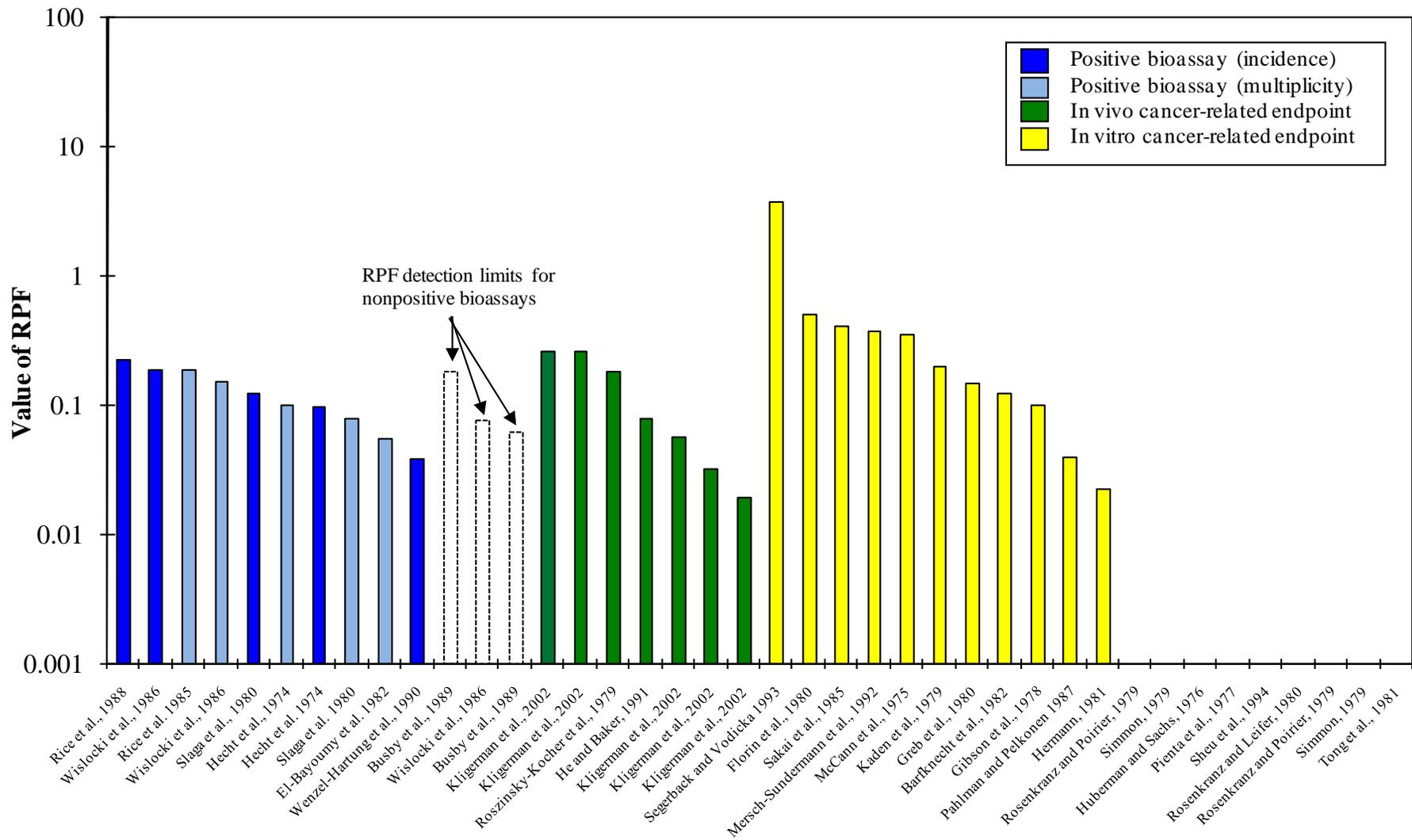
Chrysene (CH)



Chrysene (CASRN 218-01-9) is an alternant PAH comprised of four fused aromatic rings. Chrysene contains two bay regions but no fjord region in its structure.

There were 40 datasets for chrysene that met selection criteria and included benzo[a]pyrene (Figure 6-18). Included in the database are 13 in vivo tumor bioassay datasets, 4 in vivo DNA adduct datasets, 3 in vivo clastogenicity datasets, 11 mutagenicity datasets, 3 morphological/malignant cell transformation datasets, and 6 in vitro studies of DNA damage, adducts, or clastogenicity. Among the bioassays that included benzo[a]pyrene, 11 reported significant increases in tumor incidence or tumor multiplicity, and 3 did not. Significant increases in tumor incidence and/or multiplicity were reported in three dermal initiation studies in mice (Rice et al., 1988; Slaga et al., 1980; Hecht et al., 1974), a newborn mouse study in males (Wislocki et al., 1986), and a rat lung implantation bioassay (Wenzel-Hartung et al., 1990). Female mice tested in the newborn mouse assay published by Wislocki et al. (1986) did not have a significant increase in tumor incidence, resulting in one of the three nonpositive studies. The other two nonpositive findings were in males and females tested in another newborn mouse bioassay (Busby et al., 1989). The bioassays with nonpositive findings had RPF detection limits between 0.06 and 0.2. Conflicting results in male mice were reported in the two newborn mouse bioassays (Busby et al., 1989; Wislocki et al., 1986). The major difference between the two studies is the duration of follow-up; Busby et al. (1989) sacrificed the mice at 26 weeks, while Wislocki et al. (1986) followed the mice for a full year. LaVoie et al. (1994) observed that liver tumor induction in the newborn mouse bioassay is not fully realized until the mice have reached 1 year of age, and the positive findings by Wislocki et al. (1986) indeed reflect liver tumors in the male mice. Chrysene was shown to form DNA adducts when administered in vivo in both rats and mice via injection and gavage (Kligerman et al., 2002). Bacterial and mammalian mutagenicity and morphological/malignant cell transformation assays of chrysene were all positive, as were studies of clastogenicity tested in vivo. In contrast, results from in vitro studies of DNA adducts, DNA damage, and clastogenicity were not consistent.

Because the inconsistent bioassay results can be attributed to different study designs (gender, follow-up time), chrysene was considered carcinogenic and was selected for inclusion in the RPF approach.



* Missing bar indicates nonpositive cancer-related endpoint study

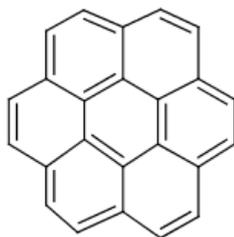
Reference

1
2

Figure 6-18. Chrysene (CH) RPFs*.

1

Coronene (CO)



2

3

4

Coronene (CASRN 191-07-1) is an alternant PAH comprised of seven fused aromatic rings. Coronene contains no bay or fjord regions in its structure.

6

7

8

9

10

11

12

13

14

15

16

17

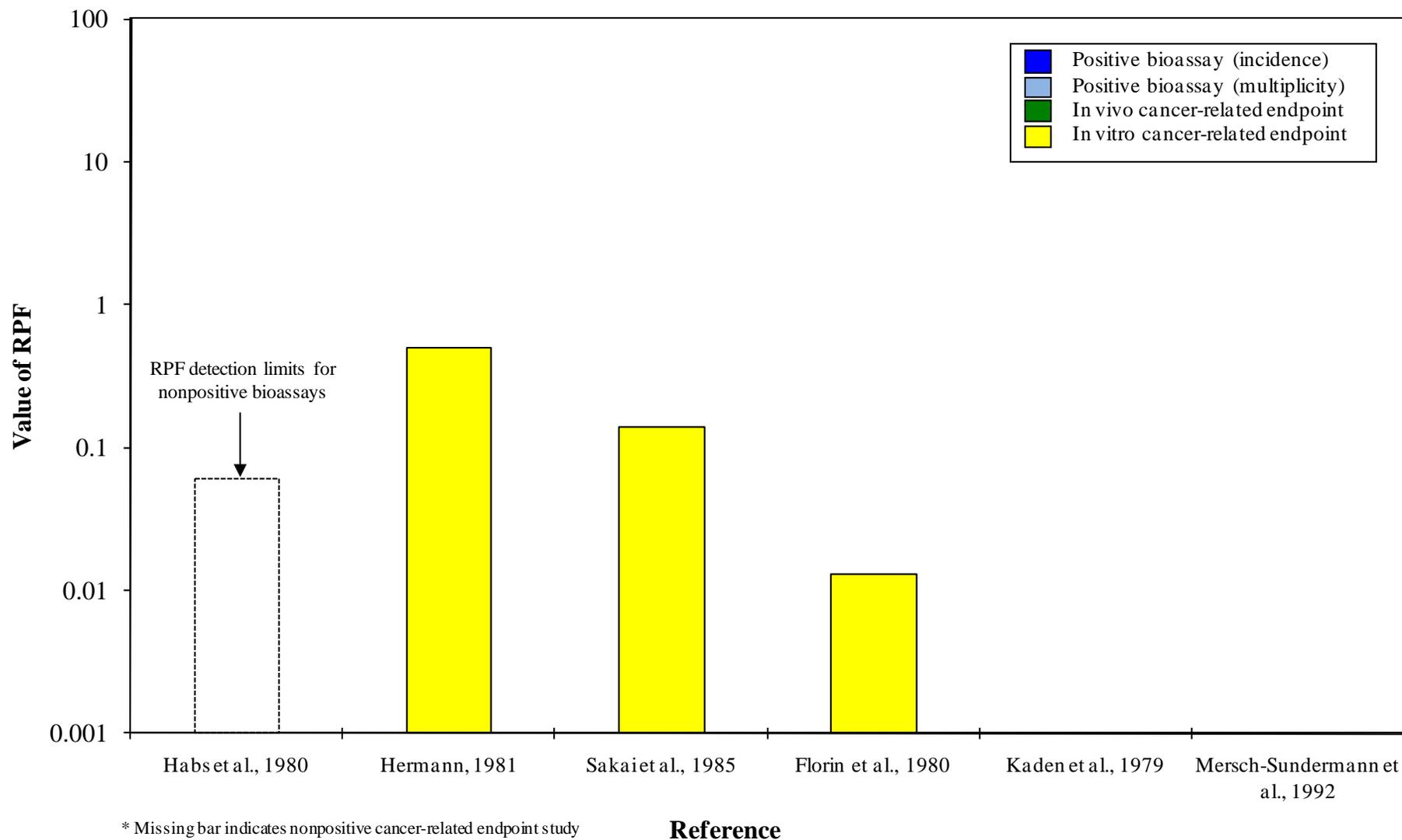
18

19

20

There were six datasets for coronene that met selection criteria and included benzo[a]pyrene (Figure 6-19). A dermal complete carcinogenicity bioassay in mice did not result in a statistically significant increase in tumor incidence (Habs et al., 1980); the RPF detection limit was 0.06. To confirm the nonpositive findings in the one tumor bioassay that included benzo[a]pyrene, other bioassays and cancer-related endpoint data were considered. There was one bioassay of coronene that did not include benzo[a]pyrene. Van Duuren et al. (1968) conducted a dermal initiation bioassay of coronene using groups of 20 mice (0.5 mg coronene in 0.5 mL benzene, followed by croton resin treatment until death). Although the authors characterized coronene as a weak tumor initiator, the incidence of tumors was not significantly increased over concurrent controls. The limited cancer-related endpoint data were mixed, with three positive bacterial mutagenicity studies (with RPFs ranging from 0.01 to 0.5), one nonpositive bacterial mutagenicity study, and a nonpositive in vitro DNA damage study.

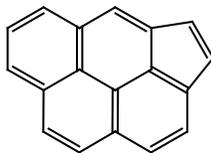
Overall, the database for coronene is both limited and inconsistent. Because the database for coronene does not provide adequate information with which to assess carcinogenicity, this PAH was not selected for inclusion in the RPF approach.



1
2

Figure 6-19. Coronene (CO) RPFs*.

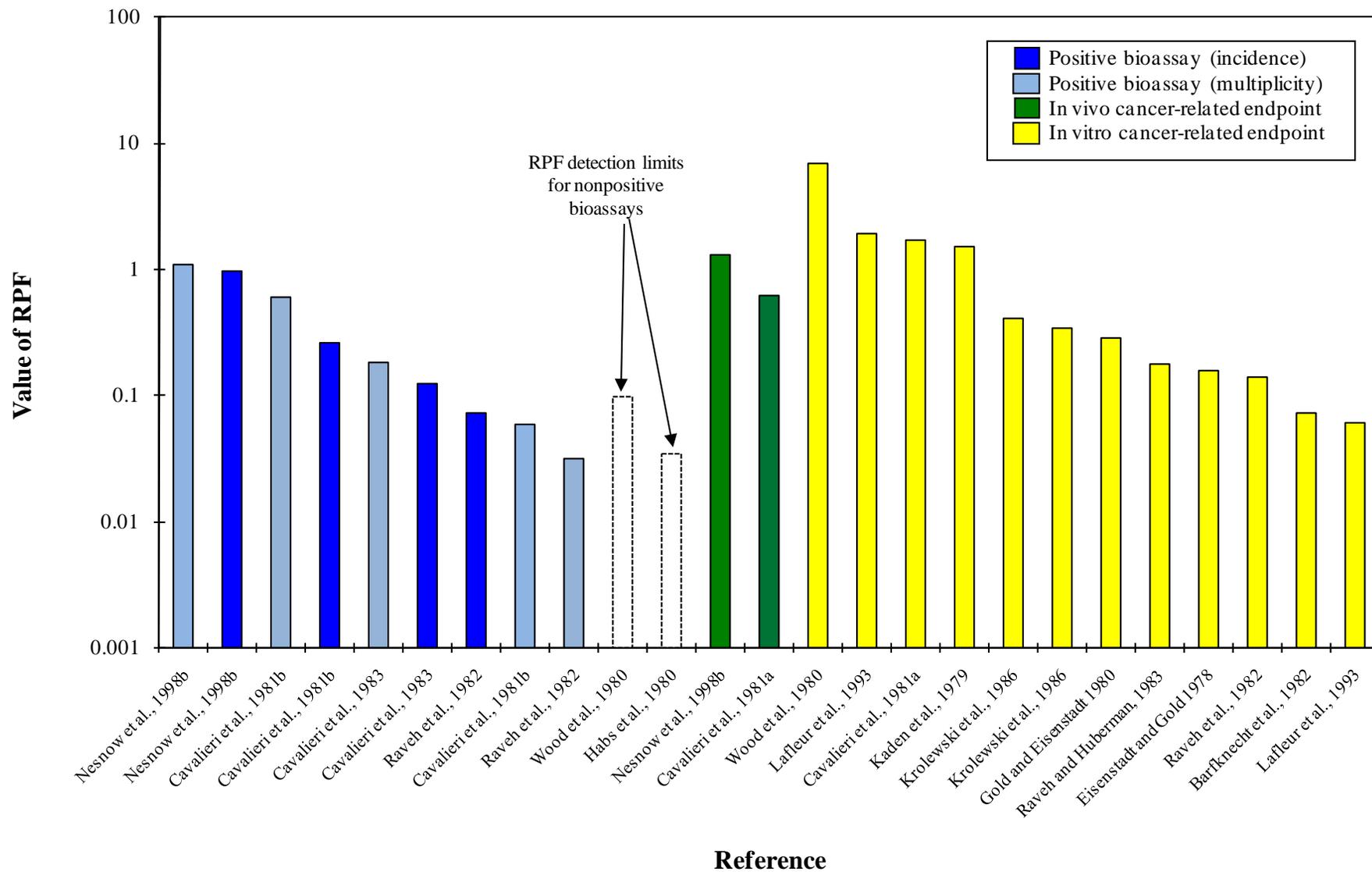
1 *Cyclopenta[c,d]pyrene (CPcdP)*



4 Cyclopenta[c,d]pyrene (CASRN 27208-37-3) is a nonalternant PAH comprised of four
5 aromatic rings and one five-membered ring. Cyclopenta[c,d]pyrene does not contain a classic
6 bay or fjord region in its structure.

7 There were 25 datasets for cyclopenta[c,d]pyrene that met selection criteria and included
8 benzo[a]pyrene (Figure 6-20). The database includes 11 in vivo tumor bioassay datasets, 2 in
9 vivo DNA adduct datasets, 11 studies of mutagenicity or morphological/malignant cell
10 transformation, and a single study of in vitro clastogenicity. Nine of the 11 tumor bioassay
11 datasets and all of the cancer-related endpoint studies gave positive results. Statistically
12 significant increases in tumor incidence and/or multiplicity were reported in two dermal
13 complete carcinogenicity bioassay (Cavalieri et al., 1983, 1981b), two dermal initiation
14 bioassays (Raveh et al., 1982; Cavalieri et al., 1981b), and an intraperitoneal study using adult
15 A/J mice (Nesnow et al., 1998b). Bioassays in which no significant increase in tumorigenicity
16 was observed included a dermal initiation (Wood et al., 1980) and complete carcinogenicity
17 study (Habs et al., 1980); these studies had RPF detection limits of 0.1 and 0.03, respectively.
18 After obtaining nonpositive results for low initiating doses of cyclopenta[c,d]pyrene, Wood et al.
19 (1980) repeated their experiment with higher doses and observed statistically significant
20 increases in tumor incidence. In the latter experiment, benzo[a]pyrene was not included, so an
21 RPF could not be calculated from these data. The study design of the nonpositive complete
22 carcinogenicity bioassay was quite similar to that of the two positive studies of this type, with the
23 exception of the mouse strain used; Habs et al. (1980) used NMRI mice, while Cavalieri et al.
24 (1983, 1981b) used Swiss mice. Although the differing results in dermal complete
25 carcinogenicity studies may be explained by slight differences in strain susceptibility, these two
26 strains are of common origin, which argues against this explanation.

27 The available cancer-related endpoint data indicate that cyclopenta[c,d]pyrene is
28 mutagenic and capable of morphological/malignant cell transformation in vitro; a single study of
29 in vitro clastogenicity was also positive. Overall, the data supporting a finding of
30 carcinogenicity for cyclopenta[c,d]pyrene are very consistent, and this compound was selected
31 for inclusion in the RPF approach.

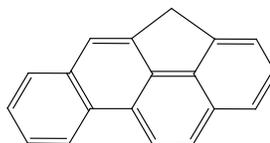


1
2

Figure 6-20. Cyclopenta[c,d]pyrene (CPcdP) RPFs.

1

4H-Cyclopenta[d,e,f]chrysene (CPdefC)



2

3

4 4H-Cyclopenta[d,e,f]chrysene (CASRN 202-98-2) is a nonalternant PAH comprised of
5 four aromatic rings and one five-membered ring. 4H-Cyclopenta[d,e,f]chrysene contains a
6 classic bay region but no fjord region in its structure.

7 There were two datasets for 4H-cyclopenta[d,e,f]chrysene that met selection criteria and

8 included benzo[a]pyrene (Figure 6-21); both were multidose dermal initiation datasets (Rice et

9 al., 1988, 1985). Rice et al. (1988) reported a statistically significant increase in tumor incidence

10 in a multidose dermal initiation study. In the second study, the incidence of tumors after

11 treatment with cyclopenta[d,e,f]chrysene exceeded 90%, precluding RPF derivation from

12 incidence data, but tumor multiplicity data were available for RPF calculation (Rice et al., 1985).

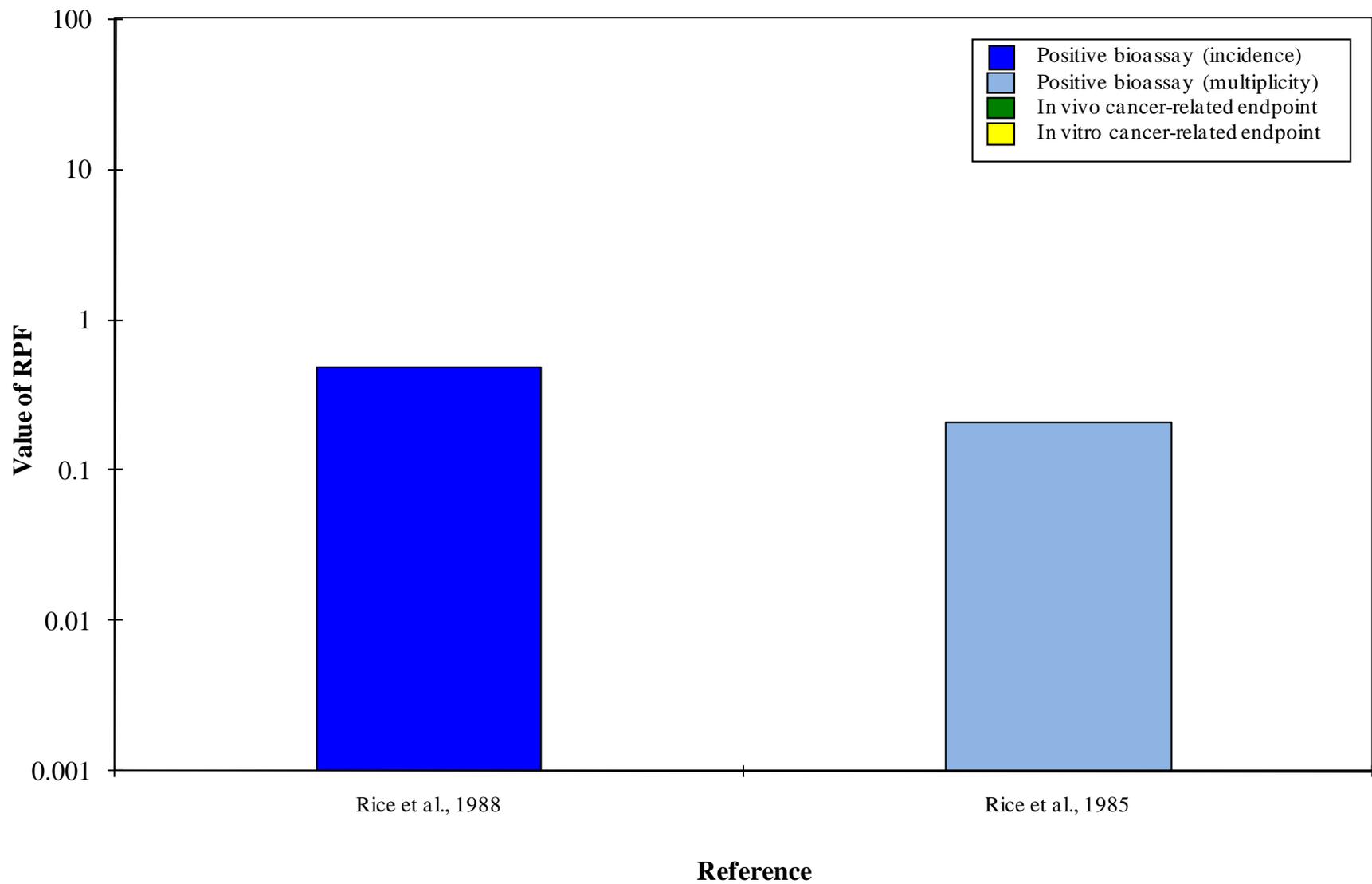
13 Cyclopenta[d,e,f]chrysene has not been tested in a bioassay without benzo[a]pyrene; however,

14 sterically hindered diol epoxides of this compound have given positive results in a newborn

15 mouse assay (Amin et al., 1995). Because the bioassay of cyclopenta[d,e,f]chrysene was

16 positive, this PAH was considered carcinogenic and was selected for inclusion in the RPF

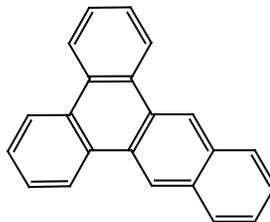
17 approach.



1
2

Figure 6-21. Cyclopenta[d,e,f]chrysene (CPdefC) RPFs.

1 *Dibenz[a,c]anthracene (DBaCA)*

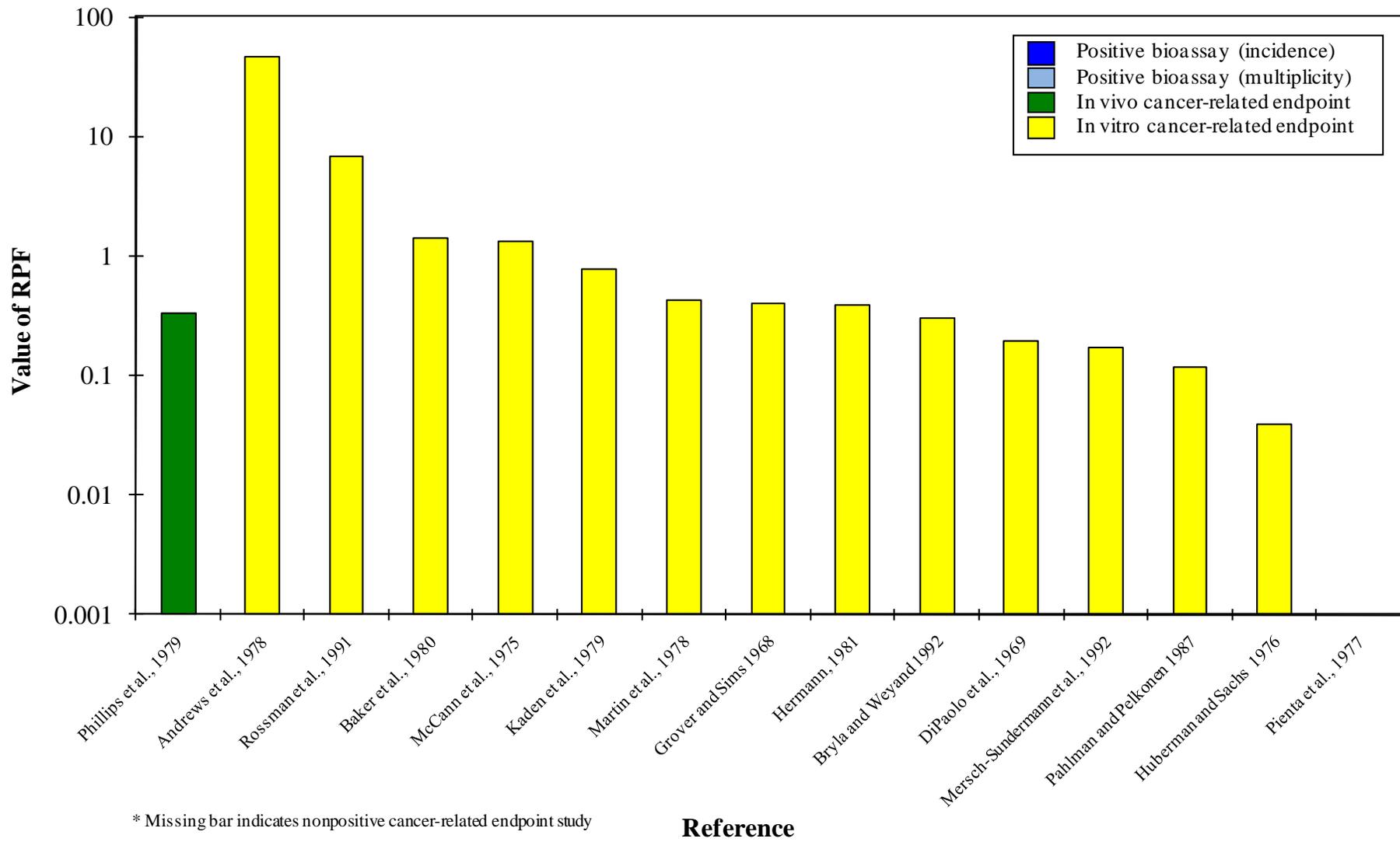


2
3
4 Dibenz[a,c]anthracene (CASRN 215-58-7) is an alternant PAH comprised of five fused
5 aromatic rings. Dibenz[a,c]anthracene contains three bay regions but no fjord region in its
6 structure.

7 There were 15 datasets for dibenz[a,c]anthracene that met selection criteria and included
8 benzo[a]pyrene (Figure 6-22). The database includes a single in vivo study of DNA adducts,
9 nine mutagenicity or morphological/malignant cell transformation studies, and five studies of in
10 vitro DNA damage or adducts. One morphological/malignant cell transformation assay gave
11 nonpositive results, while the remaining studies were positive. In the absence of positive
12 bioassays with benzo[a]pyrene, other bioassays and cancer-related data were considered to
13 evaluate the carcinogenicity of dibenz[a,c]anthracene.

14 Conflicting results were reported in three dermal initiation bioassays of
15 dibenz[a,c]anthracene in which benzo[a]pyrene was not included. Van Duuren et al. (1970)
16 observed a tumor incidence of 95% (19/20, compared to 1/20 controls) when mice were treated
17 with an initiating dose of 1 mg dibenz[a,c]anthracene in benzene followed by thrice weekly
18 treatment with phorbol myristate acetate. In contrast, there was no significant increase in tumor
19 formation when the same initiating dose was followed by thrice weekly application of croton
20 resin (Van Duuren et al., 1968); however, the latency to first tumor was substantially reduced
21 (65 versus 150 days in controls). Latency was also substantially reduced in the study by Van
22 Duuren et al. (1970), in which the first tumor appeared after 74 days, compared with 338 days in
23 controls.

24 Cancer-related endpoint data for dibenz[a,c]anthracene are predominantly positive
25 (8/9 mutagenicity or morphological/malignant cell transformation studies and 5/5 studies of in
26 vitro DNA adducts or DNA damage). Although the conflicting bioassay data are not easily
27 explained, the high incidence of tumors (19/20) in the study by Van Duuren et al. (1970) and the
28 reduced latency to tumor formation in both studies, coupled with predominantly positive cancer-
29 related endpoint data, suggest that dibenz[a,c]anthracene is carcinogenic. Contributing to this
30 conclusion is the observation that dibenz[a,c]anthracene is an alternant PAH with known
31 structural alerts for carcinogenicity (more than three rings, and three bay regions). Thus,
32 dibenz[a,c]anthracene was selected for inclusion in the RPF approach.

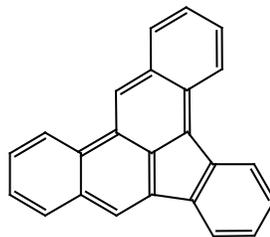


1
2

Figure 6-22. Dibenz[a,c]anthracene (DBaC) RPFs*.

1

Dibenzo[a,e]fluoranthene (DBaeF)



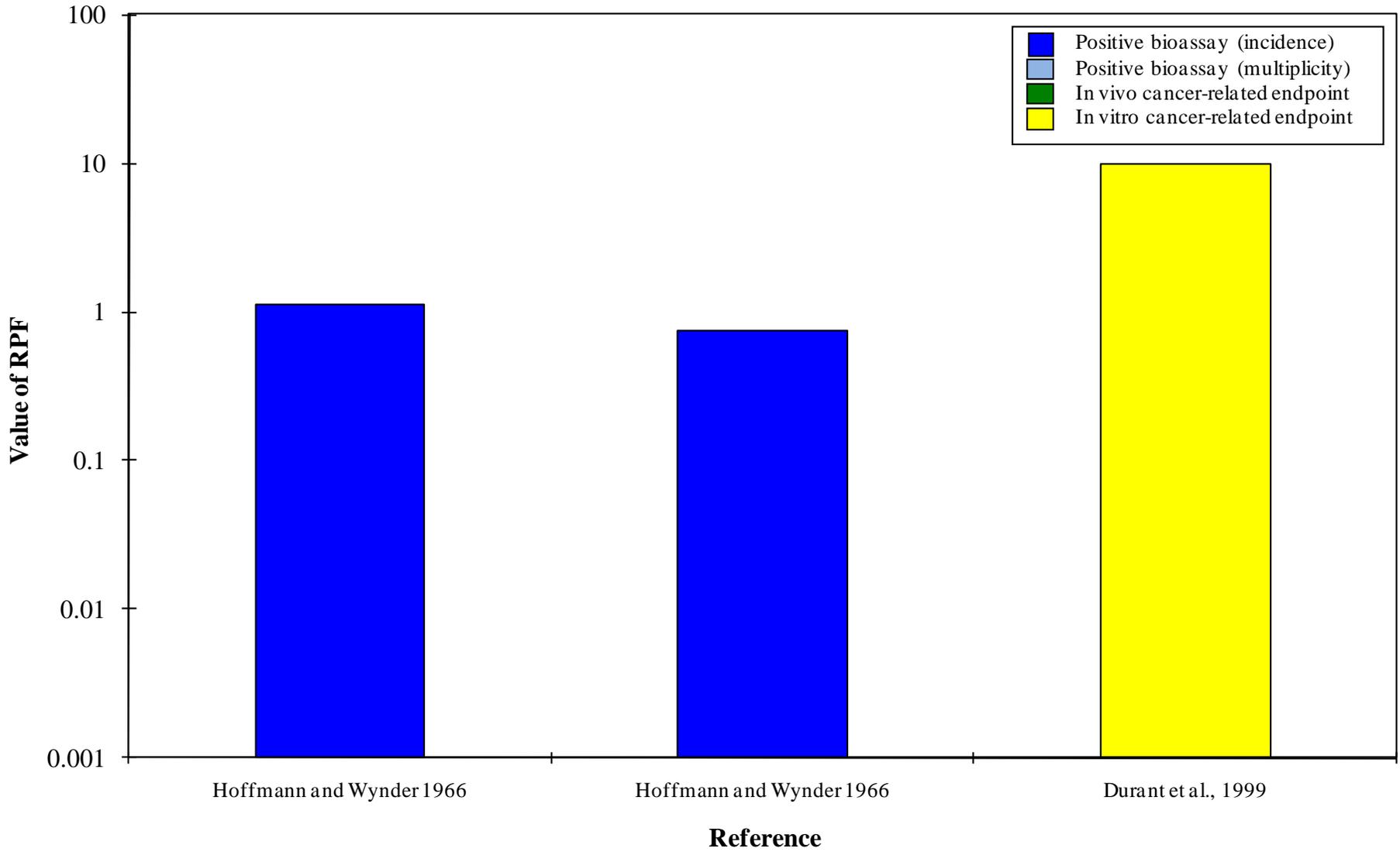
2

3

4 Dibenzo[a,e]fluoranthene (CASRN 5385-75-1) is a nonalternant PAH comprised of five
5 aromatic rings and one five-membered ring. Dibenzo[a,e]fluoranthene contains a classic bay
6 region but no fjord region in its structure.

7 There were three datasets for dibenzo[a,e]fluoranthene that met selection criteria and
8 included benzo[a]pyrene (Figure 6-23); all gave positive results. The database includes two in
9 vivo tumor bioassays and one mammalian mutagenicity study. Statistically significant increases
10 in tumor incidence were reported in dermal initiation and complete carcinogenicity bioassays in
11 mice (both reported by Hoffmann and Wynder, 1966). As the available bioassays for
12 dibenzo[a,e]fluoranthene were positive, this compound was considered carcinogenic and was
13 selected for inclusion in the RPF approach.

14

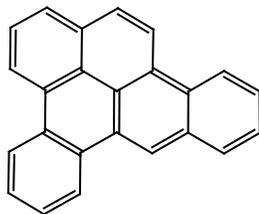


1
2

Figure 6-23. Dibenzo[a,e]fluoranthene (DBaef) RPFs.

1

Dibenzo[a,e]pyrene (DBaP)



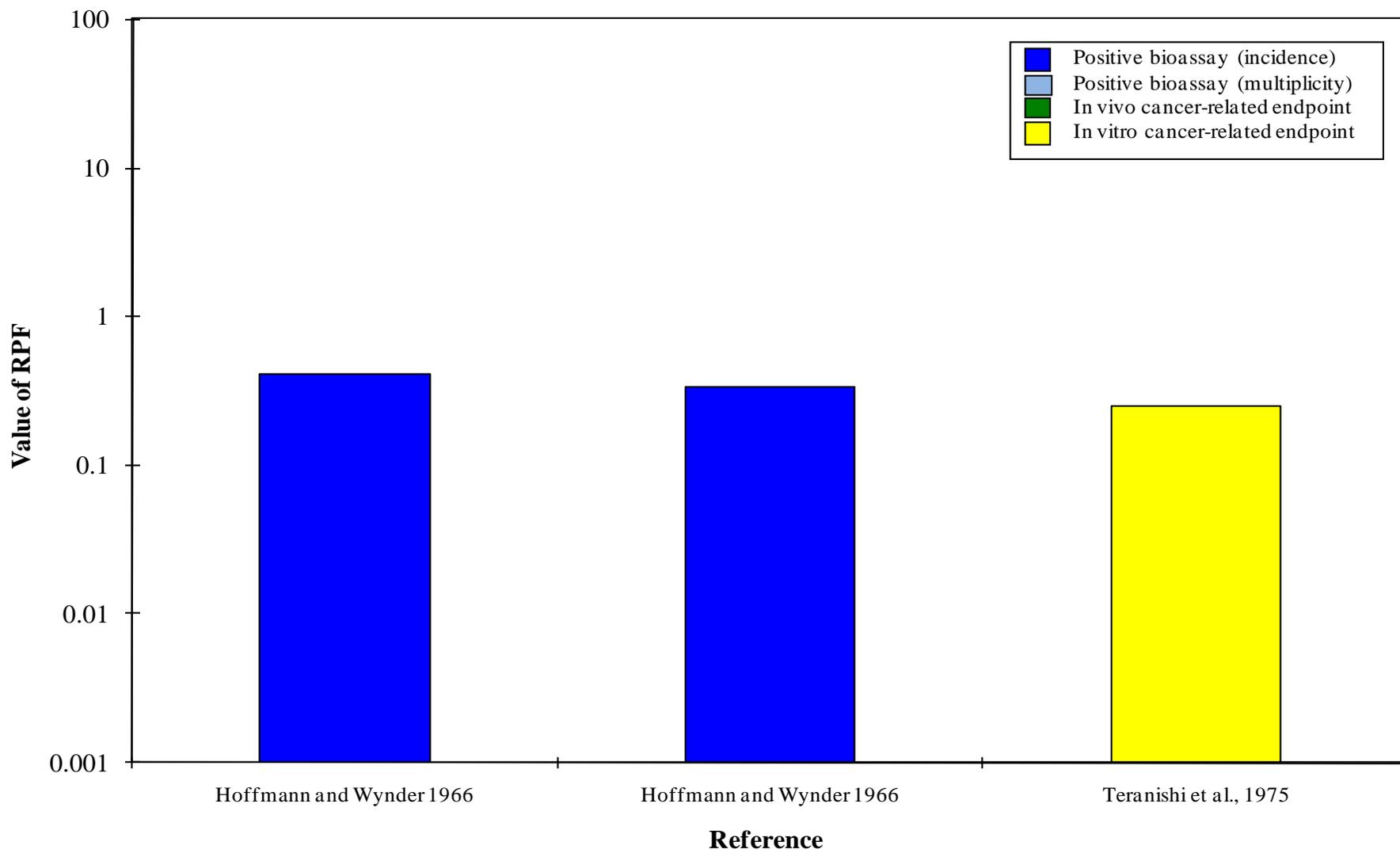
2

3

4 Dibenzo[a,e]pyrene (CASRN 192-65-4) is an alternant PAH comprised of six fused
5 aromatic rings. Dibenzo[a,e]pyrene contains three bay regions but no fjord region in its
6 structure.

7 There were three datasets for dibenzo[a,e]pyrene that met selection criteria and included
8 benzo[a]pyrene (Figure 6-24). The database includes two in vivo tumor bioassay datasets and
9 one in vitro bacterial mutagenicity dataset, all of which gave positive results. Statistically
10 significant increases in tumor incidence were reported in dermal initiation and complete
11 carcinogenicity bioassays in mice (Hoffmann and Wynder, 1966). The complete carcinogenicity
12 bioassay was confounded by significant toxicity-related mortality unrelated to tumors (Hoffmann
13 and Wynder, 1966). The one bacterial mutagenicity study reported positive results. Because the
14 available bioassays with benzo[a]pyrene were both positive, dibenzo[a,e]pyrene was considered
15 carcinogenic and was selected for inclusion in the RPF approach.

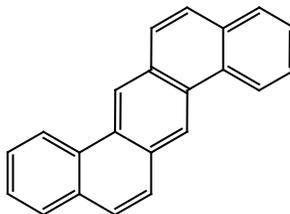
16



1
2

Figure 6-24. Dibenzo[a,e]pyrene (DBaEP) RPFs.

1

Dibenz[a,h]anthracene (DBahA)

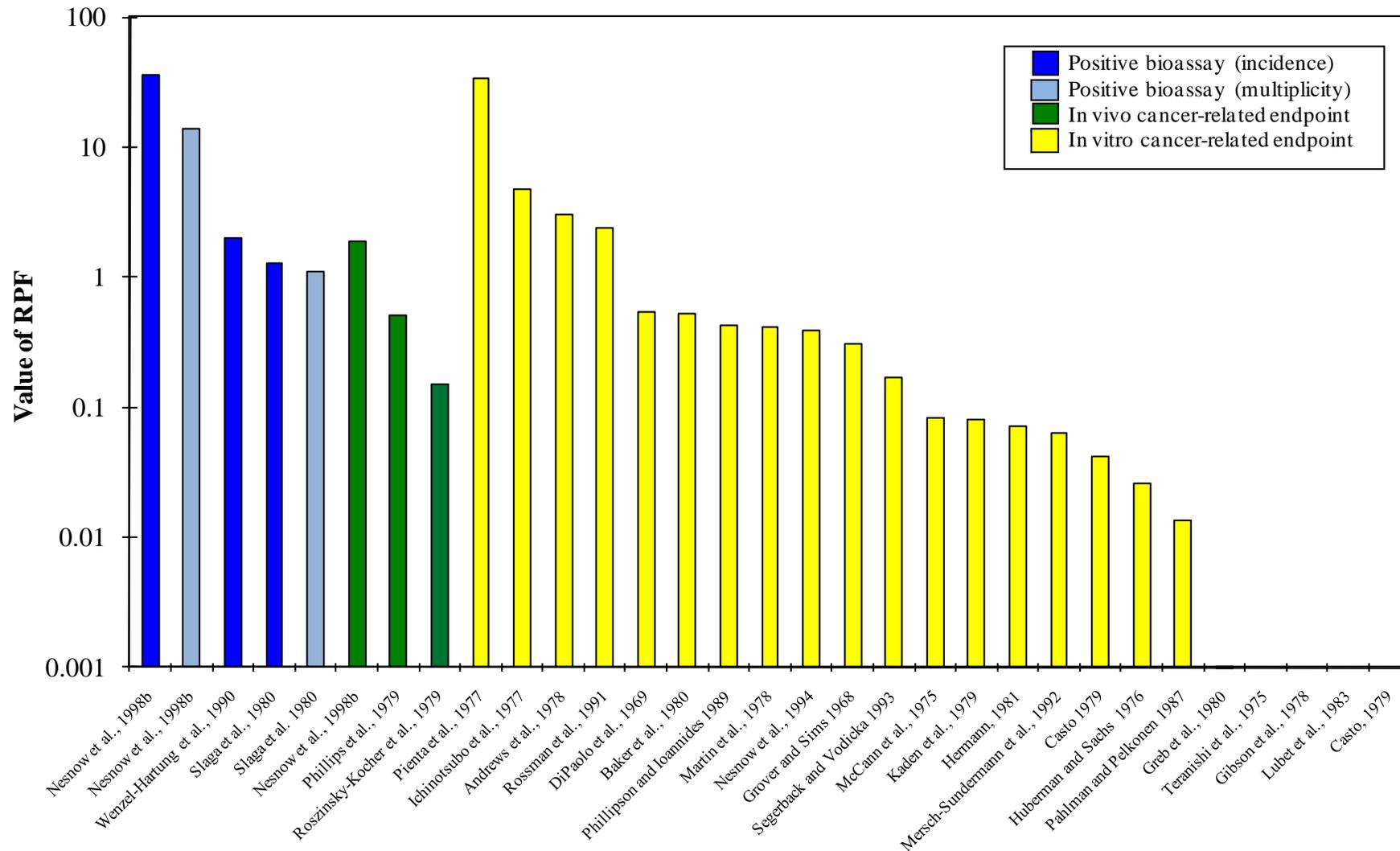
2

3

4 Dibenz[a,h]anthracene (CASRN 53-70-3) is an alternant PAH comprised of five fused
5 aromatic rings. Dibenz[a,h]anthracene contains two bay regions but no fjord region in its
6 structure.

7 There were 31 datasets for dibenz[a,h]anthracene that met selection criteria and included
8 benzo[a]pyrene (Figure 6-25). Included in the database are in vivo tumor bioassay datasets (5),
9 in vivo DNA adduct datasets (2), an in vivo clastogenicity dataset, mutagenicity datasets (10),
10 morphological/malignant cell transformation datasets (6), and in vitro DNA damage, adducts, or
11 clastogenicity datasets (7). There were three tumor bioassays for dibenz[a,h]anthracene that
12 included benzo[a]pyrene, and all resulted in statistically significant increases in tumor incidence
13 and/or multiplicity. The bioassays were in three different test systems: a rat lung implantation
14 study (Wenzel-Hartung et al., 1990), a mouse dermal initiation study reporting both incidence
15 and multiplicity (Slaga et al., 1980), and an intraperitoneal study in A/J mice (Nesnow et al.,
16 1998b). Dibenz[a,h]anthracene was shown to form DNA adducts when administered in vivo to
17 mice via intraperitoneal injection (Nesnow et al., 1998b) and dermal application (Phillips et al.,
18 1979). Mutagenicity and morphological/malignant cell transformation assays of
19 dibenz[a,h]anthracene were predominantly positive (13/16), as were studies of other cancer-
20 related endpoints. Because the available bioassays with benzo[a]pyrene were positive,
21 dibenz[a,h]anthracene was considered carcinogenic and was selected for inclusion in the RPF
22 approach.

23



* Missing bar indicates nonpositive cancer-related endpoint study

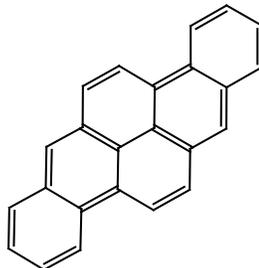
Reference

Figure 6-25. Dibenz[a,h]anthracene (DBahA) RPFs*.

1
2

1

Dibenzo[a,h]pyrene (DBahP)



2

3

4 Dibenzo[a,h]pyrene (CASRN 189-64-0) is an alternant PAH comprised of six fused
5 aromatic rings. Dibenzo[a,h]pyrene contains two bay regions but no fjord region in its structure.

6 There were five datasets for dibenzo[a,h]pyrene that met selection criteria and included

7 benzo[a]pyrene (Figure 6-26); all gave positive results. The database includes one in vivo

8 bioassay dataset, one in vivo DNA adduct dataset, two in vitro mammalian mutagenicity

9 datasets, and one in vitro DNA damage dataset. A statistically significant increase in tumor

10 incidence was reported in a dermal initiation bioassay in mice (Hoffmann and Wynder, 1966).

11 In addition, two dermal studies of complete carcinogenicity that included benzo[a]pyrene gave

12 positive results, but no RPF could be calculated because the incidence of tumors in the mice

13 exposed to dibenzo[a,h]pyrene was $\geq 90\%$ at the lowest dose tested (Cavalieri et al., 1977;

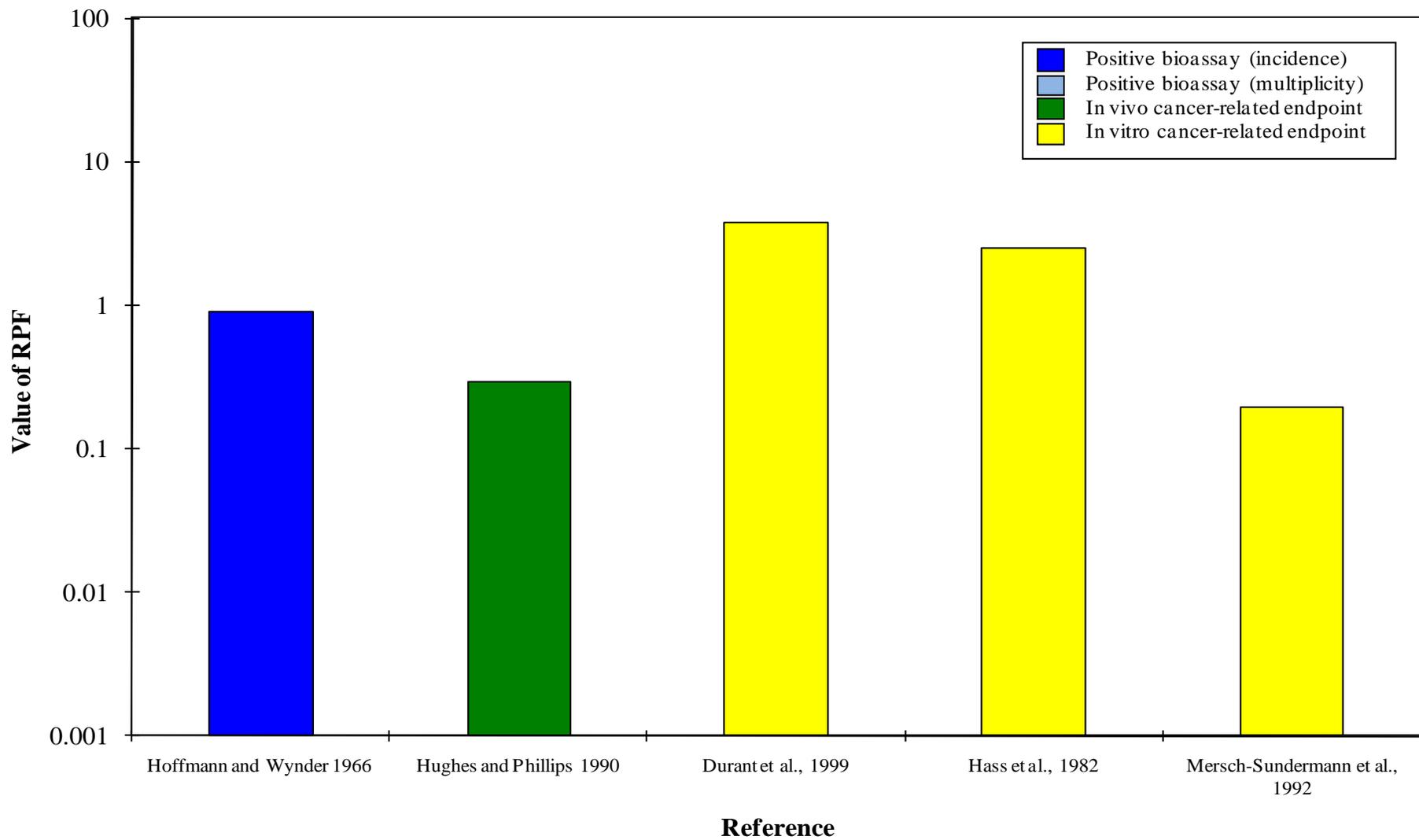
14 Hoffmann and Wynder, 1966) and tumor multiplicity was not reported. As all of the available

15 bioassays that included benzo[a]pyrene showed exposure-related tumorigenic responses,

16 dibenzo[a,h]pyrene was considered carcinogenic and was selected for inclusion in the RPF

17 approach.

18

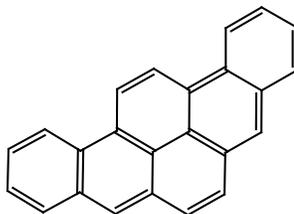


1
2

Figure 6-26. Dibenzo[a,h]pyrene (DBahP) RPFs.

1

Dibenzo[a,i]pyrene (DBaIP)



2

3

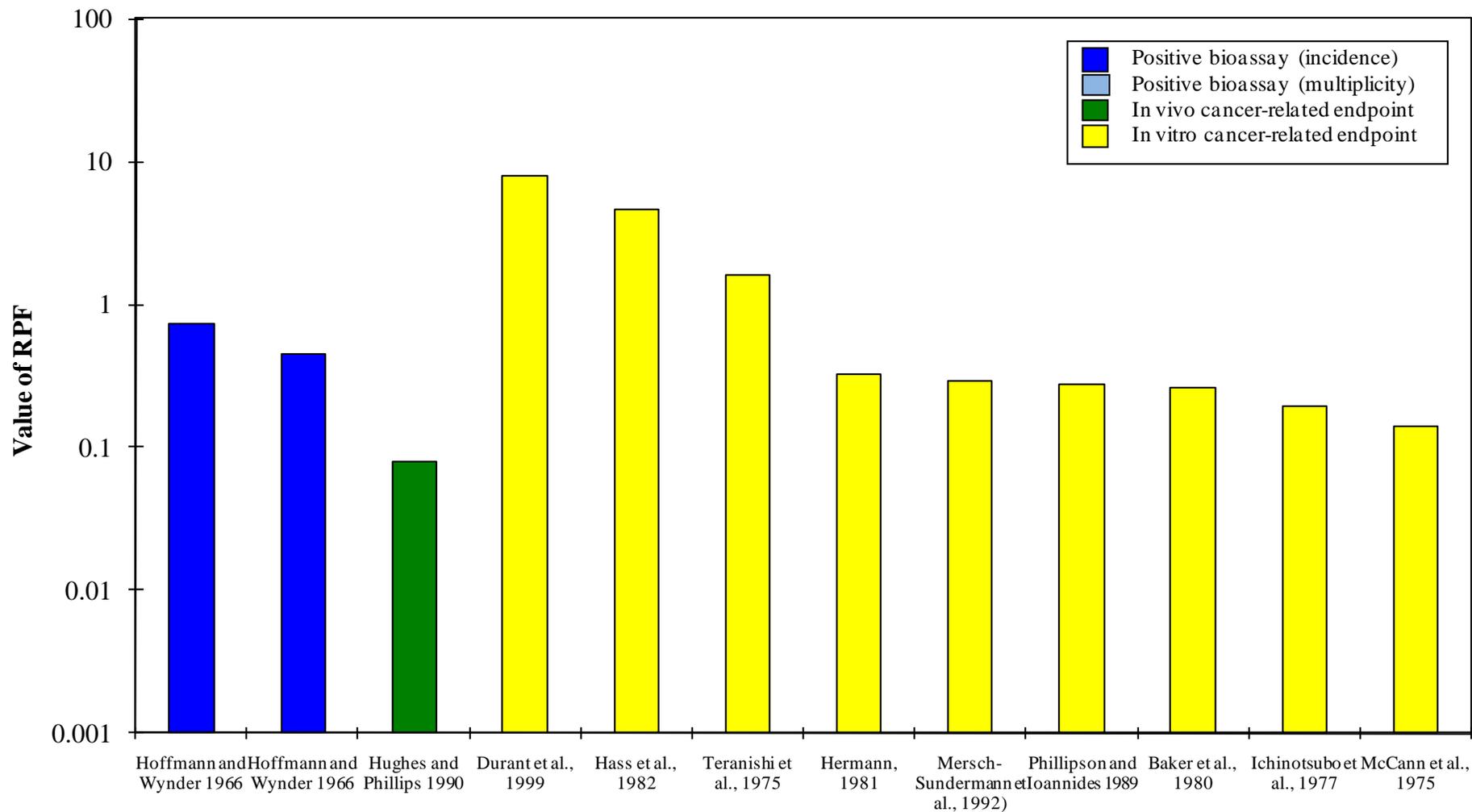
4

Dibenzo[a,i]pyrene (CASRN 189-55-9) is an alternant PAH comprised of six fused aromatic rings. Dibenzo[a,i]pyrene contains two bay regions but no fjord region in its structure.

6

There were 12 datasets for dibenzo[a,i]pyrene that met selection criteria and included benzo[a]pyrene (Figure 6-27); all gave positive results. The database includes two in vivo bioassay datasets, one in vivo DNA adduct dataset, seven in vitro mutagenicity datasets, and two in vitro DNA damage datasets. Statistically significant increases in tumor incidence were reported in dermal initiation and complete carcinogenicity bioassays in mice, both published by Hoffmann and Wynder (1966). The cancer-related endpoint studies were all positive. As the available bioassays that included benzo[a]pyrene were both positive, dibenzo[a,i]pyrene was considered carcinogenic and was selected for inclusion in the RPF approach.

14



Reference

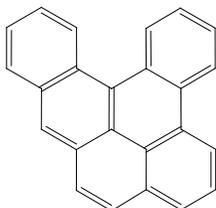
* Missing bar indicates nonpositive genotoxicity study

1

2

Figure 6-27. Dibenzo[a,i]pyrene (DbaiP) RPFs*.

1 *Dibenzo[a,l]pyrene (DBaP).*



4 Dibenzo[a,l]pyrene (CASRN 191-30-0) is an alternant PAH comprised of six fused
5 aromatic rings. Dibenzo[a,l]pyrene contains both a bay region and a fjord region in its structure.

6 There were 16 datasets for dibenzo[a,l]pyrene that met selection criteria and included
7 benzo[a]pyrene (Figure 6-28); all of the studies gave positive results. The database includes four
8 in vivo tumor bioassay datasets, three in vivo DNA adduct datasets, one bacterial mutagenicity
9 dataset, one morphological/malignant cell transformation dataset, four in vivo clastogenicity
10 datasets, and three in vitro DNA adduct or DNA damage datasets.

11 In three bioassays of dibenzo[a,l]pyrene included benzo[a]pyrene, RPFs could not be
12 calculated using incidence data, because the incidence of tumors associated with the lowest dose
13 of dibenzo[a,l]pyrene exceeded 90% (two dermal initiation experiments in mice and an
14 intramammary injection study in rats, both reported by Cavalieri et al., 1991); however, tumor
15 multiplicity data were reported for the dermal initiation experiments and were used to calculate
16 RPFs of 10 and 40. Nesnow et al. (1998b) provided tumor multiplicity and incidence data⁶ in
17 A/J mice exposed intraperitoneally; both endpoints indicated an RPF of ~30. Because the
18 available studies indicated that dibenzo[a,l]pyrene may be much more potent benzo[a]pyrene,
19 other studies were also examined to confirm the potency of this compound.

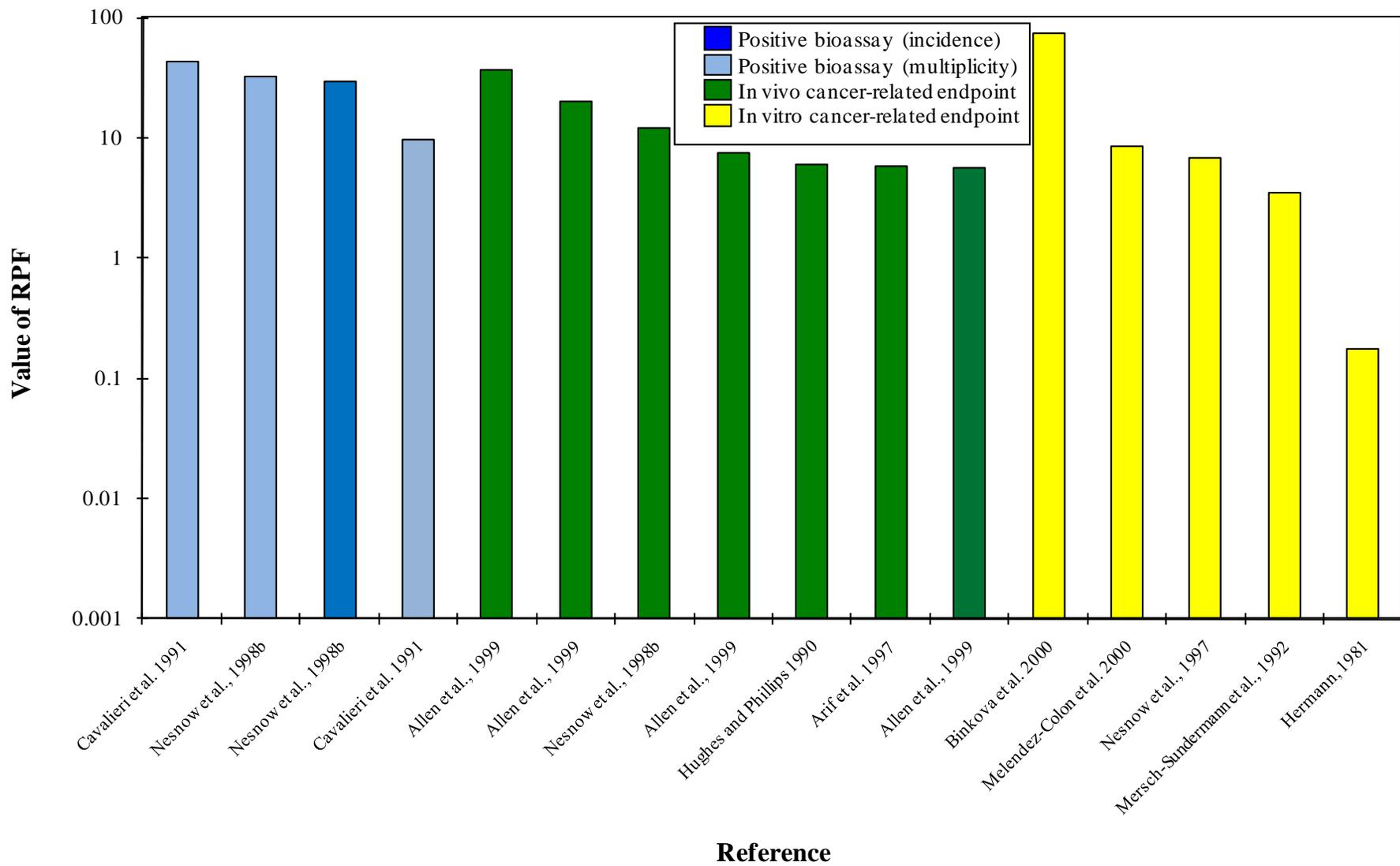
20 Dibenzo[a,l]pyrene treatment resulted in significant increases in tumor incidence in seven
21 bioassays that did not include benzo[a]pyrene, including two dermal initiation studies (Gill et al.,
22 1994; Cavalieri et al., 1989), a dermal complete carcinogenicity study (Nakatsuru et al., 2004),
23 an intramammary injection study in rats (Cavalieri et al., 1989), a newborn mouse bioassay
24 (Platt et al., 2004), an intraperitoneal bioassay using A/J mice (Prahalad et al., 1997), and a
25 gavage bioassay comparing the responses of cyp1B1 wild-type and null mice (Buters et al.,
26 2002). In several of these studies, there was significant toxicity associated with dibenzo[a,l]-
27 pyrene treatment. Tumor incidences were very high in most of the studies, including the gavage
28 study (Buters et al., 2002), which reported an overall tumor incidence of 100% in cyp1B1 wild-
29 type mice treated with a single dose of dibenzo[a,l]pyrene. A recent study examining in utero
30 and/or lactational exposure to dibenzo[a,l]pyrene showed that mouse pups exposed during late
31 gestation develop T-cell lymphomas between 3 and 6 months of age, as well multiple lung and
32 liver tumors (Castro et al., 2008). All of the cancer-related data for dibenzo[a,l]pyrene were
33 positive and resulted in high RPF estimates, including in vivo and in vitro studies of DNA

⁶Data were obtained courtesy of S. Nesnow.

1 adducts, in vivo clastogenicity studies, morphological/malignant cell transformation studies,
2 bacterial mutagenicity studies, and in vitro DNA damage or DNA adduct studies.

3 The weight of evidence supporting a finding of carcinogenicity for dibenzo[a,l]pyrene is
4 strong and suggests that this compound is very potent; thus, it was selected for inclusion in the
5 RPF approach.

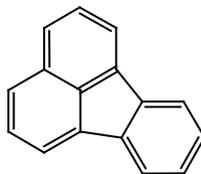
6



1
2

Figure 6-28. Dibenzo[a,l]pyrene (DBaP) RPFs.

1 *Fluoranthene (FA)*

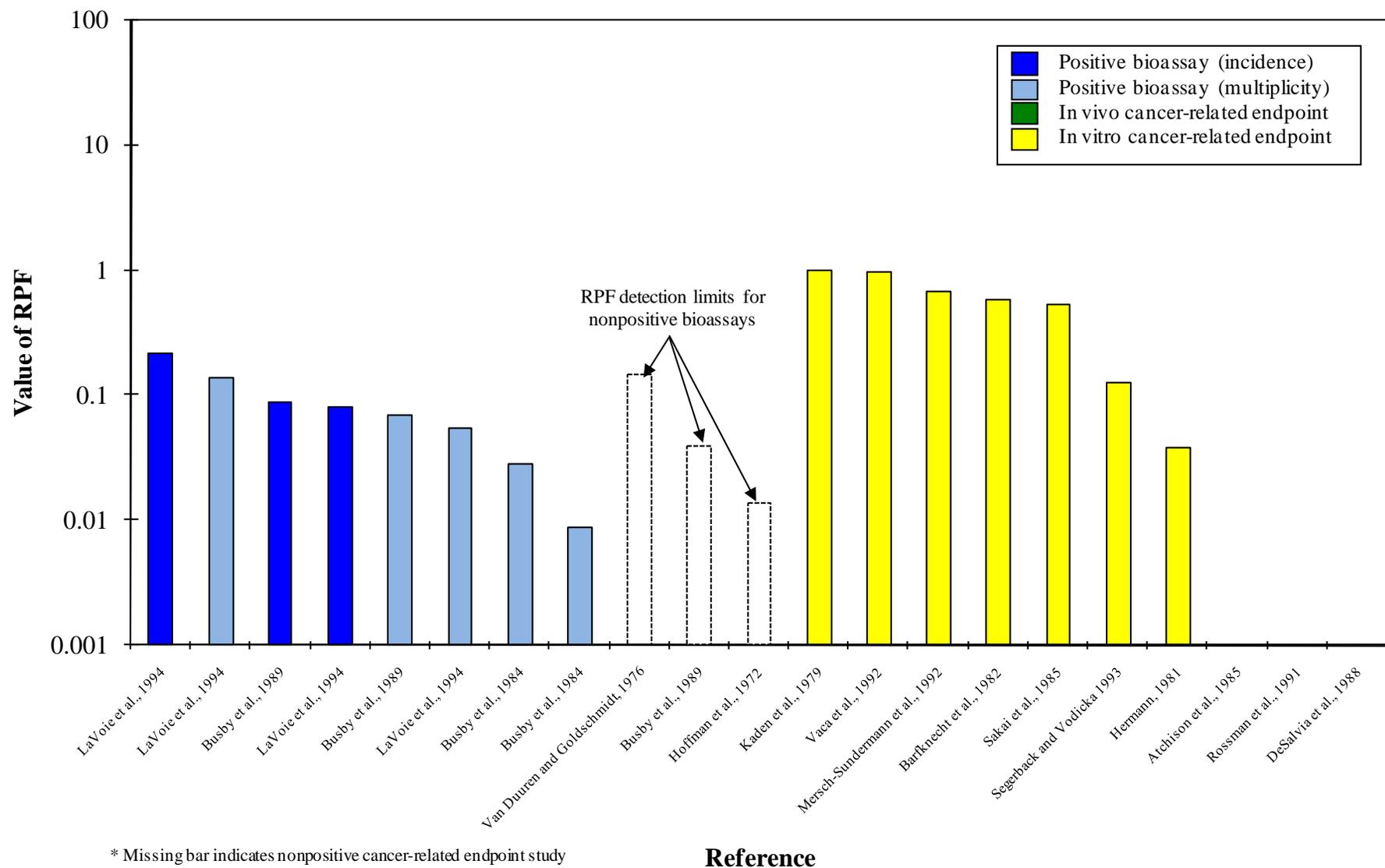


4 Fluoranthene (CASRN 206-44-0) is a nonalternant PAH comprised of three aromatic
5 rings and one five-membered ring. Fluoranthene does not contain a classic bay or fjord region in
6 its structure.

7 There were 21 datasets for fluoranthene that met selection criteria and included
8 benzo[a]pyrene (Figure 6-29). Included in the database are in vivo tumor bioassay datasets (11),
9 bacterial and mammalian mutagenicity datasets (5), a morphological/malignant cell
10 transformation assay, and in vitro studies of DNA damage, DNA adducts, or clastogenicity (4).
11 Of the bioassay datasets that included benzo[a]pyrene, nine gave positive results and two gave
12 nonpositive results. Statistically significant increases in tumor incidence and tumor multiplicity
13 were reported in newborn mouse bioassays (in male and female mice [LaVoie et al., 1994] and in
14 female mice [Busby et al., 1989]). The tumor incidence was not significantly increased by
15 fluoranthene in a mouse dermal initiation study with an RPF detection limit of 0.01 (Hoffman et
16 al., 1972) and when fluoranthene was tested alone in a dermal cocarcinogenicity bioassay with
17 an RPF detection limit of 0.1 (Van Duuren and Goldschmidt, 1976). In another newborn mouse
18 bioassay (Busby et al., 1984) that reported both incidence and multiplicity, the lowest dose of
19 benzo[a]pyrene resulted in a tumor incidence of >90%, precluding RPF calculation from the
20 incidence data; however, multiplicity data were available. Statistical analysis of the data for
21 fluoranthene demonstrated positive findings for both incidence and multiplicity in male mice, but
22 the results for the two endpoints were inconsistent in females. In female mice exposed at the
23 high dose of fluoranthene in a newborn mouse bioassay reported by Busby et al. (1984), the lung
24 tumor count was significantly increased (albeit borderline, $p = 0.0343$) while the incidence was
25 not ($p > 0.05$), and neither was statistically significantly increased at the lower dose. For the
26 purpose of this analysis, the multiplicity data were treated as an independent measure of
27 carcinogenic potency, and an RPF was calculated for the statistically increased tumor count in
28 female mice.

29 The mutagenicity studies of fluoranthene were all positive, but in vitro studies of DNA
30 damage, DNA adducts, and clastogenicity gave inconsistent results. Because the inconsistent
31 bioassay results can be attributed to different test systems (different exposure route and/or
32 gender) or study design, fluoranthene was considered carcinogenic and was selected for
33 inclusion in the RPF approach.

34

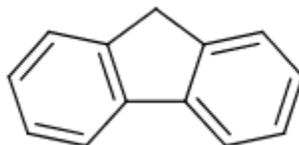


1
2

Figure 6-29. Fluoranthene (FA) RPFs*.

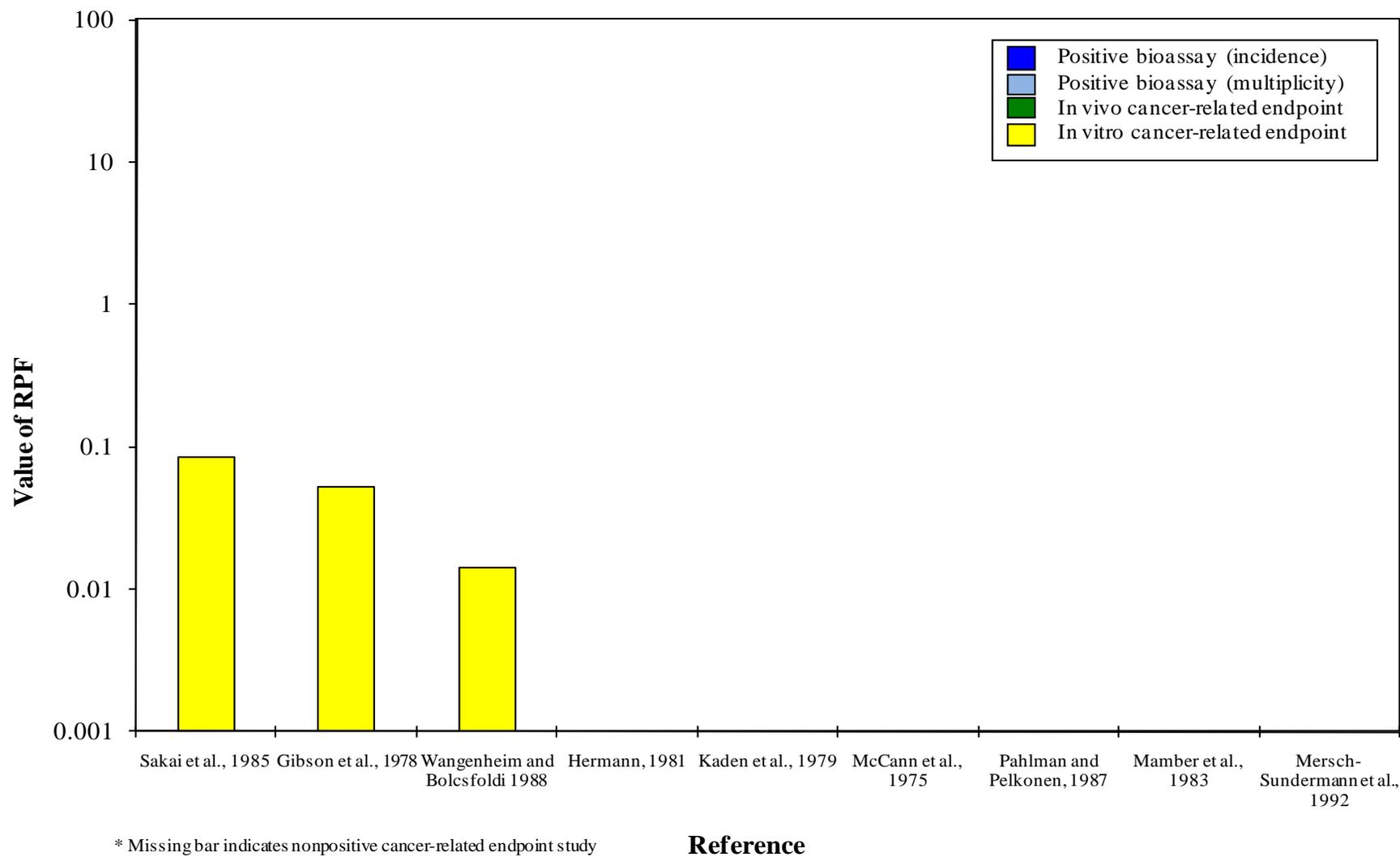
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

Fluorene (FE)



Fluorene (CASRN 86-73-7) is a nonalternant PAH comprised of two aromatic rings and one five-membered ring. Fluorene does not contain a classic bay or fjord region in its structure.

There were nine datasets for fluorene that met selection criteria and included benzo[a]pyrene (Figure 6-30). There were no tumor bioassays of fluorene that included benzo[a]pyrene, so other bioassays and cancer-related endpoint data were considered. LaVoie et al. (1980) conducted a study of skin tumor initiation in mice treated with 1 mg fluorene followed by 20 weeks of treatment with TPA; the study did not include benzo[a]pyrene. The incidence of tumor-bearing animals (5%) was not significantly increased over controls (0%) (LaVoie et al., 1980). The limited cancer-related endpoint data were mixed, with three positive and four nonpositive mutagenicity datasets, and two nonpositive in vitro DNA damage datasets. Overall, the database for fluorene is both limited and inconsistent. Because the database for fluorene does not provide adequate information with which to assess carcinogenicity, this PAH was not selected for inclusion in the RPF approach.



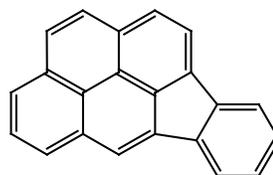
1

2

Figure 6-30. Fluorene (FE) RPFs*.

1

Indeno[1,2,3-c,d]pyrene (IP)



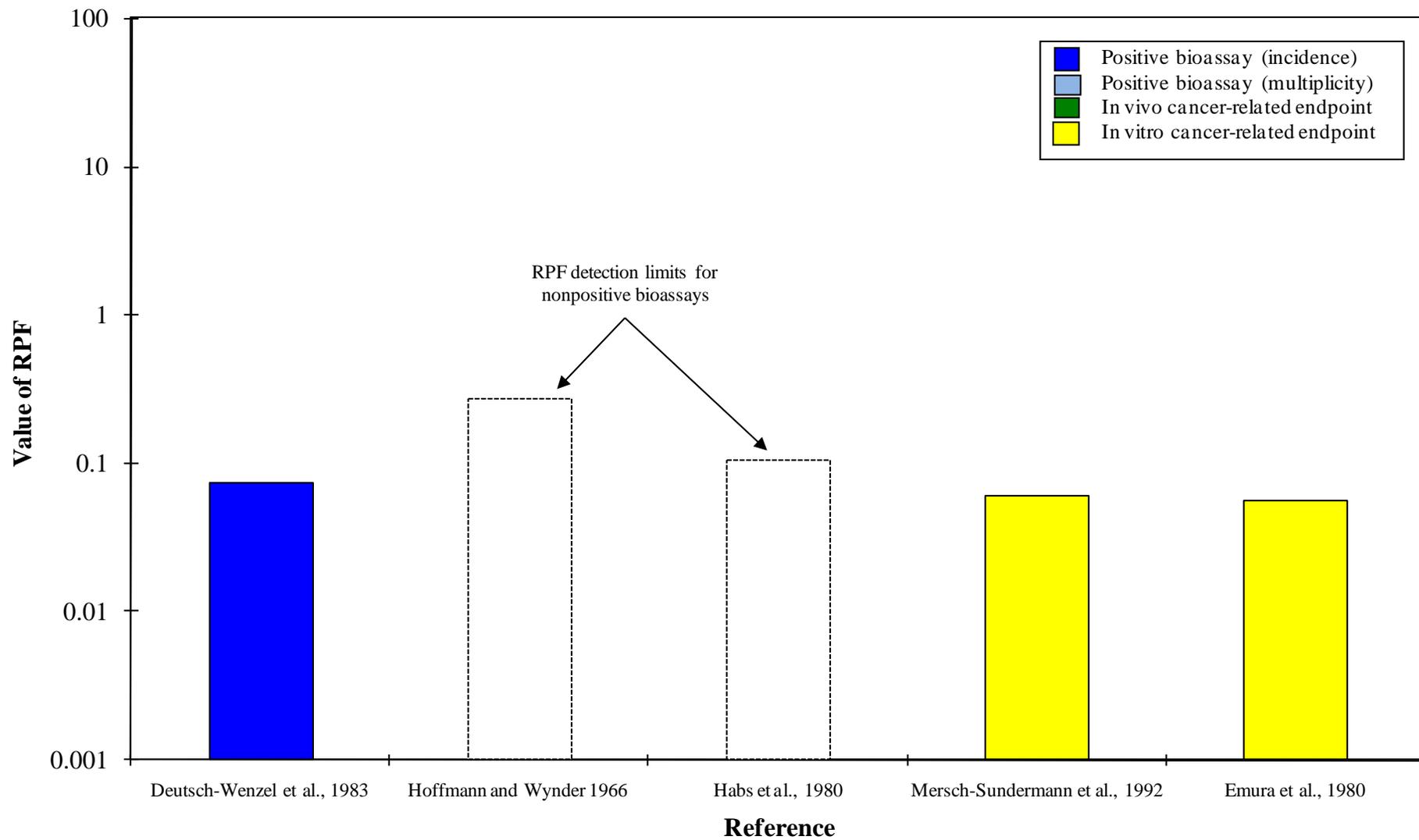
2

3

4 Indeno[1,2,3-c,d]pyrene (CASRN 193-39-5) is a nonalternant PAH comprised of five
5 aromatic rings and one five-membered ring. Indeno[1,2,3-c,d]pyrene does not contain a classic
6 bay or fjord region in its structure.

7 There were five datasets for indeno[1,2,3-c,d]pyrene that met selection criteria and
8 included benzo[a]pyrene (Figure 6-31). There are three tumor bioassays, one in vitro study of
9 morphological/malignant cell transformation (Emura et al., 1980), and one in vitro study of DNA
10 damage (Mersch-Sundermann et al., 1992). Of the three tumor bioassays, only one, a rat lung
11 implantation study (Deutsch-Wenzel et al., 1983), reported a statistically significant increase in
12 tumor incidence or multiplicity; the RPF was 0.07. Nonpositive findings were reported in mouse
13 dermal initiation (Hoffmann and Wyner, 1966) and complete carcinogenicity (Habs et al., 1980)
14 studies with RPF detection limits in the range of 0.1–0.3. Because the inconsistent bioassay
15 results can be attributed to different test systems (different species and route), and the
16 nonpositive studies may not have been sufficiently sensitive to detect an effect, indeno-
17 [1,2,3-c,d]pyrene was considered carcinogenic and was selected for inclusion in the RPF
18 approach.

19

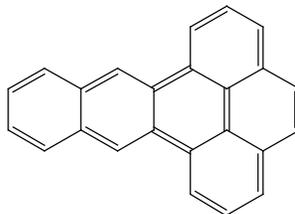


1
2

Figure 6-31. Indeno[1,2,3-c,d]pyrene (IP) RPFs.

1

Naphtho[2,3-e]pyrene (N23eP)



2

3

4 Naphtho[2,3-e]pyrene (CASRN 193-09-9) is an alternant PAH comprised of six fused
5 aromatic rings. Naphtho[2,3-e]contains two bay regions but no fjord region in its structure.

6 There were two datasets for naphtho[2,3-e]pyrene that met selection criteria and included

7 benzo[a]pyrene (Figure 6-32): a tumor bioassay dataset and an in vitro mammalian mutagenicity

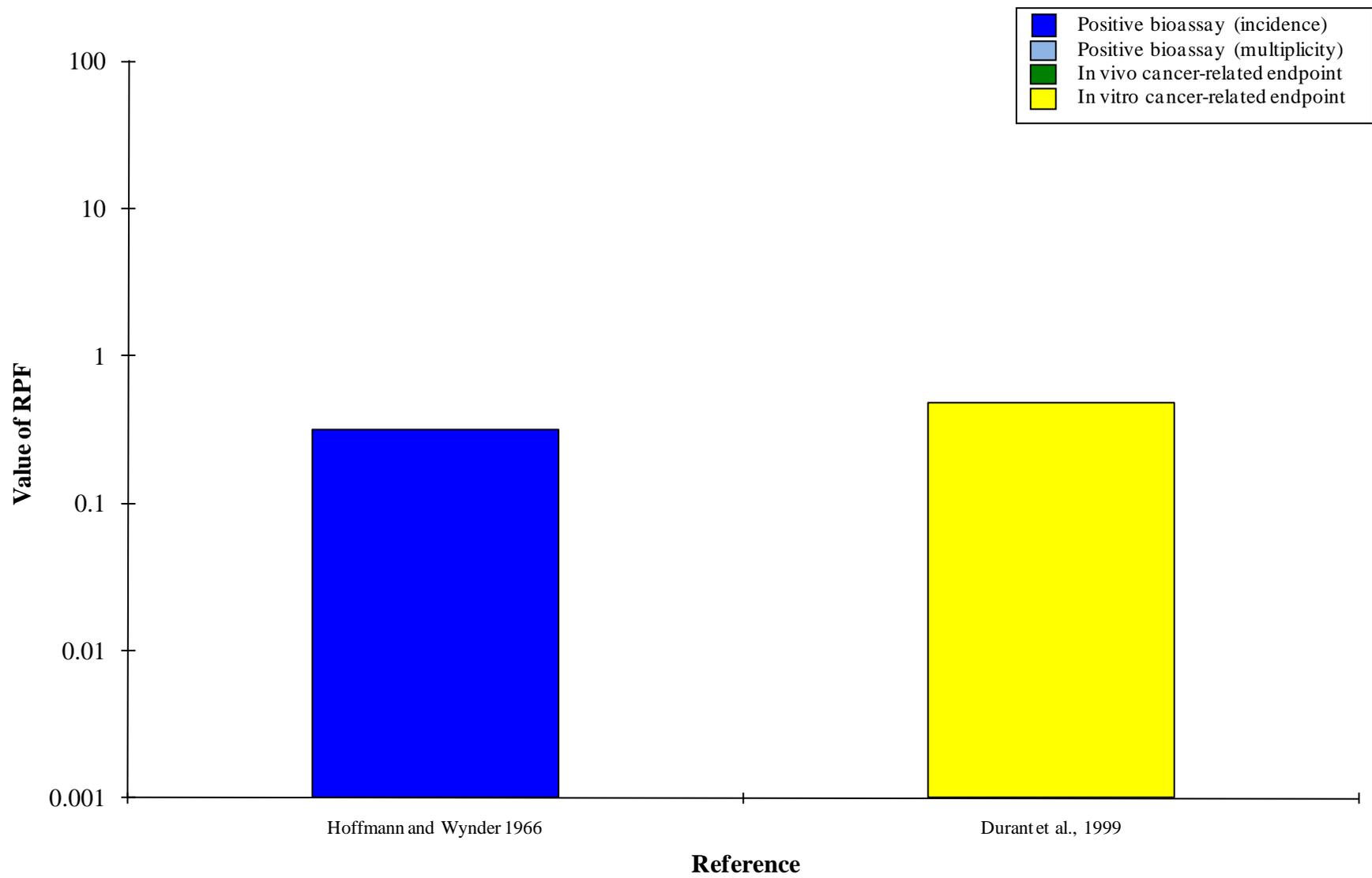
8 dataset (both were positive). The tumor bioassay was a single dose dermal initiation bioassay

9 (Hoffmann and Wynder, 1966). As the available bioassay reported a statistically significant

10 increase in tumor incidence, naphtho[2,3-e]pyrene was considered carcinogenic, and was

11 selected for inclusion in the RPF approach.

12

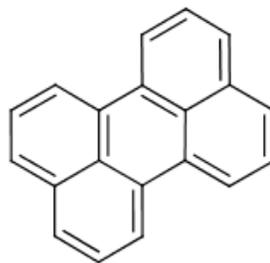


1
2

Figure 6-32. Naphtho[2,3-e]pyrene (N23eP) RPFs.

1

Perylene (Pery)



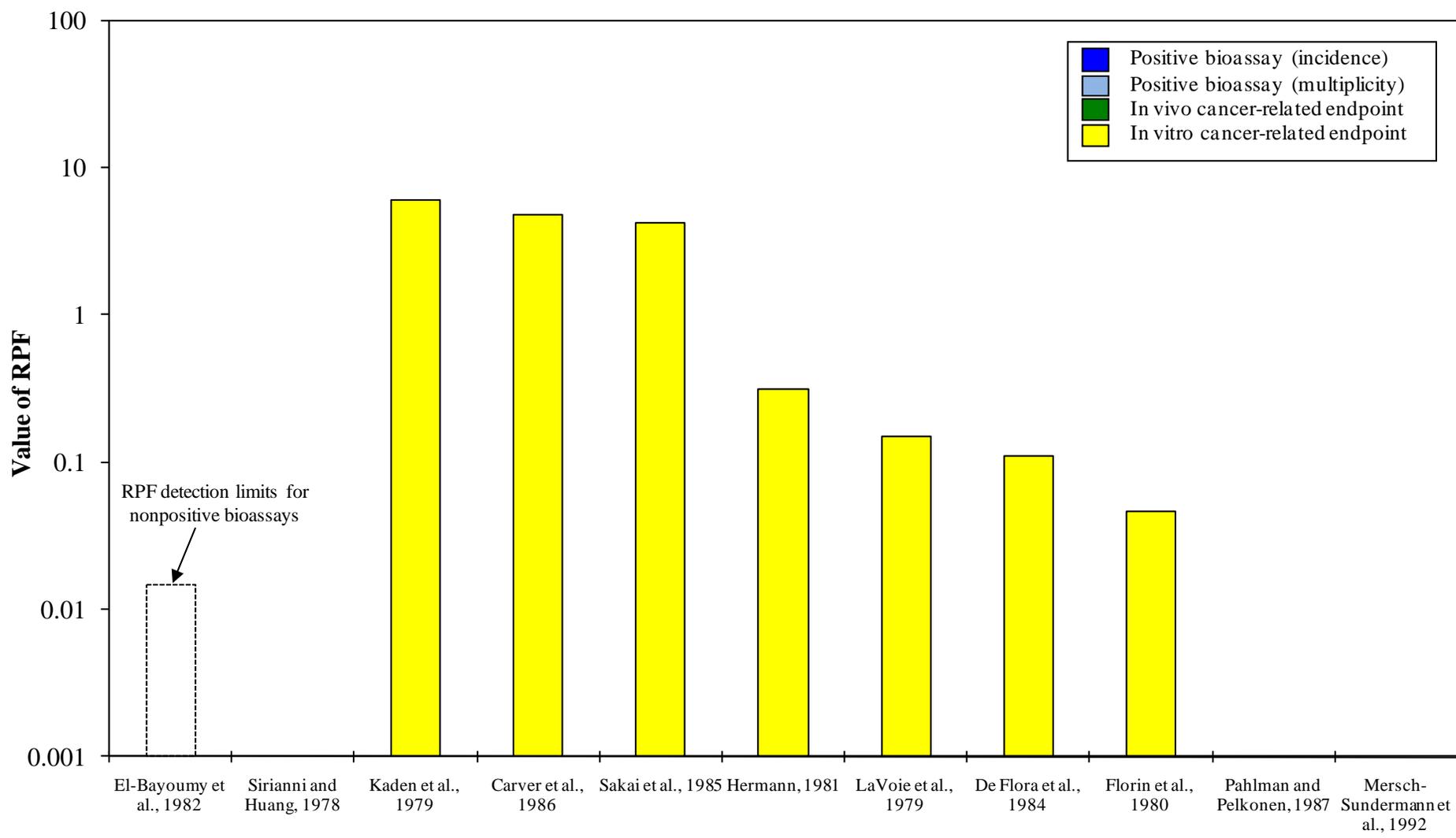
2

3

4 Perylene (CASRN 198-55-0) is an alternant PAH comprised of five fused aromatic rings.
5 Perylene contains two bay regions but no fjord region in its structure.

6 There were 11 datasets for perylene that met selection criteria and included
7 benzo[a]pyrene (Figure 6-33). The database includes an in vivo tumor bioassay dataset, an in
8 vivo clastogenicity dataset, eight bacterial mutagenicity datasets, and an in vitro DNA damage
9 dataset. The single tumor bioassay, a dermal initiation study, gave nonpositive results for
10 perylene (El-Bayoumy et al., 1982); the RPF detection limit was 0.01. To confirm the
11 nonpositive bioassay findings, other bioassays and cancer-related endpoint data were considered.
12 In a study that did not include benzo[a]pyrene, Van Duuren et al. (1970) did not observe an
13 increase in tumor incidence over controls when mice were treated by dermal application with an
14 initiating dose of 0.8 mg perylene in benzene followed by thrice weekly treatment with phorbol
15 myristate acetate for 58 weeks. However, seven of the eight bacterial mutagenicity studies gave
16 positive results, while perylene tested nonpositive in one bacterial mutagenicity study, the
17 clastogenicity study, and the DNA damage study. Overall, the database for perylene is both
18 limited and inconsistent. Because the database for perylene does not provide adequate
19 information with which to assess carcinogenicity, this PAH was not selected for inclusion in the
20 RPF approach.

21



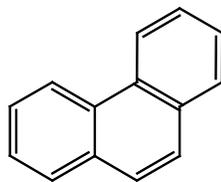
* Missing bar indicates nonpositive cancer-related endpoint study

Reference

1
2

Figure 6-33. Perylene (Pery) RPFs*.

1 *Phenanthrene (PH)*

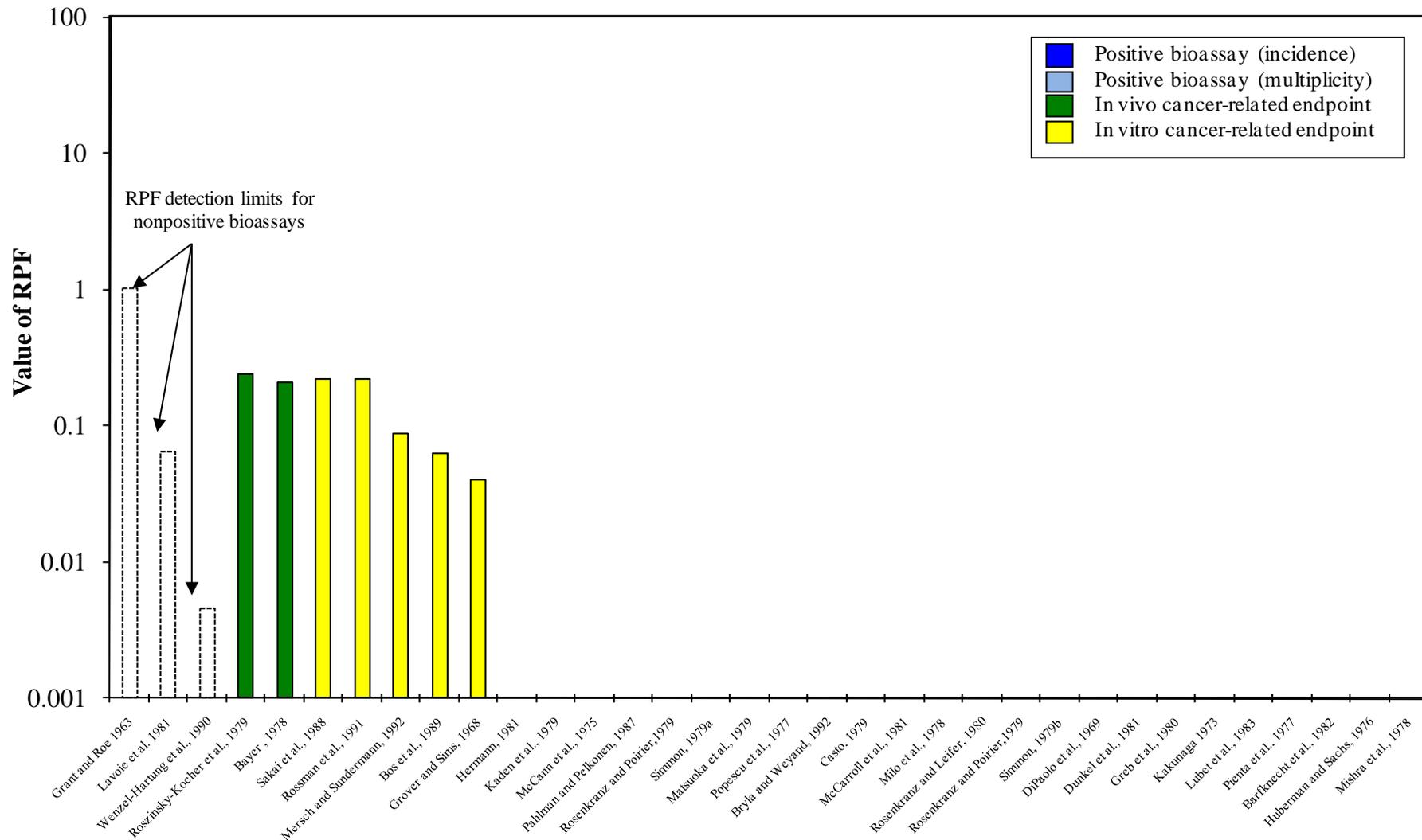


2
3
4 Phenanthrene (CASRN 85-01-8) is an alternant PAH comprised of three fused aromatic
5 rings. Phenanthrene contains a bay region in its structure, but has less than four aromatic rings.

6 There were 34 datasets for phenanthrene that met selection criteria and included
7 benzo[a]pyrene, including 3 in vivo tumor bioassay datasets, 2 in vivo clastogenicity datasets,
8 11 mutagenicity datasets, 6 morphological/malignant cell transformation datasets, and 12 in vitro
9 studies of DNA adducts, DNA damage, or clastogenicity (Figure 6-34). Only 7 studies reported
10 positive results; the remaining 27 studies reported nonpositive findings, including all 3 bioassays.
11 Nonpositive findings were reported in the three bioassays that included benzo[a]pyrene,
12 including a lung implantation study in rats (Wenzel-Hartung et al., 1990), a dermal initiation
13 study in mice (LaVoie et al., 1981), and a subcutaneous study in mice (Grant and Roe, 1963).
14 To confirm the nonpositive findings, other bioassays and cancer-related endpoint data were
15 considered. In bioassays without benzo[a]pyrene, phenanthrene did not induce significant
16 increases in tumors in a newborn mouse assay using a total dose of 1.4 μmol (Buening et al.,
17 1979) or in two dermal initiation assays (Wood et al., 1979; Salaman and Roe, 1956) using doses
18 of 10 μmol and 540 mg, respectively. However, 12/30 mice developed papillomas by week 35
19 after dermal treatment with 10 μmol phenanthrene (in benzene) followed by twice weekly
20 treatment with TPA; no control mice had papillomas (Scribner, 1973). The response was
21 statistically significantly increased over controls ($p < 0.01$).

22 In vitro assays of mutagenicity and morphological/malignant cell transformation were
23 predominantly nonpositive for phenanthrene. One of the two positive studies (Sakai et al., 1988)
24 reported a poor dose-response relationship for phenanthrene. Two studies found evidence of
25 clastogenicity after in vivo administration of phenanthrene (Roszinsky-Kocher et al., 1979;
26 Bayer, 1978). However, in the study by Bayer (1978), only the high dose gave a significant
27 response, and there was not a significant dose-response trend. When phenanthrene was tested in
28 in vitro studies of DNA adducts, DNA damage, and clastogenicity, the results were
29 predominantly nonpositive (9/12 studies). Overall, the database for phenanthrene is substantial,
30 and the weight of evidence suggests that this PAH is not carcinogenic. Based on the large
31 number of nonpositive bioassays and the abundant evidence that phenanthrene lacks genotoxic
32 action, this compound was selected for inclusion in the RPF approach and assigned an RPF of
33 zero.

34



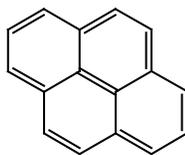
* Missing bar indicates nonpositive cancer-related endpoint study

Reference

1
2

Figure 6-34. Phenanthrene (PH) RPFs*.

1 *Pyrene (Pyr)*



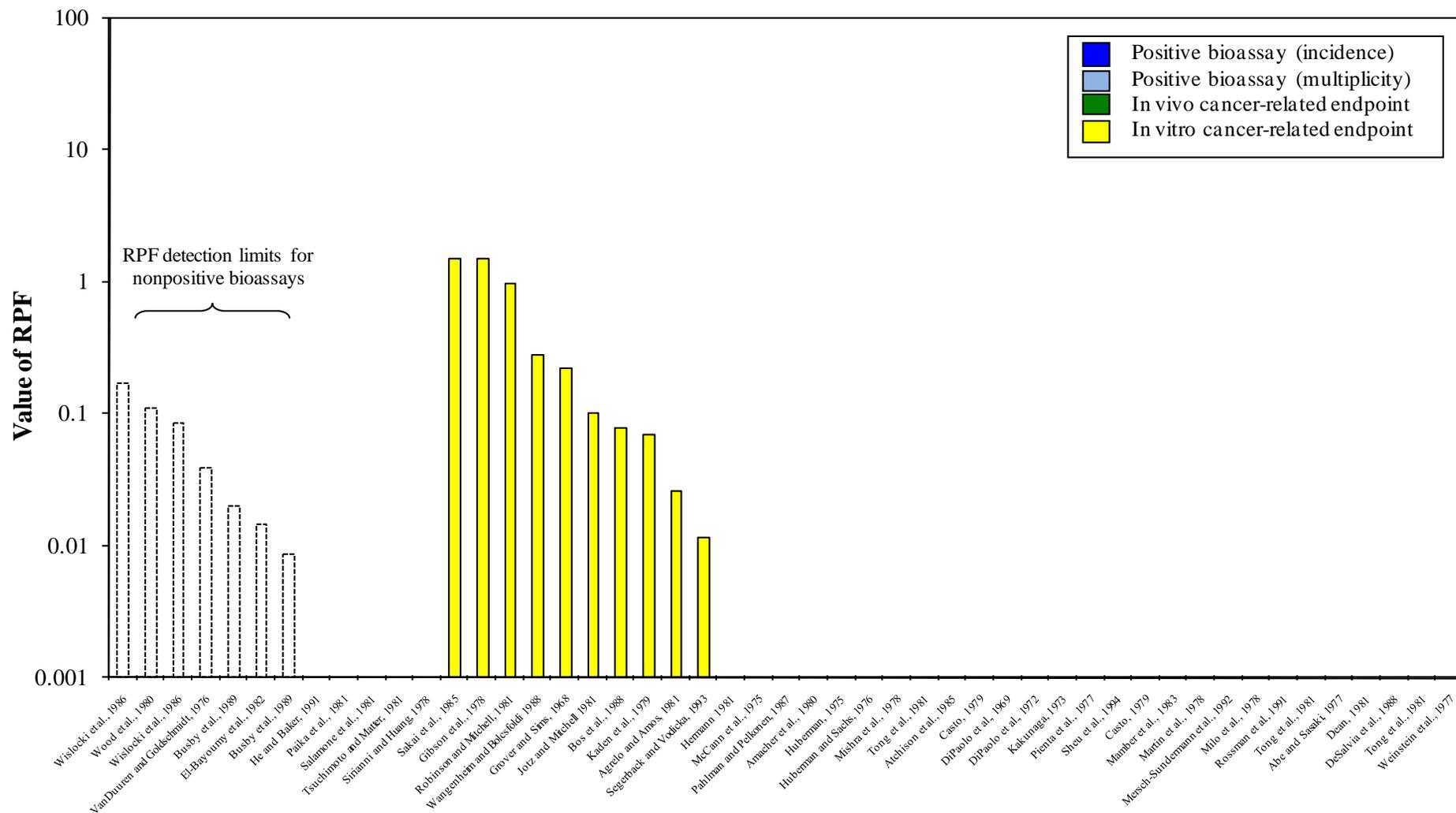
4

5 Pyrene (CASRN 129-00-0) is an alternant PAH comprised of four fused aromatic rings.
6 Pyrene does not contain a bay or fjord region in its structure.

7 There were 49 datasets for pyrene that met study quality criteria and included
8 benzo[a]pyrene (Figure 6-35). Included in the database are in vivo tumor bioassay datasets (7),
9 in vivo clastogenicity datasets (5), bacterial and mammalian mutagenicity datasets (14),
10 morphological/malignant cell transformation datasets (7), and in vitro DNA damage, DNA
11 adducts, or clastogenicity datasets (16). There were seven bioassays of pyrene that included
12 benzo[a]pyrene; all gave nonpositive results. Nonpositive results were reported in two newborn
13 mouse bioassays in which both males and females were tested (Busby et al., 1989; Wislocki et
14 al., 1986), two studies of dermal initiation (El-Bayoumy et al., 1982; Wood et al., 1980), and a
15 dermal cocarcinogenesis bioassay (Van Duuren and Goldschmidt, 1976). RPF detection limits in
16 these studies ranged from about 0.01 to 0.1 (see Figure 6-35). In an intraperitoneal bioassay
17 using A/J mice that included benzo[a]pyrene, the authors reported that pyrene treatment did not
18 induce lung adenomas (Ross et al., 1995); data were not reported, so an RPF detection limit
19 could not be estimated. In bioassays without benzo[a]pyrene, pyrene did not induce a significant
20 increase in tumors in a dermal initiation bioassay (Salaman and Roe, 1956). Scribner (1973)
21 reported a weak tumorigenic response in a dermal initiation study in mice (5/29 mice developed
22 papillomas 35 weeks after dermal treatment with 10 μmol pyrene in benzene followed by twice
23 weekly treatment with TPA as compared with 0/30 control mice, $p = 0.02$).

24 In vitro assays of bacterial and mammalian mutagenicity and morphological/malignant
25 cell transformation were predominantly nonpositive for pyrene. In five studies of clastogenicity
26 in animals exposed in vivo to pyrene, no evidence of clastogenic effects was reported. Further,
27 in vitro studies of DNA adducts, DNA damage, and clastogenicity using pyrene also largely
28 reported nonpositive results. Overall, the database for pyrene is substantial, and the weight of
29 evidence suggests that this PAH is not carcinogenic. Based on the large number of nonpositive
30 bioassays and the abundant evidence that pyrene lacks genotoxic action, this compound was
31 selected for inclusion in the RPF approach and assigned an RPF of zero.

32



* Missing bar indicates nonpositive cancer-related endpoint study

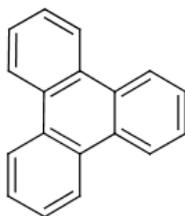
Reference

1
2

Figure 6-35. Pyrene (Pyr) RPFs*.

1

Triphenylene (TPhen)



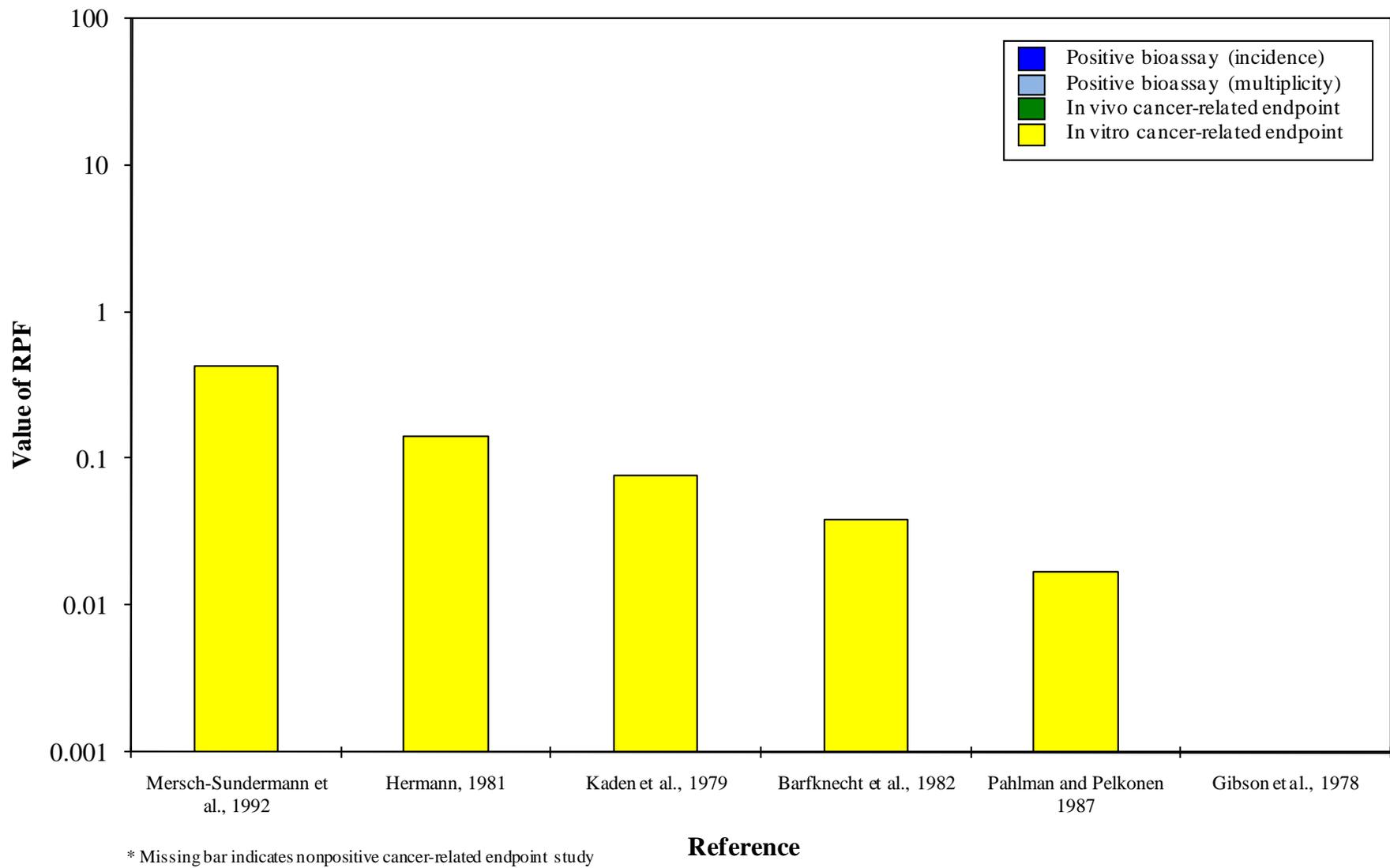
2

3

4 Triphenylene (CASRN 217-59-4) is an alternant PAH comprised of four fused aromatic
5 rings. Triphenylene contains several bay regions but no fjord region in its structure.

6 There were six datasets for triphenylene that met selection criteria and included
7 benzo[a]pyrene (Figure 6-36); all but one of the studies gave positive results. The database
8 includes five mutagenicity studies (four positive and one nonpositive) and a study of in vitro
9 DNA damage. There were no bioassays of triphenylene that met selection criteria, and no
10 bioassays without benzo[a]pyrene. Although all of the available cancer-related endpoint studies
11 for triphenylene gave positive results, the database is very limited, consisting of only a few in
12 vitro mutagenicity and DNA damage studies. The RPFs for cancer-related endpoints ranged
13 from 0.02 to 0.4. Because the database for triphenylene does not provide adequate information
14 with which to assess carcinogenicity, this PAH was not selected for inclusion in the RPF
15 approach.

16



1
2

Figure 6-36. Triphenylene (Tphen) RPFs*.

7. DERIVATION OF FINAL RPFs FOR SELECTED PAHs

The weight of evidence evaluation (Chapter 6) indicates that the available data are adequate to suggest that 24 of the 27 PAHs are carcinogenic, 3 PAHs (anthracene, phenanthrene, and pyrene) exhibited no carcinogenicity, and data are inadequate to evaluate the carcinogenicity of eight PAHs. The 8 PAHs with inadequate data are excluded from the RPF analysis.

For the three PAHs for which there were sufficient data to conclude that they were not carcinogenic (i.e., robust nonpositive tumor bioassay data and cancer-related endpoint data), a final RPF of zero was recommended. While there is little quantitative difference between selecting a final RPF of zero for a given PAH and excluding that PAH from the RPF approach, this is an important distinction for uncertainty analysis. There is substantial uncertainty in the risk associated with PAHs that are excluded from the RPF analysis due to inadequate data, as these compounds could be of low or high potency. However, for PAHs with an RPF of zero, there is evidence to suggest that these compounds are not carcinogenic, and the uncertainty associated with the cancer risk for these compounds is markedly reduced.

For each of the remaining 24 compounds, a final nonzero RPF was derived. A number of options were considered for deriving a final RPF from among the numerous values calculated for each individual PAH. These options included: prioritizing bioassay RPFs from different exposure routes based on environmentally relevant routes; prioritizing bioassay RPFs based on target organs considered relevant to human susceptibility to PAH carcinogenesis; prioritizing RPFs based on quality of the underlying study; prioritizing cancer-related endpoints by their correlation with bioassay potency (i.e., ability to predict bioassay potency); and combining (i.e., averaging) RPFs across all bioassays, across all cancer-related endpoints, or across all endpoints. Appendix G details analyses that were undertaken to assess various options for ranking or prioritizing RPFs. It was concluded that the available data did not provide a basis for prioritizing RPFs except for a preference for bioassay data over cancer-related endpoints. As a consequence, final RPFs were derived from bioassay data for any PAH that had at least one RPF based on a bioassay. For carcinogenic PAHs without bioassay data, final RPFs were calculated from all cancer-related endpoint datasets with positive results (see next section).

7.1. METHODS FOR DERIVING FINAL RPFs

For each carcinogenic PAH with bioassay data, the average RPF was calculated from bioassay datasets with positive results (nonpositive bioassay results were not included in the calculation). For those PAHs that did not have any RPF based on a bioassay, but for which the weight of evidence evaluation indicated a carcinogenic response (e.g., dibenz[a,c]anthracene), the average RPF was calculated from all cancer-related endpoint datasets with positive results (again, nonpositive results were not included in the calculation). The range of RPF values was

1 also reported. Presenting the average and the range provides an average and maximum estimate
2 for each PAH that has data from multiple studies.

3 Several options were considered for the estimation of a final RPF, including arithmetic
4 mean, geometric mean, weighted average, maximum, or order of magnitude estimates. The
5 arithmetic mean and range were chosen as a simple approach to describing the calculated RPF
6 values available for each PAH. Other estimates were not considered due to the limited number
7 of individual RPF values calculated for most PAHs and the variability in the RPF estimates.
8 There were usually not enough data (3 or fewer RPFs for 17/23 PAHs with nonzero RPFs) to
9 assess the shape of the RPF distribution for any given PAH; thus, a geometric mean was not
10 considered. Further, the range of RPF values from tumor bioassays was greater than an order of
11 magnitude for several compounds (6/23 PAHs). The variability in RPF estimates is likely due to
12 differences in study design parameters (e.g., route, species/strain, exposure duration, exposure
13 during sensitive time periods, initiation versus complete carcinogenesis protocol, tumor
14 incidence versus tumor multiplicity reporting) and dose-response methods (modeled versus point
15 estimates). Calculation of a weighted average was considered, but without a rationale for
16 assigning weights among study types or among tumor data outcomes, using a weighting
17 approach might increase uncertainty.

18 Several previous approaches for generating RPF values for PAHs have used order-of-
19 magnitude estimates (Collins et al., 1998; Malcolm and Dobson, 1994; U.S. EPA, 1993; Nisbet
20 and LaGoy, 1992, see Chapter 3). The presentation of the arithmetic mean (and range) of RPFs
21 for each PAH reflects the available data better than an order-of-magnitude approach.

22 The range was reported as a measure of variability instead of a confidence interval on the
23 average RPF. The input data for each average RPF (bioassay RPFs of different route, species,
24 sex, and target organ, or cancer-related endpoint data across a wide variety of assays and test
25 conditions) reflect such heterogeneity in study design that confidence limits would not provide
26 the statistical precision that they typically convey. All tumor bioassay RPFs (across all exposure
27 routes, species, and sexes, and including both tumor incidence and tumor multiplicity RPFs)
28 were combined to estimate the mean and range for each PAH, except as follows. Only nonzero
29 RPFs were included in the calculation of the final RPF and range for each PAH

30 While tumor multiplicity data from tumor bioassays are not generally used to estimate
31 *cancer potency*, these data were included in the dose-response assessment in order to determine
32 whether they could serve as a reliable measure of *relative cancer potency*. Several bioassays
33 reported data on both tumor incidence and tumor number, providing information that was used to
34 compare relative potencies estimated from these two endpoints. The comparison between RPFs
35 calculated from incidence and tumor multiplicity data from the same experiment showed these
36 values to be highly correlated ($r^2 = 0.76$; see further discussion in Chapter 8), indicating that
37 multiplicity RPFs are reasonably predictive of incidence RPFs. When both incidence and
38 multiplicity RPFs were calculated for the same group of animals, the results for each endpoint

1 could not be considered independent, so the higher of the two values was included in the average
2 and the lower value was excluded. As discussed further in Chapter 8, in 70% of the cases where
3 data for both incidence and multiplicity were used to calculate RPFs, the RPF associated with
4 incidence was the higher of the two (or the two values were equal) and was therefore included in
5 the average, omitting the corresponding multiplicity RPF.

6 When separate RPFs were calculated for different target organs in the same group of
7 animals, the higher value of the two RPFs was included in the average and range, and the lower
8 value was dropped from the combined data. Different RPFs were calculated for liver and lung
9 tumors in male mice (females did not develop liver tumors) in newborn mouse studies. This
10 occurrence applied only to benz[a]anthracene, chrysene, and fluoranthene tested in studies
11 reported by LaVoie et al. (1994) and Wislocki et al. (1986).

12 When separate RPFs were calculated for male and female animals in the same study
13 (generally, these were also newborn mouse studies), both sex-specific RPFs were included in the
14 aggregation, as these were two separate groups of animals. In the one dermal study that included
15 both sexes (Nesnow et al., 1984), the male and female RPFs differed by only ~50% for both
16 benz[c]aceanthrylene and benz[l]aceanthrylene. In the newborn mouse studies that resulted in
17 nonzero RPFs for both males and females (LaVoie et al., 1994, 1987; Wislocki et al., 1986), the
18 male RPF was typically three- to fivefold higher than the female RPF. Final RPFs that included
19 both male and female values from the same study were calculated for three PAHs:
20 benzo[j]fluoranthene, benz[a]anthracene, and fluoranthene.

21 Table 7-1 shows the average RPFs based on tumor bioassay data with their associated
22 range, and an overview of the tumor bioassay database (total number of studies, exposure routes
23 tested, species tested, and sexes tested) for each PAH. Table 7-2 shows the average RPF for
24 dibenz[a,c]anthracene, the only RPF based on cancer-related endpoint data, with its associated
25 range, and an overview of the database for this compound.

Table 7-1. Final RPFs based on tumor bioassay data

PAH	Average RPF	Range of RPFs	Number of datasets	Exposure routes tested	Species tested	Sexes tested
Anthanthrene	0.4	0.2–0.5	2	Dermal, lung implantation	Mouse, rat	Female
Anthracene	0	0	1 (nonpositive)	Dermal	Mouse	Female
Benz[a]anthracene	0.2	0.02–0.4	3	Dermal, intraperitoneal	Mouse	Female, male
Benz[b,c]aceanthrylene, 11H-	0.05	0.05	1	Dermal	Mouse	Female
Benzo[b]fluoranthene	0.8	0.1–2	5	Dermal, intraperitoneal, lung implantation	Mouse, rat	Female, male
Benzo[c]fluorene	20	1–50	2	Oral, intraperitoneal	Mouse	Female
Benz[e]aceanthrylene	0.8	0.6–0.9	2	Dermal	Mouse	Female, male
Benzo[g,h,i]perylene	0.009	0.009	1	Lung implantation	Rat	Female
Benz[j]aceanthrylene	60	60	1	Intraperitoneal	Mouse	Male
Benzo[j]fluoranthene	0.3	0.01–1	5	Dermal, intraperitoneal, lung implantation	Mouse, rat	Female, male
Benzo[k]fluoranthene	0.03	0.03–0.03	2	Dermal, lung implantation	Mouse, rat	Female
Benz[l]aceanthrylene	5	4–7	2	Dermal	Mouse	Female, male
Chrysene	0.1	0.04–0.2	7	Dermal, intraperitoneal, lung implantation	Mouse, rat	Female, male
Cyclopenta[c,d]pyrene	0.4	0.07–1	5	Dermal, intraperitoneal	Mouse	Female, male
Cyclopenta[d,e,f]chrysene, 4H-	0.3	0.2–0.5	2	Dermal	Mouse	Female
Dibenzo[a,e]fluoranthene	0.9	0.7–1	2	Dermal	Mouse	Female
Dibenzo[a,e]pyrene	0.4	0.3–0.4	2	Dermal	Mouse	Female
Dibenz[a,h]anthracene	10	1–40	3	Dermal, intraperitoneal, lung implantation	Mouse, rat	Female, male
Dibenzo[a,h]pyrene	0.9	0.9	1	Dermal	Mouse	Female
Dibenzo[a,i]pyrene	0.6	0.5–0.7	2	Dermal	Mouse	Female
Dibenzo[a,l]pyrene	30	10–40	3	Dermal, intraperitoneal	Mouse	Female, male
Fluoranthene	0.08	0.009–0.2	5	Intraperitoneal	Mouse	Female, male
Indeno[1,2,3-c,d]pyrene	0.07	0.07	1	Lung implantation	Rat	Female
Naphtho[2,3-e]pyrene	0.3	0.3	1	Dermal	Mouse	Female
Phenanthrene	0	0	3 (nonpositive)	Dermal, intraperitoneal, lung implantation	Mouse, rat	Female, male
Pyrene	0	0	7 (nonpositive)	Dermal, intraperitoneal	Mouse	Female, male

Table 7-2. Final RPFs based on cancer-related endpoint data (no tumor bioassay data available)

PAH	Average RPF	Range of RPFs	Types of studies	Multiple dose studies
Dibenz[a,c]anthracene	4	0.04–50	Total = 14 studies One in vivo DNA adduct Six in vitro bacterial mutagenicity One in vitro mammalian mutagenicity One in vitro morphological/malignant transformation Three in vitro DNA damage Two in vitro DNA adducts	Total = 6 studies Four in vitro bacterial mutagenicity One in vitro DNA damage One in vitro DNA adduct

1

2 **7.2. CONFIDENCE RATINGS FOR FINAL RPFs**

3 Once a final RPF was derived for a given PAH, the resulting value was assigned a
4 relative confidence rating of *high*, *medium*, *low*, or *very low*. The relative confidence rating
5 characterized the nature of the database upon which the final RPF was based. Confidence
6 rankings were based on the robustness of the database. For final RPFs based on tumor bioassay
7 data, confidence ratings considered both the available tumor bioassays and the availability of
8 supporting data for cancer-related endpoints. The most important factors that were considered
9 included the availability of in vivo data and whether multiple exposure routes were represented.
10 Other database characteristics that were considered included the availability of more than one in
11 vivo study, and whether effects were evident in more than one sex or species. The database
12 characteristics of exposure route, species, and gender are somewhat related (i.e., not independent
13 variables). For example, intraperitoneal injection studies were generally performed in both male
14 and female mice while lung implantation studies were conducted in rats only. An increase in the
15 number of exposure routes tested also results in generation of data for multiple species and
16 genders. The factors that were considered in the relative confidence rating for each RPF are
17 illustrated in Table 7-3.

Table 7-3. Relative confidence ratings for RPFs

PAH	Relative confidence	Tumor bioassay data					Supporting data for cancer-related endpoints
		In vivo data	>1 Exposure route	>2 Exposure routes	>1 Species	>1 Gender	
Benzo[b]fluoranthene	High	✓	✓	✓	✓	✓	✓
Benzo[j]fluoranthene	High	✓	✓	✓	✓	✓	✓
Chrysene	High	✓	✓	✓	✓	✓	✓
Dibenz[a,h]anthracene	High	✓	✓	✓	✓	✓	✓
Phenanthrene	High	✓	✓	✓	✓	✓	✓
Anthanthrene	Medium	✓	✓		✓		✓
Anthracene	Medium	✓	✓ ^a		✓ ^a		✓
Benz[a]anthracene	Medium	✓	✓			✓	✓
Benzo[c]fluorene	Medium	✓	✓				✓
Benzo[k]fluoranthene	Medium	✓	✓		✓		
Cyclopenta[c,d]pyrene	Medium	✓	✓			✓	✓
Dibenzo[a,l]pyrene	Medium	✓	✓			✓	✓
Pyrene	Medium	✓	✓			✓	✓
Benz[b,c]aceanthrylene, 11H-	Low	✓					
Benz[e]aceanthrylene	Low	✓				✓	✓
Benzo[g,h,i]perylene	Low	✓					✓
Benz[j]aceanthrylene	Low	✓					✓
Benz[l]aceanthrylene	Low	✓				✓	✓
Cyclopenta[d,e,f]chrysene, 4H-	Low	✓					
Dibenzo[a,e]fluoranthene	Low	✓					✓
Dibenzo[a,e]pyrene	Low	✓					✓
Dibenzo[a,h]pyrene	Low	✓					✓
Dibenzo[a,i]pyrene	Low	✓					✓
Fluoranthene	Low	✓				✓	✓
Indeno[1,2,3-c,d]pyrene	Low	✓					✓
Naphtho[2,3-e]pyrene	Low	✓					✓
Dibenz[a,c]anthracene	Very low						✓

^aBioassays of anthracene without benzo[a]pyrene included dermal studies in mice and a lung implantation study in rats.

1 *Very low relative confidence* was used to describe final RPFs based on cancer-related
2 endpoint data only (e.g., dibenz[a,c]anthracene).

3 For RPFs of zero, the confidence rating considered both the available tumor bioassays
4 (with and without benzo[a]pyrene) and the size and consistency of the cancer-related endpoint
5 database. An RPF of zero was only applied if the data implied *high* or *medium relative*
6 *confidence*. For anthracene, phenanthrene, and pyrene, the available data support a practical
7 RPF of zero.

8 9 **7.3. APPLICATION OF RPFs FOR ASSESSING CANCER RISKS FROM EXPOSURE** 10 **TO PAH MIXTURES**

11 In the proposed RPF approach, the cancer risk associated with exposure to a particular
12 mixture of PAHs is assumed to equal the sum of the risks associated with exposure to individual
13 carcinogenic components. Because quantitative cancer risk values are available only for
14 benzo[a]pyrene, exposure units (either concentrations or doses, in units of mass) for other PAHs
15 found in the mixture are expressed in terms of benzo[a]pyrene equivalents. These are summed
16 with benzo[a]pyrene to obtain an estimate of the total benzo[a]pyrene equivalents (in
17 concentration or dose) presented by the mixture. Benzo[a]pyrene equivalents for PAH
18 components in a particular mixture are calculated by multiplying the concentration (or dose) of a
19 particular PAH component in the mixture by its RPF. The total benzo[a]pyrene equivalents for a
20 particular mixture of PAHs is calculated as follows:

$$21 \qquad \qquad \qquad E = \sum RPF_j C_j + X$$

22
23
24 where:

- 25 E = the benzo[a]pyrene equivalent exposure presented by the mixture
26 RPF_j = relative potency factor of the jth PAH detected in the mixture
27 C_j = dose or concentration of the jth PAH detected in the mixture
28 X = dose or concentration of benzo[a]pyrene in the mixture.

29
30 The cancer risk for the PAH mixture is determined by multiplying the benzo[a]pyrene
31 equivalent dose or concentration by the benzo[a]pyrene cancer toxicity value (e.g., oral slope
32 factor). The proposed RPF approach considers each of the bioassay types used for RPF
33 derivation to be equivalent for the purpose of determining relative potency to benzo[a]pyrene.
34 The uncertainty associated with using a single RPF to derive benzo[a]pyrene equivalents for
35 multiple exposure routes is discussed in Section 8.6.

36 37 **7.4. SUSCEPTIBILITY FROM EARLY LIFE EXPOSURE TO CARCINOGENS**

38 According to the *Supplemental Guidance for Assessing Susceptibility from Early Life*
39 *Exposure to Carcinogens* (U.S. EPA, 2005b), benzo[a]pyrene is carcinogenic by a mutagenic

1 mode of action. For example, an acute dosing study using benzo[a]pyrene suggests that early-
 2 lifestage exposure would lead to an increased incidence of tumors compared with adult
 3 exposures of a similar dose and duration (EPA, 2005b). Mice that were treated with
 4 benzo[a]pyrene (75 or 150 µg/g body weight intraperitoneal) within 24 hours of birth or at
 5 15 days of age developed hepatomas at a higher incidence than similarly treated animals at
 6 42 days of age (Vesselinovitch et al., 1975, as cited in EPA 2005b).

7 The *Supplemental Guidance* establishes age-dependent adjustment factors (ADAFs) for
 8 three specific age groups. The ADAFs and their age groupings are 10 for <2 years, 3 for 2–<16
 9 years, and 1 for ≥16 years (U.S. EPA, 2005b). The 10- and 3-fold adjustments in slope factor are
 10 to be combined with age-specific exposure estimates when estimating cancer risks from early life
 11 (<16 years age) exposure to PAHs.

12 Because a mutagenic mode of action for benzo[a]pyrene carcinogenicity is sufficiently
 13 supported in laboratory animals and relevant to humans, and in the absence of chemical-specific
 14 data to evaluate differences in susceptibility, increased early-life susceptibility is assumed and
 15 the ADAFs should be applied, as appropriate. A common mutagenic mode of action for
 16 carcinogenic PAHs is hypothesized based on information available for the indicator chemical,
 17 benzo[a]pyrene (U.S. EPA, 2005b). In the absence of chemical-specific data to evaluate
 18 differences in susceptibility, increased early-life susceptibility to the 24 PAHs (for which RPFs
 19 were derived) in this analysis is assumed and the ADAFs should be applied, along with exposure
 20 information, as appropriate (see Table 7-4 for example).

21 Some of the studies used to derive RPFs for the PAHs were conducted in newborn mice.
 22 The RPFs calculated from the newborn mouse studies reflect only the potency of the tested PAH
 23 *relative to that of benzo[a]pyrene*, and do not take into account the potency of the PAH
 24 administered in newborn or young animals *relative to the potency of the same PAH* administered
 25 to adult animals. The ADAF should be applied to account for the latter difference.

26
**Table 7-4. Sample calculation of estimated cancer risk for
 benz[a]anthracene with the application of ADAFs**

Age group	ADAF	Benzo[a]pyrene oral slope factor (per mg/kg-d)	Adjusted benzo[a]pyrene cancer risk estimate	RPF	Benz[a]anthracene estimated cancer risk (per mg/kg-d)
0–<2	10	7.3	73	0.2	15
2–<16	3	7.3	24	0.2	4.8
≥16	1	7.3	7.3	0.2	1.5

27
 28

8. UNCERTAINTIES AND LIMITATIONS ASSOCIATED WITH THE RPF APPROACH

A description of uncertainties and limitations is an important component of the RPF approach for PAH mixtures risk assessment. Many of the general uncertainties related to chemical-specific risk assessment are also applicable to the proposed RPF approach for PAHs. These include issues related to selection of an appropriate animal model, low-dose and interspecies extrapolation, and variability within the human population. Use of a component-based approach to mixtures risk assessment leads to additional uncertainties, e.g., the lack of experimental data on potential interactions among individual components within the mixture (i.e., among PAHs and with other chemicals).

The feasibility of conducting a robust component-based approach for PAH mixtures (RPF approach) was evaluated by a PAH mixtures peer consultation workshop (U.S. EPA, 2002). Included in the discussion was a general evaluation of U.S. EPA's *Provisional Guidance* (U.S. EPA, 1993). Workshop participants highlighted the following limitations of the 1993 guidance:

- (1) The approach only considered a small subset of PAHs (i.e., unsubstituted PAHs only, no heterocyclic compounds or nitro- or alkyl- substituted PAHs);
- (2) There are no human toxicity data for any individual PAH;
- (3) The assumption of additivity may not be valid, and there may be interactions among PAHs or between PAHs and other components of a mixture (e.g., metals);
- (4) PAHs may generally have a common mode of action (i.e., mutagenicity), but multiple modes of action for carcinogenesis are possible; and
- (5) The EOPP approach was limited to the oral exposure route (i.e., a recommendation was made not to apply the factors to dermal and inhalation exposures).

The current analysis represents a significant improvement upon the previous component-based approach for PAH mixtures risk assessment. One of the most important improvements is a comprehensive review of the scientific literature dating from the 1950s through 2009 on the carcinogenicity and genotoxicity of PAHs. The search identified over 900 individual publications for a target list of 74 PAHs that had been identified in environmental media or for which toxicological data were available. Review of these publications resulted in the identification of more than 600 papers that included carcinogenicity or cancer-related endpoint data on at least one PAH and benzo[a]pyrene tested at the same time. Dose-response data were extracted, and individual RPFs were calculated from over 300 data sets representing

1 51 individual PAHs. For 35 PAHs, a weight of evidence evaluation was conducted to select
2 compounds for inclusion in the RPF approach; data were inadequate to conduct such an
3 evaluation for the remaining 16 compounds. A final RPF was derived for each PAH based on
4 tumor bioassay data (if available) or cancer-related endpoint data if no tumor bioassay RPFs
5 were available. Final RPFs were derived for 27 PAHs (see Table 7-2), significantly increasing
6 the number of PAHs that can be addressed through this approach. Each RPF was assigned a
7 relative confidence rating reflecting the size and diversity of the tumor bioassay or cancer-related
8 endpoint database that was used to derive the final RPF for that PAH.

9 Despite these improvements, many of the uncertainties highlighted during the 2002 peer
10 consultation workshop (U.S. EPA, 2002) also apply to the current analysis. The following
11 sections describe some specific uncertainties and limitations associated with the development
12 and use of RPFs for PAHs. The uncertainties that are specific to the approach presented herein
13 are discussed below in Sections 8.1 and 8.2. Sections 8.3–8.6 discuss the general uncertainties
14 associated with a component-based approach to PAH mixtures risk assessment. These include
15 the number of PAHs included in the approach, human relevance of animal data, assumptions
16 regarding mode of action and dose additivity, and cross-route extrapolation.

17

18 **8.1. DOSE-RESPONSE ASSESSMENT FOR INDIVIDUAL PAHs**

19 Several uncertainties and limitations are specifically associated with the selection of data
20 and dose-response assessment methodology used in this analysis to derive RPFs for PAHs.
21 Uncertainties are associated with the following decisions:

- 22
- 23 • Inclusion of data from studies reporting the occurrence of benign tumors in derivation
24 of RPFs;
- 25
- 26 • Use of a single dose-response model for quantal or continuous data;
- 27
- 28 • Use of varying BMR levels;
- 29
- 30 • Use of tumor incidence data at the upper end of the dose-response curve (e.g., >75%
31 incidence) to calculate some RPFs;
- 32
- 33 • Use of tumor multiplicity data to calculate some RPFs;
- 34
- 35 • Use of single-dose point estimates⁷ to calculate some RPFs;
- 36
- 37 • Reliance on data from cancer-related endpoint studies in the absence of bioassays;
38 and
- 39

⁷In this report, the term “point estimate RPF” is used to describe an RPF calculated from a single point on the dose-response curve for both the PAH of interest and benzo[a]pyrene. This term distinguishes the RPF from one calculating using a BMD modeling result from multidose data.

- Use of cancer-related data from assay conditions that maximize the benzo[a]pyrene response, even though these conditions were not necessarily optimal for other PAHs.

The decision was made to employ a single dose-response model for either quantal or continuous data due to the large number of data sets that needed be analyzed from the PAH database. The multistage model for incidence data and the linear model for continuous data were considered to be broadly applicable to different types of data as simple curve-fitting models. In some cases, the goodness-of-fit criteria indicated that the selected model did not fit the data. In these cases, high-dose groups were sequentially eliminated until an adequate fit was achieved, but other model structures (e.g., gamma, probit, logistic, etc.) were not considered.

Tumor bioassay data were modeled at a BMR of 10% in order to target the low end of the dose-response curve as the point of departure for slope estimation. When this was not feasible, usually because only a single dose was used for benzo[a]pyrene, an attempt was made to match individual target PAH response levels to the benzo[a]pyrene response chosen for the point estimate. This assumes that the shape of the dose-response curve is similar for the target PAH and benzo[a]pyrene (also a necessary assumption of dose additivity) and that the slope is constant across the dose-response curve. These assumptions may not hold, especially in studies of tumor incidence where the point estimate benzo[a]pyrene response was very high or near maximal. In many cases, the dose of benzo[a]pyrene selected as the positive control produced near maximal tumor incidence in exposed animals (i.e., >75%). There is uncertainty associated with comparing potency estimates at the high end of the dose-response curves and using the resultant RPF to estimate risks associated with low environmental exposures. The relative potency relationship between any two PAHs may be different at the low end, compared with the high end, of the dose-response curves.

It is not clear whether relative potency values estimated at the high end of the dose-response curve are reasonably predictive of relative potency at low environmental exposure levels. For this reason, additional uncertainty is involved in using RPFs that are not based on a BMR of 10% (especially those RPFs that are based on responses exceeding 75%) to estimate risks associated with low exposures.

If model fit was not achieved, then a point-estimate ratio approach was used. Point estimate ratios were also used for several other reasons:

- (1) Only a single dose group was tested;
- (2) When the standard deviation or number of replicates were not reported for continuous data sets; or
- (3) High-dose groups from multiple dose data sets were not usable due to a saturated tumor response (>90% incidence in the lowest exposure group).

1 The point estimate approach is most reliable when the chosen point is in the linear
2 portion of the dose-response curve. In many cases, however, especially for single-dose data, it
3 was not possible to determine whether the chosen point was in a linear or nonlinear portion of
4 the dose-response curve. The dose-response relationship observed in many studies of cancer-
5 related endpoints was nonlinear at high doses. Whenever possible, the point estimate was chosen
6 from the linear portion of the dose-response curve (i.e., before the response plateau that occurs at
7 high doses). Of 50 individual RPFs calculated from tumor incidence data, 21 were calculated
8 using a point of departure incidence $\leq 25\%$, 19 were calculated using a point of departure
9 incidence between 25 and 75%, and the remaining 10 were calculated using a point of departure
10 incidence between 75 and 90%. Thus, only 20% of the individual RPFs for tumor incidence data
11 were calculated from a point high (>75 and $<90\%$ incidence) on the dose-response curve.

12 For a few PAHs tested in older dermal bioassays, the authors reported mortality prior to
13 the appearance of the first tumor. For these data sets, an assumption was made that the number
14 of animals at risk for tumor development was equal to the total number of animals alive at the
15 time of the appearance of the first tumor. This approach ensures that the incidence is not
16 underestimated by including animals that did not survive long enough to develop tumors. As this
17 assumption applied to a small number of RPFs (specifically, individual RPFs for chrysene,
18 dibenzo[a,e]pyrene, dibenzo[a,e]fluoranthene, and dibenzo[a,h]pyrene calculated from data
19 reported by Hecht et al. [1974] and Hoffmann and Wynder [1966]), it had little impact on the
20 overall analysis.

21 RPFs were also calculated for many cancer-related endpoints. Many of the studies
22 describing in vitro cancer-related endpoints provided dose-response data under varying study
23 conditions. For example, bacterial mutagenesis studies utilized multiple strains, different
24 metabolic activation processes, and varying assay systems. In order to minimize the amount of
25 data used for dose-response analysis of in vitro mutagenicity studies, and to provide a consistent
26 basis for comparing RPFs for different PAHs, the data from conditions that maximize the
27 benzo[a]pyrene response within a particular study were used for the dose-response assessment.
28 In several studies, the conditions that were optimal for benzo[a]pyrene were not necessarily
29 optimal for the target PAH. For example, the concentration of S9 mix that produced the highest
30 mutation rate for benzo[a]pyrene did not produce a maximal response for perylene or
31 cyclopenta[c,d]pyrene (Carver et al., 1986; Eisenstadt and Gold, 1978). In vitro data were only
32 used in the derivation of a single final RPF (for dibenz[a,c]anthracene; see Table 7-2); thus, the
33 uncertainties associated with the use of cancer-related endpoint data are important for
34 dibenz[a,c]anthracene, but have minimal impact on the proposed RPFs for the other 26 PAHs.

35 36 **8.2. SELECTION OF PAHs FOR INCLUSION IN RPF APPROACH**

37 One of the uncertainties highlighted by the peer consultation workshop (U.S. EPA, 2002)
38 stemmed from the fact that U.S. EPA's 1993 provisional EOPP approach only considered a small

1 subset of PAHs (i.e., unsubstituted PAHs only, no heterocyclic compounds or nitro- or alkyl-
2 substituted PAHs), and EOPPs were available for only seven PAHs. Although the present report
3 considered a larger number of PAHs than previous analyses (the toxicological literature was
4 searched for data on 74 individual PAHs identified in environmental media or for which there
5 were toxicological data), the focus of this analysis remains limited to unsubstituted PAHs with
6 three or more fused aromatic rings containing only carbon and hydrogen atoms. Thus, the RPF
7 analysis presented here does not account for the possible carcinogenicity of substituted or
8 heterocyclic PAHs that may be present in complex mixtures. This may result in an
9 underestimation of PAH mixture cancer risk.

10 Of the 74 unsubstituted PAHs with three or more aromatic rings, there were studies
11 including benzo[a]pyrene that were suitable for RPF calculation for 51 compounds. The
12 methodology for selecting PAHs for inclusion in the RPF approach from among these 51 PAHs
13 is described in Chapter 6. At the outset, 16 PAHs were excluded because only one or two in
14 vitro cancer-related endpoint RPFs were available. The remaining 35 PAHs were evaluated
15 using a weight of evidence approach. The primary uncertainties associated with the selection
16 process relate to:

- 17
- 18 (1) The use of a weight of evidence approach that focused on tumor bioassays including
19 benzo[a]pyrene as opposed to a comprehensive cancer assessment to select PAHs for
20 inclusion in the approach; and
 - 21 (2) The exclusion of PAHs with limited or inconclusive data.
- 22
23

24 The weight of evidence approach was used due to the large number of compounds that
25 were under consideration. The approach was structured as a decision tree that focused primarily
26 on cancer bioassays that included benzo[a]pyrene, and only considered other data (e.g., bioassays
27 that did not include benzo[a]pyrene, or cancer-related data) when cancer bioassays with
28 benzo[a]pyrene were unavailable, nonpositive, or inconsistent (see Figure 6-1). The data
29 collection for this analysis was centered on studies that included benzo[a]pyrene, as these studies
30 would be most useful for RPF calculation. Consequently, information from bioassays that
31 included benzo[a]pyrene were readily available for use in the weight of evidence determinations.
32 Bioassays that did not include benzo[a]pyrene and cancer-related endpoint data were considered
33 only when there were conflicting or nonpositive results in the studies that did include
34 benzo[a]pyrene. There is uncertainty in drawing conclusions as to carcinogenicity based on a
35 narrow subset of the available database. Other elements of a more comprehensive weight of
36 evidence determination that were not considered include: cancer-related endpoint data from
37 studies that did not include benzo[a]pyrene; information on tumorigenicity of metabolites;
38 information on formation of reactive metabolites; other mechanistic data (e.g., AhR reactivity,
39 inhibition of gap junction intercellular communication, etc.); and QSAR assessment.

1 A number of PAHs (24 of 51 PAHs that had at least one RPF value) were excluded from
2 the relative potency approach because the available data were inadequate to draw a conclusion as
3 to carcinogenicity (see Tables 6-1 and 6-2). All of these PAHs had at least one RPF, indicating
4 that the compounds were active in at least one cancer-related endpoint assay. Excluding these
5 PAHs from the approach increases the uncertainty in assessing risks from a mixture that includes
6 them, particularly if the excluded PAHs constitute a large fraction of the mixture.

7 In summary, RPFs were proposed for only 27 of the 74 PAHs initially considered,
8 because the remaining 47 compounds did not have adequate data. Thus, even among the subset
9 of PAHs upon which this analysis was focused, RPFs were only recommended for only about
10 one-third of the compounds. Because only a fraction of any given PAH mixture can be
11 evaluated using the RPF approach, it is important to note as part of the uncertainty evaluation of
12 a risk assessment using these RPFs that there is some proportion of the total mixture (i.e., mass
13 fraction) that is comprised of compounds that are not considered in the component-based
14 approach.

15 **8.3. DERIVATION OF A FINAL RPF FOR EACH PAH**

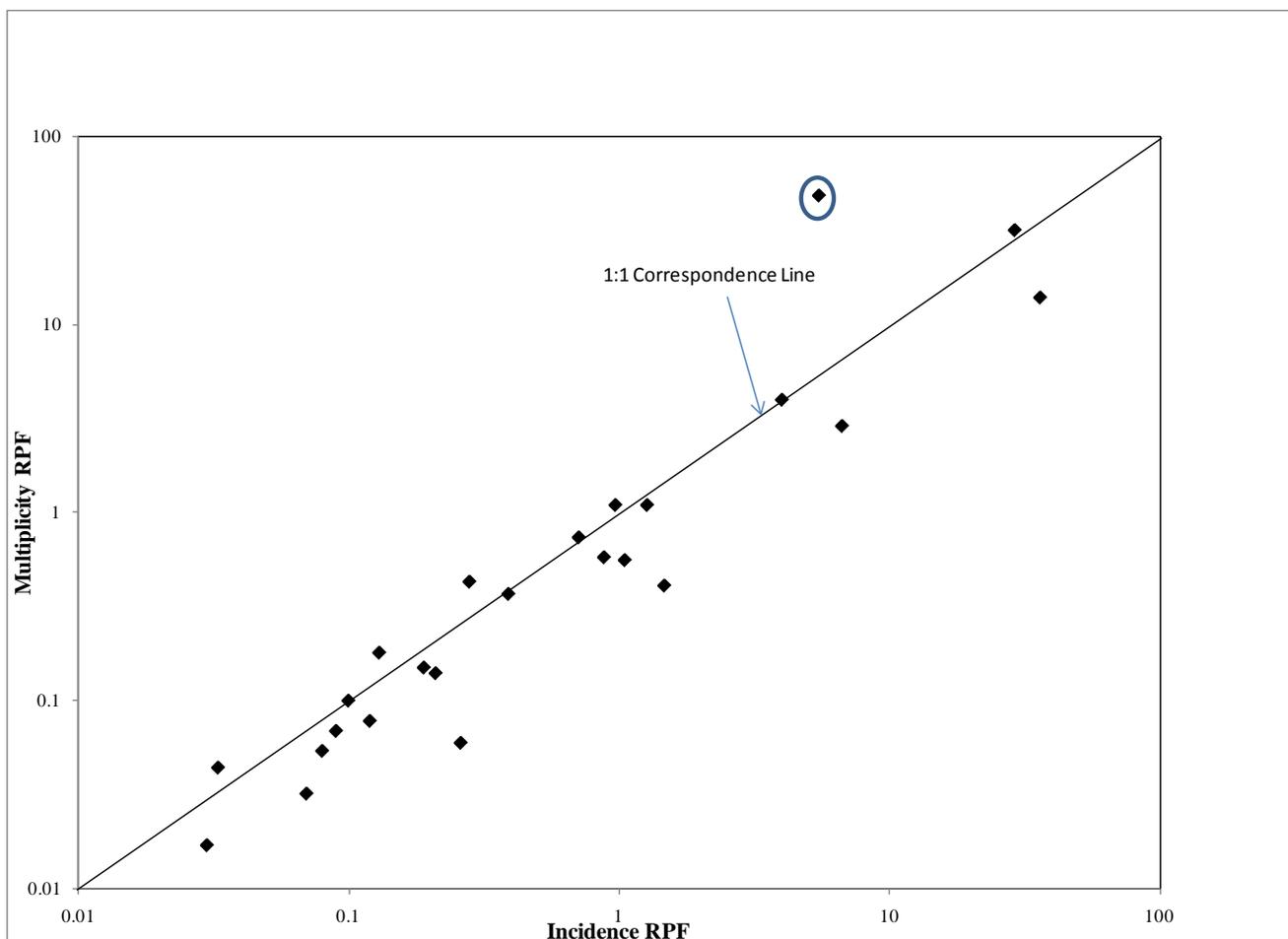
16 The methodology for deriving a final RPF value and assigning a relative confidence
17 rating is described in Sections 7.1 and 7.2. The primary uncertainties associated with RPF
18 derivation relate to:
19

- 20 (1) Combining RPFs across multiple exposure routes, species, sexes, tumor types, and
21 studies;
- 22 (2) Inclusion of RPFs based on tumor multiplicity data in the combined data;
- 23 (3) Inclusion of RPFs from female newborn mice when male RPF values were
24 demonstrably higher;
- 25 (4) Use of an arithmetic mean to derive final RPFs; and
- 26 (5) Use of cancer-related endpoint data to derive final RPFs for compounds without
27 tumor bioassay RPFs.

28 A variety of options were considered for prioritizing and/or combining RPFs.
29 Appendix G describes analyses that were undertaken to assess options for prioritizing RPFs. As
30 the appendix indicates, the current state of knowledge does not suggest a clear biological basis
31 for prioritizing RPFs. As a result, RPFs were combined across exposure routes, species, sexes,
32 tumor types, dose-response methods, and studies.

33 In addition to tumor incidence data, tumor multiplicity data were used to calculate RPFs.
34 The relationship between tumor incidence RPFs and tumor multiplicity RPFs is not known;
35 however, this analysis resulted in the calculation of both incidence and multiplicity RPFs for
36

1 24 individual datasets. These data were plotted, and a linear regression analysis was performed
2 to assess the correlation between these two relative potency estimates. Figure 8-1 shows the
3 results.



4
5 **Figure 8-1. Correlation between incidence and multiplicity RPFs.**
6

7 As shown in Figure 8-1, there is a high degree of correspondence between incidence and
8 multiplicity RPFs calculated from results in the same animals, with one exception (see circled
9 data point). The regression analysis indicated an r^2 of 0.76 for the correlation when the outlier
10 was excluded, or only 0.28 when it was included. The outlier datapoint reflects the incidence
11 and multiplicity RPFs for benzo[c]fluorene calculated for the one oral study (Weyand et al.,
12 2004). All of the other datapoints reflect incidence and multiplicity RPFs for dermal or
13 intraperitoneal exposure studies; thus, one possible explanation for the outlier is that the
14 relationship between incidence and multiplicity after oral exposure differs from the relationship
15 after exposure via other routes. However, there was good correspondence between incidence
16 and multiplicity in dermal and intraperitoneal studies, despite the marked differences in
17 absorption, distribution, and metabolism of PAHs administered by these two exposure routes.

1 Compound-specific differences in the association between incidence and multiplicity RPFs also
2 seem unlikely; the dataset shown in Figure 8-1 also includes a comparison between incidence
3 and multiplicity RPFs for benzo[c]fluorene in an intraperitoneal exposure study, and there is
4 good correspondence between the two (RPF = 1 for incidence and RPF = 0.6 for multiplicity).
5 The most plausible explanation for the outlier is that the basis for the multiplicity RPF in the oral
6 study of benzo[c]fluorene (RPF = 50) was estimated using a point high on the dose-response
7 curve (incidence was 100%), at which a large mean number of tumors per animal (46 ± 2.8) was
8 recorded, while the incidence RPF (RPF = 5) for the same study was estimated using BMD
9 modeling at a response point lower on the curve (BMR of 0.7). All of the other comparisons
10 between incidence and multiplicity RPFs from the same set of animals were based on
11 multiplicity responses <10 tumors per animal. Although there is little information with which to
12 explore this hypothesis, it is possible that RPFs for multiplicity that are calculated using
13 unusually high tumor number are not reliable measures of relative incidence potency. This could
14 result from changes in the slope of the tumor number versus dose curve at high tumor number, or
15 from methodology limitations that hamper accurate measurement of high tumor numbers.

16 Notwithstanding the one outlier, as the remaining incidence and multiplicity RPFs from
17 the same study were highly correlated, only one of the two metrics (the higher of the incidence or
18 multiplicity RPF from the same study) was included in the average and range. Figure 8-1 shows
19 that multiplicity RPFs exhibit a slight tendency to underestimate the RPF from incidence data
20 (more points are to the right of the 1:1 correspondence line); thus, the higher value was usually
21 calculated from incidence data. Specifically, 15/24 incidence RPFs were higher than the
22 corresponding multiplicity RPF from the same study, and 2/24 of the incidence and multiplicity
23 RPFs were identical. Thus, only 7/24 multiplicity RPFs were higher than their corresponding
24 incidence RPFs.

25 As discussed in Section 7.1, in newborn mouse studies that resulted in nonzero RPFs for
26 both males and females (LaVoie et al., 1994, 1987; Wislocki et al., 1986), the male RPF was
27 typically three- to fivefold higher than the female RPF, but both were included in the final RPF
28 calculation. Final RPFs that included both male and female values from the same study were
29 calculated for three PAHs: benzo[a]anthracene, benzo[j]fluoranthene, and fluoranthene. An
30 alternative approach would be to select the RPF associated with the most sensitive sex (i.e.,
31 males) and to omit the female RPF from the final calculation. The net effect of including female
32 RPFs for these three compounds is to reduce the average RPF and, in some cases, to reduce the
33 lower limit of the range of RPFs. For benzo[a]anthracene and benzo[j]fluoranthene, the final
34 RPF is unchanged whether or not the female RPF is included. For fluoranthene, inclusion of the
35 female RPFs yields a final RPF of 0.08, while excluding the female RPFs would result in a final
36 RPF of 0.1.

37 Final RPFs were calculated as the arithmetic mean and range of RPFs from tumor
38 bioassay data when such data were available. Presenting the average and the range provides both

1 an average and a maximum estimate for each PAH that has data from multiple studies. Other
 2 options for deriving a central tendency RPF include geometric mean, median, weighted average,
 3 and order of magnitude estimates. The arithmetic mean represents a simple approach to
 4 describing the calculated RPF values available for each PAH. There were usually not enough
 5 data (≤ 3 RPFs for 18/24 PAHs with nonzero RPFs) to assess the shape of the RPF distribution
 6 for any given PAH, so a geometric mean was not considered. Calculation of a weighted average
 7 was considered, but without a clear biological rationale for assigning weights among study types
 8 or tumor data outcomes, using a weighting approach might increase uncertainty. Finally, the use
 9 of simple means and ranges of estimated RPFs rather than order of magnitude estimates, as has
 10 been previously done for estimating RPFs for PAHs, was considered to better reflect the
 11 available data and provide a clearer characterization of uncertainty.

12 Cancer-related endpoint data were relied upon for the derivation of an RPF for only one
 13 PAH (dibenz[a,c]anthracene). For this compound, there were no tumor bioassay data suitable for
 14 the determination of an RPF. However, cancer-related endpoint data provided qualitative
 15 support for the finding of carcinogenicity for this compound (see individual narrative for this
 16 compound in Section 6.2). Although the mutagenic mode of action for benzo[a]pyrene (U.S.
 17 EPA, 2005b) suggests that, in general, these endpoints may be relevant to PAH carcinogenicity,
 18 the predictive value of a positive response in these tests has not been conclusively demonstrated.
 19 Thus, there is considerable uncertainty in an RPF based on cancer-related endpoint data.
 20 Appendix G includes analysis of the correlation between average RPFs calculated from cancer-
 21 related endpoint data and tumor bioassay data. As shown in Table 8-1, and further discussed in
 22 Appendix G, cancer-related endpoint RPFs are reasonably predictive of tumor bioassay RPFs;
 23 however, the relationship between these RPFs and the relative potency of a given PAH in
 24 humans exposed via environmentally relevant routes is unknown.

25

Table 8-1. Results of simple linear regression of log-transformed average tumor bioassay RPF versus log average genotoxicity RPF

Genotoxicity endpoint	r ²	Slope	p-Value	n
All in vivo DNA adducts	0.64	1.22	<0.01	10
All in vivo nonbioassays	0.55	1.16	<0.01	11
All nonbioassay endpoints (in vitro and in vivo)	0.40	1.10	<0.01	20
All in vitro nonbioassays	0.39	0.91	<0.01	19
All in vivo micronuclei and sister chromatid exchanges	0.39	0.81	>0.05 (nonsignificant)	6
All in vitro mutagenicity	0.032	0.33	>0.05 (nonsignificant)	17

26

27 For three PAHs (anthracene, phenanthrene, and pyrene), a final RPF of zero was
 28 recommended. As noted earlier in Chapter 6, there is little quantitative difference between
 29 selecting a final RPF of zero for a given PAH and excluding that PAH from the RPF approach.
 30 However, excluding PAHs from the RPF approach implies substantial uncertainty (these

1 compounds could be of low or high potency), while assigning an RPF of zero suggests lower
 2 uncertainty because there is evidence to suggest that these compounds are not carcinogenic.
 3 Nevertheless, there remains uncertainty in the RPFs for these three compounds, as all of them
 4 included one or more studies suggesting activity in cancer-related endpoint assays. In addition, it
 5 is possible that available bioassay studies for these compounds may not provide sufficient
 6 sensitivity to allow for a potency comparison with benzo[a]pyrene; thus, the RPF of zero should
 7 not be considered a characterization of the inherent carcinogenicity of anthracene, phenanthrene,
 8 or pyrene.

9 In the present analysis, RPFs for individual PAHs were based on data of varying quality
 10 and reproducibility, so there is additional uncertainty in risks estimated for mixtures containing
 11 differing concentrations of individual PAHs. Confidence ratings were assigned to each RPF to
 12 qualitatively characterize the uncertainty in each individual RPF. Table 8-2 shows the
 13 distribution of PAHs with RPFs of each confidence rating. As the table indicates, there are
 14 5 PAHs with RPFs of high confidence, 8 PAHs with RPFs of medium confidence, 13 PAHs with
 15 RPFs of low confidence, and 1 PAH with an RPF of very low confidence. The confidence
 16 ratings assigned to the RPFs may be used to qualitatively assess the uncertainty in a mixtures risk
 17 assessment that utilizes the RPFs. For example, if a high proportion of the total cancer risk
 18 predicted for a given mixture is attributable to benzo[a]pyrene and other PAHs with RPFs of
 19 high or medium confidence, then the confidence in the overall cancer risk assessment will be
 20 relatively high. If, in contrast, benzo[a]pyrene contributes a relatively small fraction of the
 21 overall risk, and/or the mixture consists primarily of PAHs with RPFs of low confidence, then
 22 the confidence in the overall cancer risk assessment will be correspondingly lower. Thus, it will
 23 be important to consider the relative contribution of benzo[a]pyrene to the total risk, as well as
 24 the relative confidence ratings of the RPF values for component PAHs, in the uncertainty
 25 evaluation for cancer risk assessments that employ these RPFs.

Table 8-2. PAHs with RPFs of varying relative confidence

High confidence RPF	Medium confidence RPF	Low confidence RPF	Very low confidence RPF
Benzo[b]fluoranthene Benzo[j]fluoranthene Chrysene Dibenz[a,h]anthracene Phenanthrene	Anthanthrene Anthracene Benz[a]anthracene Benzo[c]fluorene Benzo[k]fluoranthene Cyclopenta[c,d]pyrene Dibenzo[a,l]pyrene Pyrene	Benz[b,c]aceanthrylene, 11H- Benz[e]aceanthrylene Benzo[g,h,i]perylene Benz[j]aceanthrylene Benz[l]aceanthrylene Cyclopenta[d,e,f]chrysene, 4H- Dibenzo[a,e]fluoranthene Dibenzo[a,e]pyrene Dibenzo[a,h]pyrene Dibenzo[a,i]pyrene Fluoranthene Indeno[1,2,3-c,d]pyrene Naphtho[2,3-e]pyrene	Dibenz[a,c]anthracene

27

1 **8.4. USE OF ANIMAL DATA TO PREDICT HUMAN CANCER RISK FOR PAHs**

2 Section 4.2 briefly summarizes the epidemiology and human biomarker data related to
3 exposure to PAH mixtures and carcinogenicity. Exposure to certain PAH mixtures is clearly
4 associated with cancer in humans. Epidemiology studies evaluating emissions from coke
5 production, coal gasification, aluminum production, iron and steel founding, coal tars, coal tar
6 pitches, and soot have demonstrated associations between exposure and increased risk of lung
7 cancer in humans (see review of Bostrom et al., 2002). Skin and scrotal cancers have been
8 associated with exposure to coal tar, coal tar pitches, nonrefined mineral oils, shale oils, and soot
9 (Larsen and Larsen, 1998; WHO, 1998; ATSDR, 1995). While human epidemiology data may
10 be sufficient for the purpose of quantifying the cancer risks associated with exposure to a few
11 PAH mixtures, there are no data for many mixtures; hence the need for other approaches
12 including surrogate-mixture and component-based approaches. As noted by the peer
13 consultation workshop (U.S. EPA, 2002), there are no human data on cancer response to
14 individual PAHs that could be used as the basis for, or as a supplement to, a component-based
15 approach. As a result, the RPF approach relies on animal bioassay data to predict human cancer
16 risk associated with individual PAHs.

17 The use of animal bioassays in predicting relative carcinogenic potency in humans
18 represents a source of uncertainty in this approach. As there are no human data on cancer
19 response to individual PAHs, including benzo[a]pyrene, there can be no quantitative evaluation
20 of uncertainty in extrapolating from RPFs based on animal bioassay data to relative potency in
21 humans. Possible species differences in toxicokinetics, toxicodynamics, and mode of action
22 contribute to the uncertainty. Cancer-related endpoint data are available using human cells (e.g.,
23 epidermal keratinocytes, lymphoblasts, human epithelial cells) for the evaluation of
24 mutagenicity, DNA adducts, unscheduled DNA synthesis, DNA damage, and clastogenicity or
25 sister chromatid exchange frequency (see Section 4.3). Findings in human cells were generally
26 consistent with those in other mammalian cells; however, whether this finding of consistency
27 extends to effects in vivo, and specifically to formation of tumors, is not known.

28 In addition, animal bioassays use various routes of administration (e.g., intraperitoneal
29 and subcutaneous injection), which may not be directly relevant to expected routes of exposure
30 for humans. It is difficult to determine whether the relative potency based on animal bioassays
31 using injection routes of exposure is predictive of relative potency that would be observed in
32 humans exposed through environmentally relevant exposure routes (see further discussion of
33 exposure-route uncertainties in Section 8.6). An additional source of uncertainty in the use of
34 animal bioassay data stems from differences in the doses used in animal bioassays as compared
35 with low doses received by humans exposed in the environment. Mechanistic data, primarily
36 obtained using benzo[a]pyrene, provide support for the human relevance of PAH tumorigenicity
37 in animals. There is evidence linking three pathways activating benzo[a]pyrene to DNA-reactive
38 agents [(+)-anti-BPDE, radical cations, benzo[a]pyrene-7,8-dione, and reactive oxygen species]

1 with key mutational events in genes (p53 tumor suppressor gene and H-ras or K-ras oncogenes)
2 that can lead to tumor initiation. Results in support of mutagenic modes of action via the diol
3 epoxide and radical cation pathways include in vivo results in animals. All of these activation
4 pathways occur in human tissues, and associations have been made between spectra of mutations
5 in the p53 tumor suppressor gene or ras oncogenes induced by benzo[a]pyrene metabolites with
6 spectra of mutations in these genes in tumor tissue from benzo[a]pyrene-exposed animals or
7 tumor tissue in humans.

8 Support for the association between the diol epoxide pathway and tumor initiation
9 includes observation that: (+)-anti-BPDE activated the H-ras-1 proto-oncogene to transform
10 NIH/3T3 cells via G→T point mutations in the 12th codon (Marshall et al., 1984); (+)-anti-
11 BPDE reacts with the p53 tumor suppressor gene at several hotspots mutated in lung cancer
12 patients (Denissenko et al., 1996; Puisieux et al., 1991); the spectra of p53 and K-ras mutations
13 in lung tumors of nonsmoking patients, chronically exposed to smoky coal emissions, was
14 consistent with (+)-anti-BPDE mutations in these genes (DeMarini et al., 2001); elevated BPDE-
15 DNA adducts have been observed in coke oven workers and chimney sweepers (Pavanello et al.,
16 1999); and the spectra of mutation in the K-ras, H-ras, and p53 genes in forestomach tumors of
17 mice fed benzo[a]pyrene in the diet for 2 years were consistent with (+)-anti-BPDE DNA
18 reactions (Culp et al., 2000).

19 Support for the radical cation pathway includes observations that depurinated adducts,
20 (expected products from reactions of benzo[a]pyrene radical cations with DNA) accounted for
21 74% of identified DNA adducts in mouse skin exposed to benzo[a]pyrene (Rogan et al., 1993)
22 and 9/13 examined tumors from mice exposed to dermal applications of benzo[a]pyrene had
23 H-ras oncogene mutations attributed to depurinated DNA adducts from benzo[a]pyrene radical
24 cations (Chakravarti et al., 1995).

25 Support for the aldo-keto reductase pathway includes in vitro demonstration that several
26 types of DNA damage can occur from o-quinones and reactive oxygen species (Park et al., 2006;
27 Balu et al., 2004; McCoull et al., 1999; Flowers-Geary et al., 1997, 1996), benzo[a]pyrene-
28 7,8-dione can induce mutations in the p53 tumor suppressor gene using an in vitro yeast reporter
29 gene assay (Park et al., 2008; Shen et al., 2006; Yu et al., 2002), and dominant p53 mutations
30 induced by benzo[a]pyrene,7,8-dione in this system corresponded with p53 mutation hotspots
31 observed in human lung cancer tissue (Park, 2008).

32 All three activation pathways are expected to occur in human tissues (Jiang et al., 2007),
33 and associations have been made between spectra of mutations in the p53 tumor suppressor gene
34 or ras oncogenes induced by benzo[a]pyrene metabolites with spectra of mutations in these genes
35 in tumor tissue from benzo[a]pyrene-exposed animals or humans. In particular, DeMarini et al.
36 (2001) demonstrated mutations in the p53 tumor suppressor gene and the K-ras oncogene in the
37 lung tumors of nonsmokers, whose tumors were associated with exposure to smoky coal.

1 The available information supporting these actions for benzo[a]pyrene is consistent with
2 what is known about the mode of action for other PAHs demonstrated to induce cancer in
3 animals, including cyclopenta[cd]pyrene, dibenz[a,h]anthracene, and dibenzo[a,l]pyrene
4 (Cogliano et al., 2008; Straif et al., 2005). All PAHs that have been studied require metabolic
5 activation to produce carcinogenic responses in animals, and there is evidence for activation to
6 DNA reactive intermediates via several pathways (Straif et al., 2005; Xue and Warshawsky,
7 2005; WHO, 1998; Cavalieri and Rogan, 1995). For example, incubation of rat liver
8 microsomes with dibenzo[a,l]pyrene, a PAH that is more tumorigenically potent than
9 benzo[a]pyrene in mouse skin and rat mammary tissue, formed depurinated DNA adducts from
10 the radical cation pathway, as well as DNA adducts from the diol epoxide pathway (Cavalieri
11 and Rogan, 1995).

12 In summary, the relevance of animal bioassay data to the prediction of human
13 carcinogenic potency remains a significant area of uncertainty in the use of this and other
14 approaches to PAH cancer risk assessment. However, mechanistic data on benzo[a]pyrene and
15 other PAHs provide evidence that the molecular events leading to PAH-induced tumor formation
16 in animals are relevant to humans.

17

18 **8.5. ASSUMPTIONS OF A COMMON MODE OF ACTION AND DOSE ADDITIVITY**

19 A discussion of the potential modes of action for PAH carcinogenicity is presented in
20 Section 2.4. Individual carcinogenic PAHs are linked by a common effect (i.e., tumorigenicity),
21 which may occur through multiple mechanisms. Reactive metabolites produced during
22 metabolic transformations of PAHs include diol epoxides, reactive oxygen species, radical
23 cations, and o-quinones. The formation of these metabolites is not mutually exclusive, and the
24 carcinogenic process for PAHs is likely to be related to some combination of molecular events
25 resulting from formation of several reactive species. Reactive metabolites of PAHs interact with
26 DNA to form adducts and produce DNA damage resulting in mutations in cancer-related genes
27 such as tumor suppressor genes or oncogenes. These events appear to reflect the initiation
28 potency of an individual PAH (e.g., strong mutagens are generally potent initiators) (Sjogren et
29 al., 1996). Certain PAHs exhibit promotional effects that may be related to cytotoxicity and the
30 formation of reactive oxygen species, AHR affinity, and the upregulation of genes related to
31 biotransformation (i.e., induction of CYP1A1), growth, and differentiation (Bostrom et al.,
32 2002). The inhibition of gap junctional intracellular communication is also related to tumor
33 promotion by PAHs (Bostrom et al., 2002). The ability of certain PAHs to act as tumor
34 promoters as well as initiators may increase their carcinogenic potency in animal bioassays
35 conducted at high doses. Initiation potency may be more relevant to low-level environmental
36 exposure in humans (Bostrom et al., 2002; Sjogren et al., 1996); however, the proposed RPF
37 approach is not unduly affected by this as it relies largely on high-dose animal bioassay data for

1 selecting RPF values. This represents an uncertainty in the use of the RPF approach in
2 estimating human cancer risks from PAHs.

3 Conceptually, the uncertainty related to relative potency for initiation versus promotion
4 could be reduced by using separate RPF schemes for each part of the carcinogenic process. This
5 would require selection of indicator compounds that best represent the initiation and promotion
6 processes, and use of mechanistic data to determine relative potency for each process (i.e.,
7 mutagenicity for initiation, AhR binding, or enzyme induction for promotion). There are several
8 problems with this approach, including the lack of data to support the selection of indicator
9 compounds and the complete carcinogenic nature of many PAHs (i.e., they act as both initiators
10 and promoters). The initiation and promotion potency of an individual PAH is determined by its
11 chemical structure. Some PAHs are strong mutagens, but have low affinity for the AhR (e.g.,
12 fjord-region PAHs) (Bostrum et al., 2002; Sjogren et al., 1996). Other PAHs are complete
13 carcinogens, with initiating properties (i.e., mutagenesis) and AhR affinity leading to tumor
14 promotion (e.g., benzo[a]pyrene, dibenz[a,h]anthracene) (Bostrum et al., 2002; Sjogren et al.,
15 1996). Benzo[a]pyrene is considered a good indicator compound for similar PAHs with
16 complete carcinogenic activity. However, the relative potency of other PAHs, especially those
17 that act primarily via either initiation or promotion, may be over- or underestimated.

18 There is evidence that an assumption of similar toxicological action is reasonable for
19 PAHs; however, the carcinogenic process for individual PAHs is likely to be related to some
20 unique combination of multiple molecular events resulting from formation of several reactive
21 species. The absence of a clearly-defined common mode of action increases the level of
22 uncertainty associated with the use of an RPF approach. It is not possible to determine whether
23 cancer risks would be under- or overestimated by using a PAH RPF approach that assumes a
24 common mode of action. The assumption that interactions among PAH mixture components do
25 not occur at low levels of exposure cannot be conclusively demonstrated using experimental
26 approaches. The experimental data relating to dose additivity for PAH carcinogenicity are
27 discussed in Section 2.8. It appears that interactions may occur at higher doses of PAH mixtures
28 given in combination. This remains a significant uncertainty in the proposed RPF approach.

29 30 **8.6. EXTRAPOLATION OF RPFs ACROSS EXPOSURE ROUTES**

31 The peer consultation workshop (U.S. EPA, 2002) also identified uncertainty in
32 extrapolation of RPFs across exposure routes. As with the 1993 *Provisional Guidance*, RPFs
33 proposed in this analysis are also based on in vivo bioassay data collected using various routes of
34 administration (e.g., dermal, intraperitoneal, subcutaneous, intramammillary, intramuscular, or
35 intravenous injection, as well as lung implantation, tracheal implantation, and transplacental
36 exposure after subcutaneous injection). The RPF approach considers each bioassay type
37 equivalent for the purpose of determining relative potency to benzo[a]pyrene.

1 Table 8-3 compares the average RPFs (calculated from raw numbers and rounded to one
2 significant digit) based on tumor bioassay data for each PAH across exposure routes. Dermal
3 studies are shown collectively as well as separated by study type (complete or initiation).
4 Likewise, intraperitoneal studies are shown grouped as well as separated by target organ (lung
5 and liver).

Table 8-3. Comparisons among average tumor bioassay RPF values by exposure route and target organ

PAH	Dermal		Dermal complete		Dermal initiation		Intraperitoneal		Intraperitoneal, target organ = lung		Intraperitoneal, target organ = liver		Lung implantation		Oral	
	n	Average	n	Average	n	Average	n	Average	n	Average	n	Average	n	Average	n	Average
AA	1	0.5	1	0.5	–	–	–	–	–	–	–	–	1	0.2	–	–
AC	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
BaA	1	0.02	–	–	1	0.02	2	0.2 ^a	1	0.08	2	0.4	–	–	–	–
BbcAC (1,12-MBA)	1	0.05	–	–	1	0.05	–	–	–	–	–	–	–	–	–	–
BbF	2	0.4	1	0.3	1	0.4	2 ^b	1 ^c	1	1	–	–	1	0.1	–	–
BcFE	–	–	–	–	–	–	1	1 ^d	1	1	–	–	–	–	1	50
BeAC	2	0.8	–	–	2	0.8	–	–	–	–	–	–	–	–	–	–
BghiP	–	–	–	–	–	–	–	–	–	–	–	–	1	0.009	–	–
BjAC	–	–	–	–	–	–	1	60 ^d	1	60	–	–	–	–	–	–
BjF	2	0.03	–	–	2	0.03	2 ^b	0.7 ^a	1	0.4	1	1	1	0.03	–	–
BkF	1	0.03	–	–	1	0.03	–	–	–	–	–	–	1	0.03	–	–
BlAC	2	5	–	–	2	5	–	–	–	–	–	–	–	–	–	–
CH	5	0.1	–	–	5	0.1	1	0.2 ^a	–	–	1	0.2	1	0.04	–	–
CPcdP	4	0.3	2	0.4	2	0.2	1	1 ^d	1	1	–	–	–	–	–	–
CPdefC	2	0.3	–	–	2	0.3	–	–	–	–	–	–	–	–	–	–
DBacA	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
DBaeF	2	0.9	1	1	1	0.7	–	–	–	–	–	–	–	–	–	–
DBaeP	2	0.4	1	0.3	1	0.4	–	–	–	–	–	–	–	–	–	–
DBahA	1	1	–	–	1	1	1	40 ^d	1	40	–	–	1	2	–	–
DBahP	1	0.9	–	–	1	0.9	–	–	–	–	–	–	–	–	–	–
DBaiP	2	0.6	1	0.7	1	0.5	–	–	–	–	–	–	–	–	–	–
DBalP	2	30	–	–	2	30	1	30 ^d	1	30	–	–	–	–	–	–
FA	–	–	–	–	–	–	5	0.08 ^a	4	0.05	1	0.2	–	–	–	–
IP	–	–	–	–	–	–	–	–	–	–	–	–	1	0.07	–	–
N23eP	1	0.3	–	–	1	0.3	–	–	–	–	–	–	–	–	–	–

Table 8-3. Comparisons among average tumor bioassay RPF values by exposure route and target organ

PAH	Dermal		Dermal complete		Dermal initiation		Intraperitoneal		Intraperitoneal, target organ = lung		Intraperitoneal, target organ = liver		Lung implantation		Oral	
	n	Average	n	Average	n	Average	n	Average	n	Average	n	Average	n	Average	n	Average
PH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

^aNewborn mouse model.

^bNumber of intraperitoneal RPFs includes those calculated for combined lung and liver incidence; these are not included in numbers of RPFs with lung or liver tumors.

^cIncludes both newborn mouse and adult A/J mouse models.

^dAdult A/J mouse model.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38

The table shows a marked difference between the oral and intraperitoneal RPFs for benzo[c]fluorene (BcFE) (RPF = 50 for oral multiplicity and RPF = 1 for intraperitoneal incidence). However, as discussed earlier, this difference may result more from the use of a high tumor number to calculate the oral multiplicity RPF for this compound than route differences; if the oral incidence RPF is used for comparison, the two routes are more similar (RPF = 1 for intraperitoneal incidence versus RPF = 5 for oral incidence). Based on the latter comparison, which represents the only data with which to compare oral RPFs with those calculated from other routes, there appears to be fairly good correspondence between intraperitoneal and oral RPFs; however, this is based on only one PAH.

Based on the comparisons in the table, RPFs based on initiation and complete dermal carcinogenicity studies are similar (within a factor of 2). However, there are few PAHs with both types of dermal studies.

With respect to other route comparisons, the table generally shows that RPFs calculated from lung implantation and dermal studies are of the same order of magnitude, while RPFs calculated from intraperitoneal studies are higher for most compounds. The intraperitoneal RPF for dibenzo[a,l]pyrene is similar to its dermal RPF. At first glance, one might attribute the higher intraperitoneal RPFs calculated from newborn mouse assays (footnoted “a” in the table) to greater sensitivity of the newborn mouse, compared with an adolescent or adult mouse, to the carcinogenic action of PAHs. However, since the RPFs reflect potency of the PAH relative to benzo[a]pyrene, and not potency of the newborn mouse relative to other systems, the higher RPF cannot reflect a greater sensitivity of the animal model, since both the PAH of interest and benzo[a]pyrene have been tested in the same model. There is little information to evaluate whether RPFs from newborn mouse studies tend to be higher or lower than the adult A/J mouse model when both are exposed via intraperitoneal injection. Only one compound, benzo[b]fluoranthene (BbF), had RPFs calculated from both newborn mouse and adult A/J mouse models, and the values were similar; the newborn mouse RPF was 2, while the A/J mouse RPF was 1. In summary, it is not clear whether the intraperitoneal RPFs are higher than dermal or lung implantation RPFs due to route-specific differences or animal model differences (for example, differential metabolism in various animal systems).

Cross-route extrapolation of relative potency estimates is a necessary, though uncertain, aspect of the RPF approach. It is difficult to determine which of the available study types (e.g., dermal, intraperitoneal, intratracheal) is most predictive of potential risks from oral and inhalation exposure in humans. In order to prioritize bioassays by exposure route, robust data are needed on relative potencies for oral and inhalation exposures for comparison with relative potencies based on other exposure routes.

The inhalation RPF scheme used by the California EPA (2004) employed a hierarchy of bioassay data based on exposure route (inhalation studies were preferred, followed by

1 intratracheal or intrapulmonary instillation, oral administration, skin-painting, and subcutaneous
2 or intraperitoneal injection). Apart from the obvious preference for exposure routes that targeted
3 the respiratory tract (inhalation, intratracheal, intrapulmonary), the basis for prioritizing the other
4 exposure routes is not evident. Pufulete et al. (2004), who were also focused on PAHs as air
5 contaminants, suggested that the clearance of PAHs after intratracheal instillation may be similar
6 to clearance after inhalation exposure. The authors acknowledged that the high concentrations of
7 PAHs used in intratracheal and intrapulmonary instillation studies may lead to major differences
8 in pharmacokinetics, compared with inhalation exposure (Pufulete et al., 2004). Nevertheless,
9 the authors suggested that intratracheal instillation of low doses of PAHs might be an appropriate
10 surrogate exposure model for assessing relative potency of inhalation exposure. It is important
11 to note that no intratracheal instillation studies were identified in the search for studies from
12 which to calculate RPFs; thus, the information provided by Pufulete et al. (2004) is not directly
13 useful for suggesting route-specific RPFs. Pufulete et al. (2004) did not provide any specific
14 information on the relevance of intrapulmonary administration (a route used in several of the
15 bioassays used to calculate RPFs) to inhalation exposure.

16 As noted by U.S. EPA (2004), cross-route extrapolation would be contraindicated if there
17 were convincing toxicokinetic evidence that absorption of PAHs does not occur by one or more
18 exposure routes. Available data on the absorption of PAHs indicate that, in general, PAHs are
19 readily absorbed via ingestion, inhalation, and dermal exposure routes; however, the rate of
20 uptake varies with route and other factors (e.g., matrix, intake of fats and oils) (ATSDR, 1995).
21 Evidence for absorption of PAHs through these routes includes measurement of PAH-DNA
22 adducts at sites distal from the route of entry, measurement of urinary metabolites, and
23 radiotracer studies in animals (ATSDR, 1995). U.S. EPA (2004) indicated that demonstration of
24 any degree of uptake for each of the routes of interest is sufficient to allow the qualitative
25 judgment to apply the route-to-route extrapolation; thus, cross-route extrapolation is supported
26 by current data on the bioavailability of PAHs across several exposure routes.

27 U.S. EPA (2004, 1994) also noted that point-of-entry toxicity may be considered contrary
28 evidence for cross-route extrapolation. With respect to PAHs, available information on this issue
29 is mixed. The one inhalation bioassay of benzo[a]pyrene (Thyssen et al., 1981) identified the
30 upper respiratory tract as the site of tumor formation, suggesting a point-of-entry effect;
31 however, the authors did not specify the organs that were examined histologically in the study.
32 Dermal bioassays of benzo[a]pyrene have generally evaluated only skin tumors, precluding their
33 use in determining whether distal tumors are induced. A number of early oral cancer bioassays
34 of benzo[a]pyrene suggested that tumor formation was limited to the forestomach (Rigdon and
35 Neal, 1969, 1966; Neal and Rigdon, 1967). In oral carcinogenicity bioassays of MGP residue
36 (Weyand et al., 1995) and coal tar preparations (Culp et al., 1998; Gaylor et al., 1998) that
37 included separate groups exposed to benzo[a]pyrene, there were significant differences in target
38 organ distribution of tumors between benzo[a]pyrene and the complex mixtures.

1 Benzo[a]pyrene-induced tumors were observed primarily at the point of contact (i.e., the
2 forestomach), while MGP residue and coal tar produced tumors in the lung, liver, forestomach,
3 skin, and other organs. Other PAHs (e.g., benzo[c]fluorene) were proposed as the primary
4 compounds responsible for tumors at distal sites such as the lung (Koganti et al., 2000; Culp et
5 al., 1998). However, a gavage study in rats (Kroese et al., 2001) and a dietary study in A/J mice
6 (Weyland et al., 2004) each demonstrated that oral exposure to benzo[a]pyrene could induce
7 tumors at distal sites, including the lung, liver, and auditory canal. Tissue-specific differences in
8 metabolic activation and DNA binding of PAHs may contribute to the observed differences in
9 target organ sensitivity (Weyand and Wu, 1995; Culp and Beland, 1994).

10 In summary, available information provides some support for cross-route extrapolation.
11 Absorption of PAHs across oral, inhalation, and dermal routes is evident and, while many of the
12 cancer bioassays of benzo[a]pyrene suggested tumor formation limited to the point-of-entry, at
13 least one recent study (Kroese et al., 2001) suggests that tumors may also be induced at distal
14 sites. Furthermore, there is evidence that other PAHs (e.g., benzo[c]fluorene) may induce
15 tumors at distal sites after oral exposure (Weyand et al., 2004; Koganti et al., 2000; Culp et al.,
16 1998). However, cross-route extrapolation of RPFs is a significant source of uncertainty in this
17 approach.

18 Another approach to the issue of route-to-route extrapolation would be to prefer RPFs
19 derived from particular target tissues deemed relevant to the exposure route of interest. For
20 example, RPFs based on lung tumor data might be preferred for use in inhalation risk
21 assessment. To examine whether lung tumor RPFs were consistent across routes, RPFs
22 calculated from lung tumor potency in intraperitoneal studies (both newborn mouse and adult
23 A/J mouse models) were compared with RPFs from lung implantation studies in Table 8-3.
24 RPFs for both intraperitoneal-lung and lung implantation studies were available for only four
25 compounds (benzo[b]fluoranthene, benzo[j]fluoranthene, chrysene, and dibenz[a,h]anthracene);
26 for each of these, the intraperitoneal lung tumor RPF exceeded the lung implantation RPF. No
27 information assessing the concordance between lung tumor potency after intraperitoneal
28 administration and inhalation cancer potency was identified in the literature. The use of the final
29 RPFs derived in this analysis across all routes of exposure is recommended given the information
30 outlined above and in the absence of data to indicate otherwise.

9. REFERENCES

- Abe, S; Sasaki, M. (1977) Chromosome aberrations and sister chromatid exchanges in Chinese hamster cells exposed to various chemicals. *J Natl Cancer Inst* 58:1635–1641.
- Agrelo, C; Amos, H. (1981) DNA repair in human fibroblasts. *Prog Mutat Res* 1:528–532.
- Albert, RE; Lewtas, J; Nesnow, S; et al. (1983) Comparative potency method for cancer risk assessment: application to diesel particulate emissions. *Risk Anal* 3:101–117.
- Albert, RE; Miller, ML; Cody, TE; et al. (1991) Benzo[a]pyrene-induced skin damage and tumor promotion in the mouse. *Carcinogenesis* 12:1273–1280.
- Allen, JA; Coombs, MM. (1980) Covalent binding of polycyclic aromatic hydrocarbons to mitochondrial and nuclear DNA. *Nature* 287:244–245.
- Allen, CCR; Boyd, DR; Hempenstall, F; et al. (1999) Contrasting effects of a nonionic surfactant on the biotransformation of polycyclic aromatic hydrocarbons to cis-dihydrodiols by soil bacteria. *Appl Environ Microbiol* 65:1335–1339.
- Allen-Hoffmann, BL; Rheinwald, JG. (1984) Polycyclic aromatic hydrocarbon mutagenesis of human epidermal keratinocytes in culture. *Proc Natl Acad Sci USA* 81:7802–7806.
- Amacher, DE; Paillet, SC. (1982) Hamster hepatocyte-mediated activation of procarcinogens to mutagens in the L5178Y/TK mutation assay. *Mutat Res* 106:305–316.
- Amacher, DE; Paillet, SC. (1983) The activation of procarcinogens to mutagens by cultured rat hepatocytes in the L5178Y/TK mutation assay. *Mutat Res* 113:77–88.
- Amacher, DE; Turner, GN. (1980) Promutagen activation by rodent-liver postmitochondrial fractions in the L5178Y/TK cell mutation assay. *Mutat Res* 74:485–501.
- Amacher, DE; Paillet, SC; Turner, GN; et al. (1980) Point mutations at the thymidine kinase locus in L5178Y mouse lymphoma cells. II. Test validation and interpretation. *Mutat Res* 72:447–474.
- Amin, S; Desai, D; Dai, W; et al. (1995) Tumorigenicity in newborn mice of fjord region and other sterically hindered diol epoxides of benzo[g]chrysene, dibenzo[a,l]pyrene (dibenzo[def,p]chrysene), 4H-cyclopenta[def]chrysene and fluoranthene. *Carcinogenesis* 16:2813–2817.
- Andrews, AW; Thibault, LH; Lijinsky, W. (1978) The relationship between carcinogenicity and mutagenicity of some polynuclear hydrocarbons. *Mutat Res* 51:311–318.
- Archibong, AE; Inyang, F; Ramesh, A; et al. (2002) Alteration of pregnancy related hormones and fetal survival in F-344 rats exposed by inhalation to benzo[a]pyrene. *Reprod Toxicol* 16:801–808.
- Arif, JM; Smith, WA; Gupta, RC. (1997) Tissue distribution of DNA adducts in rats treated by intramammillary injection with dibenzo[a,l]pyrene, 7,12-dimethylbenz[a]anthracene and benzo[a]pyrene. *Mutat Res* 378:31–39.
- Atchison, M; Atchison, ML; Van Duuren, BL. (1985) Cocarcinogenesis in vitro using Balb/3T3 cells and aromatic hydrocarbon cocarcinogens. *Cell Biol Toxicol* 1:323–331.
- ATSDR (Agency for Toxic Substances and Disease Registry). (1995) Toxicological profile for polycyclic aromatic Hydrocarbons (PAHs). Public Health Service, U.S. Department of Health and Human Services.
- Ayrton, AD; McFarlane, M; Walker, R; et al. (1990) Induction of the P-450 I family of proteins by polycyclic aromatic hydrocarbons: possible relationship to their carcinogenicity. *Toxicology* 60:173–186.

- Baird, WM; Salmon, CP; Diamond, L. (1984) Benzo[e]pyrene-induced alterations in the metabolic activation of benzo[a]pyrene and 7,12-dimethylbenz[a]anthracene by hamster embryo cells. *Cancer Res* 44:1445–1452.
- Baird, WM; Hooven, LA; Mahadevan, B; et al. (2002) Responses of human cells to PAH-induced DNA damage. *Polycycl Aromat Compd* 22:771–780.
- Baker, RS; Bonin, AM; Stupans, I; et al. (1980) Comparison of rat and guinea pig as sources of the S9 fraction in the Salmonella/mammalian microsome mutagenicity test. *Mutat Res* 71:43–52.
- Balu, N; Padgett, WT; Lambert, GR; et al. (2004) Identification and characterization of novel stable deoxyguanosine and deoxyadenosine adducts of benzo[a]pyrene-7,8-quinone from reactions of physiological pH. *Chem Res Toxicol* 17(6):827–838.
- Balu, N; Padgett, WT; Nelson, GB. (2006) Benzo[a]pyrene-7,8-quinone-3'-mononucleotide adduct standards for ³²P postlabeling analysis: detection of benzo[a]pyrene-7,8-quinone-calf thymus DNA adducts. *Anal Biochem* 15(2):213–223.
- Barfknecht, TR; Hites, RA; Cavaliers, EL; et al. (1982) Human cell mutagenicity of polycyclic aromatic hydrocarbon components of diesel emissions. *Dev Toxicol Environ Sci* 10:277–294.
- Barrai, I; Barale, R; Scapoli, C; et al. (1992) The analysis of the joint effect of substances on reversion systems and the assessment of antimutagenicity. *Mutat Res* 267:173–182.
- Barry, G; Cook, JW; Haslewood, GAD; et al. (1935) The production of cancer by pure hydrocarbons. Part III. *Proc Royal Soc London* 117:318–351.
- Bartsch, H; Malaveille, C; Camus, AM; et al. (1980) Validation and comparative studies on 180 chemicals with *S. typhimurium* strains and V79 Chinese hamster cells in the presence of various metabolizing systems. *Mutat Res* 76:1–50.
- Bayer, U. (1978) In vivo induction of sister chromatid exchanges by three polyaromatic hydrocarbons. *Carcinogenesis* 3:423–428.
- Beland, F; Culp, S. (1998) Chronic bioassay of two composite samples from selected manufactured gas plant waste sites. Jefferson, AK: Division of Biochemical Toxicology, National Center for Toxicological Research. Technical Report 6722.02. Unpublished report.
- Biancifiori, C; Caschera, F. (1962) The relation between pseudopregnancy and the chemical induction by four carcinogens of mammary and ovarian tumours in BALB/c mice. *Br J Cancer* 16:722–730.
- Bingham, E; Falk, HL. (1969) The modifying effects of carcinogens on the threshold response. *Arch Environ Health* 19:779–783.
- Binkova, B; Giguere, Y; Rossner, P, Jr.; et al. (2000) The effect of dibenzo[a,1]pyrene and benzo[a]pyrene on human diploid lung fibroblasts: the induction of DNA adducts, expression of p53 and p21(WAF1) proteins and cell cycle distribution. *Mutat Res* 471:57–70.
- Blackburn, GL; Roy, TA; Bleicher, WT, Jr.; et al. (1996) Comparison of biological and chemical predictors of dermal carcinogenicity of petroleum oils. *Polycycl Aromat Compd* 11:201–210.
- Blaha, L; Kapplova, P; Vondracek, J; et al. (2002) Inhibition of gap-junctional intercellular communication by environmentally occurring polycyclic aromatic hydrocarbons. *Toxicol Sci* 65:43–51.
- Bols, NC; Schirmer, K; Joyce, EM; et al. (1999) Ability of polycyclic aromatic hydrocarbons to induce 7-ethoxyresorufin-o-deethylase activity in a trout liver cell line. *Ecotoxicol Environ Saf* 44:118–128.
- Bolton, JL; Trush, MA; Penning, TM; et al. (2000) Role of quinones in toxicology. *Chem Res Toxicol* 13(3):2–17.

Bos, RP; Theuws, JLG; Jongeneelen, FJ; et al. (1988) Mutagenicity of bi-, tri- and tetra-cyclic aromatic hydrocarbons in the 'taped-plate assay' and in the conventional Salmonella mutagenicity assay. *Mutat Res* 204:203–206.

Bostrom, E; Engen, S; Eide, I. (1998) Mutagenicity testing of organic extracts of diesel exhaust particles after spiking with polycyclic aromatic hydrocarbons (PAH). *Arch Toxicol* 72:645–649.

Bostrom, CC; Gerde, P; Hanberg, A; et al. (2002) Cancer risk assessment, indicators, and guidelines for polycyclic aromatic hydrocarbons in the ambient air. *Environ Health Perspect* 110(Suppl 3):451–488.

Bosveld, AT; de Bie, PA; van den Brink, NW; et al. (2002) In vitro EROD induction equivalency factors for the 10 PAHs generally monitored in risk assessment studies in The Netherlands. *Chemosphere* 49:75–83.

Brookes, P; Lawley, PD. (1964) Evidence of the binding of polynuclear aromatic hydrocarbons to the nucleic acids of mouse skin: relation between carcinogenic power of hydrocarbons and their binding to deoxyribonucleic acid. *Nature* 202:781–784.

Bruce, ED; Austenrieth, RL; Burghardt, RC; et al. (2008) Using quantitative structure-activity relationships (QSAR) to predict toxic endpoints for polycyclic aromatic hydrocarbons (PAH). *J Toxicol Environ Health Part A* 71:1073–1084.

Brune, K; Kalin, H; Schmidt, R; et al. (1978) Inflammatory, tumor initiating and promoting activities of polycyclic aromatic hydrocarbons and diterpene esters in mouse skin as compared with their prostaglandin releasing potency in vitro. *Cancer Lett* 4:333–342.

Brune, H; Deutsch-Wenzel, RP; Habs, M; et al. (1981) Investigation of the tumorigenic response to benzo[a]pyrene in aqueous caffeine solution applied orally to Sprague-Dawley rats. *J Cancer Res Clin Oncol* 102:153–157.

Bryan, WR; Shimkin, MB. (1943) Quantitative analysis of dose-response data obtained with three carcinogenic hydrocarbons in strain C3H male mice. *J Natl Cancer Inst* 3:503–531.

Bryla, P; Weyand, EH. (1992) Detection of PAH:DNA adducts from auto-oxidation using ³²P-postlabeling. *Cancer Lett* 65:35–41.

Buening, MK; Levin, W; Wood, A; et al. (1979) Tumorigenicity of the dihydrodiols of dibenz[a,h]anthracene on mouse skin and in newborn mice. *Cancer Res* 39:1310–1314.

Burdick, AD; Davis, JW; Liu, KJ; et al. (2003) Benzo[a]pyrene quinones increase cell proliferation, generate reactive oxygen species, and transactivate the epidermal growth factor receptor in breast epithelial cells. *Cancer Res* 63:7825–7833.

Busby, WFJ; Goldman, ME; Newberne, PM; et al. (1984) Tumorigenicity of fluoranthene in a newborn mouse lung adenoma bioassay. *Carcinogenesis* 5:1311–1316.

Busby, WFJ; Stevens, EK; Martin, CN; et al. (1989) Comparative lung tumorigenicity of parent and mononitro-polynuclear aromatic hydrocarbons in the BLU:Ha newborn mouse assay. *Toxicol Appl Pharmacol* 99:555–563.

Buterin, T; Hess, MT; Luneva, N; et al. (2000) Unrepaired fjord region polycyclic aromatic hydrocarbon-DNA adducts in *ras* codon 61 mutational hot spots. *Cancer Res* 60:1849–1856.

Buters, JT; Mahadevan, B; Quintanilla-Martinez, L; et al. (2002) Cytochrome P450 1B1 determines susceptibility to dibenzo[a,l]pyrene-induced tumor formation. *Chem Res Toxicol* 15:1127–1135.

California EPA (California Environmental Protection Agency). (2002) Air toxics hot spots program risk assessment guidelines. Part II. Technical support document for describing available cancer potency factors. Office of Environmental Health Hazard Assessment, Air Toxicology and Epidemiology Section, Oakland, CA.

California EPA (California Environmental Protection Agency). (2004) No Significant Risk Levels (NSRLs) for the Proposition 65 carcinogens benzo[b]fluoranthene, benzo[j]fluoranthene, chrysene, dibenzo[a,h]pyrene, dibenzo[a,i]pyrene, and 5-methylchrysene by the oral route. Office of Environmental Health Hazard Assessment, Reproductive and Cancer Hazard Assessment Section, Oakland, CA.

Carver, JH; Machado, ML; MacGregor, JA. (1985) Petroleum distillates suppress in vitro metabolic activation: higher (S-9) required in the Salmonella/microsome mutagenicity assay. *Environ Mutagen* 7:369–379.

Carver, JH; Machado, ML; MacGregor, JA. (1986) Application of modified Salmonella/microsome prescreen to petroleum-derived complex mixtures and polynuclear aromatic hydrocarbons (PAH). *Mutat Res* 174:247–253.

Casale, GP; Higginbotham, S; Johansson, SL; et al. (1997) Inflammatory response of mouse skin exposed to the very potent carcinogen dibenzo[a,l]pyrene: a model for tumor promotion. *Fundam Appl Toxicol* 36(1):71–78.

Casale, GP; Cheng, Z; Liu, J; et al. (2000) Profiles of cytokine mRNAs in the skin and lymph nodes of SENCAR mice treated epicutaneously with dibenzo[a,l]pyrene or dimethylbenz[a]anthracene reveal a direct correlation between carcinogen-induced contact hypersensitivity and epidermal hyperplasia. *Mol Carcinog* 27(2):125–140.

Casto, BC. (1979) Polycyclic hydrocarbons and Syrian hamster embryo cells: cell transformation, enhancement of viral transformation and analysis of DNA-damage. In: Jones, PW; Leber, P, eds. *Polynuclear aromatic hydrocarbons*. Ann Arbor, MI: Ann Arbor Science Publishers, pp. 51–66.

Castro, DJ; Lohr, CV; Fischer, KA; et al. (2008) Lymphoma and lung cancer in offspring born to pregnant mice dosed with dibenzo[a,l]pyrene: the importance of in utero vs. lactational exposure. *Toxicol Appl Pharmacol* 233:454–458.

Cavalieri, EL; Rogan, EG. (1992) The approach to understanding aromatic hydrocarbon carcinogenesis. The central role of radical cations in metabolic activation. *Pharmacol Ther* 55:183–199.

Cavalieri, EL; Rogan, EG. (1995) Central role of radical cations in metabolic activation of polycyclic aromatic hydrocarbons. *Xenobiotica* 25:677–688.

Cavalieri, EL; Mailander, P; Pelfrene, A. (1977) Carcinogenic activity of anthanthrene on mouse skin. *Z Krebsforsch Klin Onkol Cancer Res Clin Oncol* 89:113–118.

Cavalieri, E; Rogan, E; Thilly, WG. (1981a) Carcinogenicity, mutagenicity and binding studies of the environmental contaminant cyclopenteno(c,d]pyrene and some of its derivatives. In: Cook, M; Dennis, AJ, eds. *Chemical analysis and biological fate: polynuclear aromatic hydrocarbons*. Columbus, OH: Battelle Press, pp. 487–499.

Cavalieri, E; Rogan, E; Toth, B; et al. (1981b) Carcinogenicity of the environmental pollutants cyclopenteno[cd]pyrene and cyclopentano[cd]pyrene in mouse skin. *Carcinogenesis* 2:277–281.

Cavalieri, E; Munhall, A; Rogan, E; et al. (1983) Syncarcinogenic effect of the environmental pollutants cyclopenteno[cd]pyrene and benzo[a]pyrene in mouse skin. *Carcinogenesis* 4:393–397.

Cavalieri, EL; Rogan, EG; Cremonesi, P; et al. (1988a) Radical cations as precursors in the metabolic formation of quinones from benzo[a]pyrene and 6-fluorobenzo[a]pyrene. Fluoro substitution as a probe for one-electron oxidation in aromatic substrates. *Biochem Pharmacol* 37(11):2173–2182.

Cavalieri, E; Rogan, E; Sinha, D. (1988b) Carcinogenicity of aromatic hydrocarbons directly applied to rat mammary gland. *Cancer Res Clin Oncol* 114:3–9.

Cavalieri, EL; Rogan, EG; Higginbotham, S; et al. (1989) Tumor-initiating activity in mouse skin and carcinogenicity in rat mammary gland of dibenzo[a]pyrenes: the very potent environmental carcinogen dibenzo[a,l]pyrene. *J Cancer Res Clin Oncol* 115:67–72.

Cavalieri, EL; Higginbotham, S; RamaKrishna, NV; et al. (1991) Comparative dose-response tumorigenicity studies of dibenzo[a,l]pyrene versus 7,12-dimethylbenz[a]anthracene, benzo[a]pyrene and two dibenzo[a,l]pyrene dihydrodiols in mouse skin and rat mammary gland. *Carcinogenesis* 12:1939–1944.

- Cavalieri, EL; Rogan, EG; Ramakrishna, NVS; et al. (1993) Mechanisms of benzo[a]pyrene and 7,12-dimethylbenz[a]anthracene activation: qualitative aspects of the stable and depurination DNA adducts obtained from radical cations and diol epoxides. In: Polycyclic aromatic hydrocarbons: synthesis, properties, analytical measurements, occurrence and biological effects. Bordeaux, France: Gordon and Breach Science Publishers, pp. 725–732.
- Cavalieri, EL; Rogan, EG; Li, KM; et al. (2005) Identification and quantification of the depurinating DNA adducts formed in mouse skin treated with dibenzo[a,l]pyrene (DB[a,l]P) or its metabolites and in rat mammary gland treated with DB[a,l]P. *Chem Res Toxicol* 18(6):976–983.
- CCME (Canadian Council of the Ministers of the Environment). (2003) Canadian soil quality guidelines for potentially carcinogenic and higher molecular weight polycyclic aromatic hydrocarbons (environmental and human health aspects). Scientific supporting document. UMA Group, Ltd., Victoria, British Columbia.
- Chakravarti, D; Pelling, JC; Cavalieri, EL; et al. (1995) Relating aromatic hydrocarbon-induced DNA adducts and c-H-ras mutations in mouse skin papillomas: the role of apurinic sites. *Proc Natl Acad Sci USA* 92(22):10422–10426.
- Chakravarti, D; Mailander, PC; Cavalieri, EL; et al. (2000) Evidence that error-prone DNA repair converts dibenzo[a,l]pyrene-induced depurinating lesions into mutations: formation, clonal proliferation and regression of initiated cells carrying H-ras oncogene mutations in early preneoplasia. *Mutat Res* 456(1–2):17–32.
- Chakravarti, D; Venugopal, D; Mailander, PC; et al. (2008) The role of polycyclic aromatic hydrocarbon-DNA adducts in inducing mutations in mouse skin. *Mutat Res* 649(1–2):161–178.
- Chang, RL; Levin, W; Wood, AW; et al. (1981) Tumorigenicity of the diastereomeric bay-region benzo(e)pyrene 9,10-diol-11,12-epoxides in newborn mice. *Cancer Res* 41:915–918.
- Chang, HF; Huffer, DM; Chiarelli, MP; et al. (2002) Characterization of DNA adducts derived from syn-benzo[ghi]fluoranthene-3,4-dihydrodiol-5,5a-epoxide and comparative DNA binding studies with structurally-related anti-diolepoxides of benzo[ghi]fluoranthene and benzo[c]phenanthrene. *Chem Res Toxicol* 15:198–208.
- Chen, TT; Heidelberger, C. (1969) Quantitative studies on the morphological/malignant cell transformation of mouse prostate cells by carcinogenic hydrocarbons in vitro. *Int J Cancer* 4:166–178.
- Chen, S; Nguyen, N; Tamura, K; et al. (2003) The role of the Ah receptor and p38 in benzo[a]pyrene-7,8-dihydrodiol and benzo[a]pyrene-7,8-dihydrodiol-9,10-epoxide-induced apoptosis. *J Biol Chem* 278:19526–19533.
- Cherng, SH; Lin, P; Yang, JL; et al. (2001) Benzo[g,h,i]perylene synergistically transactivates benzo[a]pyrene-induced CYP1A1 gene expression by aryl hydrocarbon receptor pathway. *Toxicol Appl Pharmacol* 170:63–68.
- Chu, ML; Chen, CW. (1984) Evaluation and estimation of potential carcinogenic risks of polynuclear aromatic hydrocarbons. In: Polynuclear aromatic hydrocarbons in the workplace: proceedings of a symposium; Chemical Congress of Pacific Basin Societies.
- Clement Associates. (1988) Comparative potency approach for estimating the cancer risk associated with exposure to mixtures of polycyclic aromatic hydrocarbons. Fairfax, VA: ICF Clement Associates.
- Clement Associates. (1990) Development of relative potency estimates for PAHs and hydrocarbon combustion product fractions compared to benzo[a]pyrene and their use in carcinogenic risk assessments. Fairfax, VA: ICF Clement Associates.
- Cogliano, VJ; Baan, RA; Straif, K; et al. (2008) Use of mechanistic data in IARC evaluations. *Environ Mol Mutagen* 49(2):100–109.
- Collins JF; Brown, JP; Alexeeff, GV; et al. (1998) Potency equivalency factors for some polycyclic aromatic hydrocarbons and polycyclic aromatic hydrocarbon derivatives. *Regul Toxicol Pharmacol* 28:45–54.

- Conney, AH; Chang, RL; Cui, XX; et al. (2001) Dose-dependent differences in the profile of mutations induced by carcinogenic (R,S,S,R) bay- and fjord-region diol epoxides of polycyclic aromatic hydrocarbons. *Adv Exp Med Biol* 500:697–707.
- Cooper, CS; Pal, K; Hewer, A; et al. (1982) The metabolism and activation of polycyclic aromatic hydrocarbons in epithelial cell aggregates and fibroblasts prepared from rat mammary tissue. *Carcinogenesis* 3:203–210.
- Culp, SJ; Beland, FA. (1994) Comparison of DNA adduct formation in mice fed coal tar or benzo[a]pyrene. *Carcinogenesis* 15:247–252.
- Culp, SJ; Gaylor, DW; Sheldon, WG; et al. (1996a) DNA adduct measurements in relation to tumor incidence during the chronic feeding of coal tar or benzo[a]pyrene to mice. *Polycycl Aromat Compd* 11:161–168.
- Culp, SJ; Gaylor, DW; Sheldon, WG; et al. (1996b) Relationship between DNA adduct levels and tumor incidence in mice fed coal tar or benzo[a]pyrene for two years. *Proc Am Assoc Cancer Res* 37:101.
- Culp, SJ; Gaylor, DW; Sheldon, WG; et al. (1998) A comparison of the tumors induced by coal tar and benzo[a]pyrene in a 2-year bioassay. *Carcinogenesis* 19:117–124.
- Culp, SJ; Warbritton, AR; Smith, BA; et al. (2000) DNA adduct measurements, cell proliferation and tumor mutation induction in relation to tumor formation in B6C3F1 mice fed coal tar or benzo[a]pyrene. *Carcinogenesis* 21(7):1433–1440.
- Dasgupta, PS; Lahiri, T. (1992) Alteration of brain catecholamines during growth of benzo[a]pyrene induced murine fibrosarcoma. *Neoplasma* 39:163–165.
- Davis, C; Desai, D; Amin, S; et al. (1999) Comparison of the morphological transforming activities of fjord-region PAHs with dibenzo[a,e]pyrene and benzo[a]pyrene. *Polycycl Aromat Compd* 16:141–149.
- Dean, BJ. (1981) Activity of 27 coded compounds in the RLI chromosome assay. *Prog Mutat Res* 1:570–579.
- De Flora, S; Zanacchi, P; Camoirano, A; et al. (1984) Genotoxic activity and potency of 135 compounds in the Ames reversion test and in a bacterial DNA-repair test. *Mutat Res* 133:161–198.
- DeMarini, DM; Landi, S; Tian, D; et al. (2004) Lung tumor *KRAS* and *TP53* mutations in nonsmokers reflect exposure to PAH-rich coal combustion emissions. *Cancer Res* 61:6679–6681.
- Denissenko, MF; Pao, A; Tang, M; et al. (1996) Preferential formation of benzo[a]pyrene adducts at lung cancer mutational hotspots in P53. *Science* 274(5286):430–432.
- DeSalvia, R; Meschini, R; Fiore, M; et al. (1988) Induction of sister-chromatid exchanges by procarcinogens in metabolically competent Chinese hamster epithelial liver cells. *Mutat Res* 207:69–75.
- Deutsch-Wenzel, RP; Brune, H; Grimmer, G; et al. (1983) Experimental studies in rat lungs on the carcinogenicity and dose- response relationships of eight frequently occurring environmental polycyclic aromatic hydrocarbons. *J Natl Cancer Inst* 71:539–544.
- Devanesan, PD; Cremonesi, P; Nunnally, JE; et al. (1990) Metabolism and mutagenicity of dibenzo[a,e]pyrene and the very potent environmental carcinogen dibenzo[a,l]pyrene. *Chem Res Toxicol* 3:580–586.
- DiGiovanni, J; Rymer, J; Slaga, TJ; et al. (1982) Anticarcinogenic and cocarcinogenic effects of benzo[e]pyrene and dibenz[u,c]anthracene on skin tumor initiation by polycyclic hydrocarbons. *Carcinogenesis* 3:371–375.
- DiPaolo, JA; Donovan, JP; Nelson, RL. (1969) Quantitative studies of in vitro transformation by chemical carcinogens. *J Natl Cancer Inst* 42:867–874.
- DiPaolo, JA; Takano, K; Popescu, NC. (1972) Quantitation of chemically induced neoplastic transformation of BALB/3T3 cloned cell lines. *Cancer Res* 35:2686–2695.

- DiPaolo, JA; Nelson, RL; Donovan, PJ; et al. (1973) Host-mediated in vivo-in vitro assay for chemical carcinogenesis. *Arch Pathol* 95:380–385.
- Dunkel, VC; Pienta, RJ; Sivak, A; et al. (1981) Comparative neoplastic transformation responses of Balb 3T3 cells, Syrian hamster embryo cells, and Rauscher mm-me leukemia virus-infected Fischer 344 rat embryo cells to chemical carcinogens. *J Natl Cancer Inst* 67:1303–1315.
- Dunkel, VC; Zeiger, E; Brusick, D; et al. (1984) Reproducibility of microbial mutagenicity assays: tests with *Salmonella typhimurium* and *Escherichia coli* using a standardized protocol. *Environ Mutagen* 6:1–251.
- Durant, JL; Lafleur, AL; Busby, WF, Jr.; et al. (1999) Mutagenicity of C24H14 PAH in human cells expressing CYP1A1. *Mutat Res* 446:1–14.
- Eisenstadt, E; Gold, A. (1978) Cyclopenta[c,d]pyrene: a highly mutagenic polycyclic aromatic hydrocarbon. *Proc Natl Acad Sci USA* 75:1667–1669.
- El-Bayoumy, K; Hecht, SS; Hoffmann, D. (1982) Comparative tumor initiating activity on mouse skin of 6-nitrobenzo[a]pyrene, 6-nitrochrysene, 3-nitroperylene, 1-nitropyrene and their parent hydrocarbons. *Cancer Lett* 16:333–337.
- Emura, M; Richter-Reichhelm, HB; Schneider, P; et al. (1980) Sensitivity of Syrian golden hamster fetal lung cells to benzo[a]pyrene and other polycyclic hydrocarbons in vitro. *Toxicology* 17:149–155.
- Evans, CH; DiPaolo, JA. (1975) Neoplastic transformation of guinea pig fetal cells in culture induced by chemical carcinogens. *Cancer Res* 35:1035–1044.
- Evans, EL; Mitchell, AD. (1981) Effects of 20 coded chemicals on sister chromatid exchange frequencies in cultured Chinese hamster cells. *Prog Mutat Res* 1:538–550.
- Fahmy, M; Fahmy, OG. (1980) Altered control of gene activity in the soma by carcinogens. *Mutat Res* 72:165–172.
- Falk, HL; Kotin, P; Thompson, S. (1964) Inhibition of carcinogenesis. The effect of hydrocarbons and related compounds. *Arch Environ Health* 13:169–179.
- Flesher, JW; Harvey, RG; Sydnor, KL. (1976) Oncogenicity of K-region epoxides of benzo[a]pyrene and 7,12-dimethylbenz[a]anthracene. *Int J Cancer* 18:351–353.
- Florin, I; Rutberg, L; Curvall, M; et al. (1980) Screening of tobacco smoke constituents for mutagenicity using the Ames' test. *Toxicology* 18:219–232.
- Flowers, L; Ohnishi, T; Penning, TM. (1997) DNA strand scission by polycyclic aromatic hydrocarbon o-quinones: role of reactive oxygen species, Cu(II)/Cu(I) redox cycling and o-semiquinone anion radicals. *Biochemistry* 36:8640–8648.
- Flowers-Geary, L; Harvey, RG; Penning, TM. (1993) Cytotoxicity of polycyclic aromatic hydrocarbon o-quinones in rat and human hepatoma cells. *Chem Res Toxicol* 6(3):252–260.
- Flowers-Geary, L; Blecinski, W; Harvey, RG; et al. (1996) Cytotoxicity and mutagenicity of polycyclic aromatic hydrocarbon ortho-quinones produced by dihydrodiol dehydrogenase. *Chem Biol Interact* 99(1–3):55–72.
- Frolich, A; Wurgler, FE. (1990) Drosophila wing-spot test: improved detectability of genotoxicity of polycyclic aromatic hydrocarbons. *Mutat Res* 234:71–80.
- Gaylor, DW; Moolgavkar, S; Krewski, D; et al. (1998) Recent bioassay results on coal tars and benzo[a]pyrene: implications for risk assessment. *Regul Toxicol Pharmacol* 28:178–179.

- Geacintov, NE; Cosman, M; Hingerty, BE; et al. (1997) NMR solution structures of stereoisomeric covalent polycyclic aromatic carcinogen – DNA adducts: principles, patterns, and diversity. *Chem Res Toxicol* 10(2):111–146.
- Gehly, EB; Landolph, JR; Heidelberger, C; et al. (1982) Induction of cytotoxicity, mutation, cytogenetic changes and neoplastic transformation by benzo[a]pyrene and derivatives in C3H/10T 1/2 clone 8 mouse fibroblasts. *Cancer Res* 42:1866–1875.
- Gibson, TL; Smart, VB; Smith, LL. (1978) Non-enzymic activation of polycyclic aromatic hydrocarbons as mutagens. *Mutat Res* 49:153–161.
- Gill, HS; Kole, PL; Wiley, JC; et al. (1994) Synthesis and tumor-initiating activity in mouse skin of dibenzo[a,l]pyrene syn- and anti-fjord-region diolepoxides. *Carcinogenesis* 15:2455–2460.
- Gold, A; Eisenstadt, E. (1980) Metabolic activation of cyclopenta[cd]pyrene to 3,4-epoxycyclopenta[cd]pyrene by rat liver microsomes. *Cancer Res* 40:3940–3944.
- Goldschmidt, BM; Katz, C; Van Duuren, BL. (1973) The cocarcinogenic activity of noncarcinogenic aromatic hydrocarbons. *Proc Am Assoc Cancer Res* 14:84.
- Goldstein, LS; Safe, S; Weyand, EH. (1994) Carcinogenicity of coal tars: a multidisciplinary approach. *Polycycl Aromat Compd* 7:161–174.
- Grant, G; Roe, FJC. (1963) The effect of phenanthrene on tumour induction by 3,4-benzopyrene administered to newly born mice. *Br J Cancer* 17:261–265.
- Greb, W; Strobel, R; Rohrborn, G. (1980) Transformation of BHK 21/CL 13 cells by various polycyclic aromatic hydrocarbons using the method of Styles. *Toxicol Lett* 7:143–148.
- Grimmer, G; Brune, H; Deutsch-Wenzel, R; et al. (1984) Contribution of polycyclic aromatic hydrocarbons to the carcinogenic impact of gasoline engine exhaust condensate evaluated by implantation into the lungs of rats. *J Natl Cancer Inst* 72:733–739.
- Grimmer, G; Brune, H; Deutsch-Wenzel, R; et al. (1987a) Contribution of polycyclic aromatic hydrocarbons and nitro-derivatives to the carcinogenic impact of diesel engine exhaust condensate evaluated by implantation into the lungs of rats. *Cancer Lett* 37:173–180.
- Grimmer, G; Brune, H; Deutsch-Wenzel, R; et al. (1987b) Contribution of polycyclic aromatic hydrocarbons and polar polycyclic aromatic compounds to the carcinogenic impact of flue gas condensate from coal-fired residential furnaces evaluated by implantation into the rat lung. *J Natl Cancer Inst* 78:935–942.
- Grimmer, G; Brune, H; Dettbarn, G; et al. (1988) Contribution of polycyclic aromatic compounds to the carcinogenicity of sidestream smoke of cigarettes evaluated by implantation into the lungs of rats. *Cancer Lett* 43:173–177.
- Grover, PL; Sims, P. (1968) Enzyme-catalysed reactions of polycyclic hydrocarbons with deoxyribonucleic acid and protein in vitro. *Biochem J* 110:159–160.
- Guthrie, J; Robertson, IG; Zeiger, E; et al. (1982) Selective activation of some dihydrodiols of several polycyclic aromatic hydrocarbons to mutagenic products by prostaglandin synthetase. *Cancer Res* 42:1620–1623.
- Habs, M; Schmähl, D; Misfeld, J. (1980) Local carcinogenicity of some environmentally relevant polycyclic aromatic hydrocarbons after lifelong topical application to mouse skin. *Arch Geschwulstforsch* 50:266–274.
- Habs, M; Jahn, SA; Schmähl, D. (1984) Carcinogenic activity of condensate from colcoquit seeds (*Citrullus colocynthis*) after chronic epicutaneous administration to mice. *J Cancer Res Clin Oncol* 108:154–156.
- Harvey, RG. (1996) Mechanisms of carcinogenesis of polycyclic aromatic hydrocarbons. *Polycycl Aromat Compd* 9:1–23.

- Hass, BS; Brooks, EE; Schumann, KE; et al. (1981) Synergistic, additive, and antagonistic mutagenic responses to binary mixtures of benzo[a]pyrene and benzo[e]pyrene as detected by strains TA98 and TA100 in the Salmonella/microsome assay. *Environ Mutagen* 3:159–166.
- Hass, BS; McKeown, CK; Sardella, DJ; et al. (1982) Cell-mediated mutagenicity in Chinese hamster V79 cells of dibenzopyrenes and their bay-region fluorene-substituted derivatives. *Cancer Res* 42:1646–1649.
- He, SL; Baker, R. (1991) Micronuclei in mouse skin cells following in vivo exposure to benzo[a]pyrene, 7,12-dimethylbenz[a]anthracene, chrysene, pyrene and urethane. *Environ Mol Mutagen* 17:163–168.
- Hecht, SS; Bondinell, WE; Hoffman, D. (1974) Chrysene and methylchrysenes: presence on tobacco smoke and carcinogenicity. *J Natl Cancer Inst* 53:1121–1133.
- Hermann, M. (1981) Synergistic effects of individual polycyclic aromatic hydrocarbons on the mutagenicity of their mixtures. *Mutat Res* 90:399–409.
- Higginbotham, S; RamaKrishna, NV; Johansson, SL; et al. (1993) Tumor-initiating activity and carcinogenicity of dibenzo[a,l]pyrene versus 7,12-dimethylbenz[a]anthracene and benzo[a]pyrene at low doses in mouse skin. *Carcinogenesis* 14:875–878.
- Hoffmann, D; Wynder, EL. (1966) [Contribution on the carcinogenic effect of dibenzopyrenes]. *Z Krebsforsch* 68:137–149.
- Hoffmann, D; Rathkamp, G; Nesnow, S; et al. (1972) Fluoranthenes: quantitative determination in cigarette smoke, formation by pyrolysis and tumor initiating activity. *J Natl Cancer Inst* 49:1165–1175.
- Homburger, F; Hsueh, SS; Kerr, CS et al. (1972) Inherited susceptibility of inbred strains of Syrian hamsters to induction of subcutaneous sarcomas and mammary and gastrointestinal carcinomas by subcutaneous and gastric administration of polynuclear hydrocarbons. *Cancer Res* 32:360–366.
- Horton, AW; Christian, GM. (1974) Cocarcinogenic versus incomplete carcinogenic activity among aromatic hydrocarbons: contrast between chrysene and benzo[b]-triphenylene. *J Natl Cancer Inst* 53:1017–1020.
- Huberman, E. (1975) Mammalian cell transformation and cell-mediated mutagenesis by carcinogenic polycyclic hydrocarbons. *Mutat Res* 29:285–291.
- Huberman, E; Sachs, L. (1974) Cell-mediated mutagenesis of mammalian cells with chemical carcinogens. *Int J Cancer* 13:326–333.
- Huberman, E; Sachs, L. (1976) Mutability of different genetic loci in mammalian cells by metabolically activated carcinogenic polycyclic hydrocarbons. *Proc Natl Acad Sci USA* 73:188–192.
- Huggins, C; Yang, NC. (1962) Induction and extinction of mammary cancer. A striking effect of hydrocarbons permits analysis of mechanisms of causes and cure of breast cancer. *Science* 137:257–262.
- Hughes, NC; Phillips, DH. (1990) Covalent binding of dibenzopyrenes and benzo[a]pyrene to DNA: evidence for synergistic and inhibitory interactions when applied in combination to mouse skin. *Carcinogenesis* 11:1611–1620.
- Hughes, NC; Phillips, DH. (1991) Dependence on dose of initial and persistent levels of benzo[a]pyrene and dibenzo[a,e]pyrene DNA adducts in mouse tissues. *Proc Am Assoc Cancer Res* 32:98.
- Hughes, NC; Phillips, DH. (1993) ³²P-postlabeling analysis of the covalent binding of benzo[ghi]perylene to DNA in vivo and in vitro. *Carcinogenesis* 14:127–133.
- IARC (International Agency for Research on Cancer). (1973) Certain polycyclic aromatic hydrocarbons and heterocyclic compounds. In: IARC monographs on the evaluation of carcinogenic risk of chemicals to humans. Vol. 3. Lyon, France.

IARC (International Agency for Research on Cancer). (1983) Polynuclear aromatic compounds. Part 1. Chemical, environmental and experimental data. In: IARC monographs on the evaluation of carcinogenic risk of chemicals to humans. Vol. 32. Lyon, France.

IARC (International Agency for Research on Cancer). (1984a) Polynuclear aromatic compounds. Part 2. Carbon black, mineral oils (lubricant base oils and derived products) and some nitroarenes. In: IARC monographs on the evaluation of carcinogenic risk of chemicals to humans. Lyon, France, pp. 87–168.

IARC (International Agency for Research on Cancer). (1984b) Polynuclear aromatic compounds. Part 3. Industrial exposures in aluminum production, coal gasification, coke production, and iron and steel founding. In: IARC monographs on the evaluation of carcinogenic risk of chemicals to humans. Lyon, France, pp. 37–111.

IARC (International Agency for Research on Cancer). (1985) Polynuclear aromatic compounds. Part 4. Bitumens, coal-tars and derived products, shale-oils and soots. In: IARC monographs on the evaluation of carcinogenic risk of chemicals to humans. Lyon, France, pp. 65–159.

IARC (International Agency for Research on Cancer). (1986) Some halogenated hydrocarbons and pesticide exposures. In: IARC monographs on the evaluation of carcinogenic risk of chemicals to humans. Lyon, France.

IARC (International Agency for Research on Cancer). (1987) Overall evaluation of carcinogenicity: an updating of IARC Monographs volumes 1 to 42. In: IARC monographs on the evaluation of carcinogenic risks to humans. Suppl. 7. Lyon, France.

IARC (International Agency for Research on Cancer). (1989) Occupational exposures in petroleum refining; crude oil and major petroleum fuels. In: IARC monographs on the evaluation of carcinogenic risk of chemicals to humans. Vol. 45. Lyon, France, pp. 239–270.

Ichinotsubo, D; Mower, HF; Setliff, J; et al. (1977) The use of rec-bacteria for testing of carcinogenic substances. *Mutat Res* 46:53–56.

Jeffy, BD; Chen, EJ; Gudas, JM; et al. (2000) Disruption of cell cycle kinetics by benzo[a]pyrene: inverse expression patterns of BRCA-1 and p53 in MCF-7 cells arrested in S and G2. *Neoplasia* 2:460–470.

Jeffy, BD; Chirmomas, RB; Chen, EJ; et al. (2002) Activation of the aromatic hydrocarbon receptor pathway is not sufficient for transcriptional repression of BRCA-1: requirements for metabolism of benzo[a]pyrene to 7r,8t-dihydroxy-9t,10-epoxy-7,8,9,10-tetrahydrobenzo[a]pyrene. *Cancer Res* 62:113–121.

Jerina, DM; Lehr, RE. (1977) The bay-region theory: a quantum mechanical approach to aromatic hydrocarbon-induced carcinogenicity. In: *Microsomes and drug oxidations*. Oxford: Pergamon Press, pp. 709–720.

Jerina, DM; Yagi, H; Lehr, RE; et al. (1978) The bay-region theory of carcinogenesis by polycyclic aromatic hydrocarbons. In: *Polycyclic hydrocarbons and cancer: environment, chemistry and metabolism*. Boca Raton, Florida: CRC Press, pp. 173–188.

Jerina, DM; Chadha, A; Cheh, AM; et al. (1991) Covalent bonding of bay-region diol epoxides to nucleic acids. *Adv Exp Med Biol* 283:533–553.

Jiang, H; Shen, YM; Quinn, AM; et al. (2005) Competing roles of cytochrome P450 1A1/1B1 and aldo-keto reductase 1A1 in the metabolic activation of (±)-7,8-dihydroxy-7,8-dihydro-benzo[a]pyrene in human bronchoalveolar cell extracts. *Chem Res Toxicol* 18:365–374.

Jiang, H; Gelhaus, SL; Mangal, D; et al. (2007) Metabolism of benzo[a]pyrene in human bronchoalveolar H358 cells using liquid chromatography-mass spectrometry. *Chem Res Toxicol* 20:1331–1341.

Johnsen, NM; Schwarze, PE; Nyholm, SH; et al. (1997) Genotoxic effects of cyclopenta-fused polycyclic aromatic hydrocarbons in different types of isolated rat lung cells. *Carcinogenesis* 18:193–199.

Johnsen, NM; Brunborg, G; Haug, K; et al. (1998) Metabolism and activation of cyclopenta polycyclic aromatic hydrocarbons in isolated human lymphocytes, HL-60 cells and exposed rats. *Chem Biol Interact* 114:77–95.

- Jotz, MM; Mitchell, AD. (1981) Effects of 20 coded chemicals on the forward mutation frequency at the thymidine kinase locus in L5178Y mouse lymphoma cells. *Prog Mutat Res* 1:580–593.
- Kaden, DA; Hites, RA; Thilly, WG. (1979) Mutagenicity of soot and associated polycyclic aromatic hydrocarbons to *Salmonella typhimurium*. *Cancer Res* 39:4152–4159.
- Kakunaga, T. (1973) A quantitative system for assay of morphological/malignant cell transformation by chemical carcinogens using a clone derived from BALB-3T3. *Int J Cancer* 12(2):463–473.
- Katz, M; Heddle, JA; Salamone, MF. (1981) Mutagenic activity of polycyclic aromatic hydrocarbons and other environmental pollutants. Columbus, OH: Battelle Press, pp. 519–528.
- Kligerman, AD; Moore, MM; Erexson, GL; et al. (1986) Genotoxicity studies of benz[*l*]aceanthrylene. *Cancer Lett* 31:123–131.
- Kligerman, AD; Nelson, GB; Ross, JA; et al. (2002) Effect of the route of administration on the induction of cytogenetic damage and DNA adducts in peripheral blood lymphocytes of rats and mice by polycyclic aromatic hydrocarbons. *Polycycl Aromat Compd* 22:814–851.
- Kochhar, TS. (1982) Effects of polycyclic hydrocarbons on the induction of chromosomal aberrations in absence of an exogenous metabolic activation system in cultured hamster cells. *Experientia* 38:845–846.
- Koganti, A; Singh, R; Rozett, K; et al. (2000) 7H-benzo[*c*]fluorene: a major DNA adduct-forming component of coal tar. *Carcinogenesis* 21:1601–1609.
- Kondraganti, SR; Fernandez-Salguero, P; Gonzalez, FJ; et al. (2003) Polycyclic aromatic hydrocarbon-inducible DNA adducts: evidence by ³²P-postlabeling and use of knockout mice for AH receptor-independent mechanisms of metabolic activation in vivo. *Int J Cancer* 103:5–11.
- Krahn, DF; Heidelberger, C. (1977) Liver homogenate-mediated mutagenesis in Chinese hamster V79 cells by polycyclic aromatic hydrocarbons and aflatoxins. *Mutat Res* 46:27–44.
- Krewski, D; Thorslund, T; Withey, J. (1989) Carcinogenic risk assessment of complex mixtures. *Toxicol Ind Health* 5:851–867.
- Kroese, ED; Muller, JJA; Mohn, GR; et al. (2001) Tumorigenic effects in Wistar rats orally administered benzo[*a*]pyrene for two years (gavage studies). Implications for human cancer risks associated with oral exposure to polycyclic aromatic hydrocarbons. National Institute of Public Health and the Environment, Bilthoven, Netherlands.
- Krolewski, B; Nagasawa, H; Little, JB. (1986) Effect of aliphatic amides on oncogenic transformation, sister chromatid exchanges, and mutations induced by cyclopenta[*cd*]-pyrene and benzo[*a*]pyrene. *Carcinogenesis* 7:1647–1650.
- Laaksonen, AM; Mantyljarvi, RA; Hanninen, OO. (1983) Fibroblast cultures of nude mouse skin as targets for transformation by chemical carcinogens. *Med Biol* 61:59–64.
- Lacassagne, A; Buu-Hoi, NP; Zajdela, F; et al. (1968) The true dibenzo[*a,l*]pyrene, a new, potent carcinogen. *Naturwissenschaften* 55:43.
- Lafleur, AL; Longwell, JP; Marr, JA; et al. (1993) Bacterial and human cell mutagenicity study of some C18H10 cyclopenta-fused polycyclic aromatic hydrocarbons associated with fossil fuels combustion. *Environ Health Perspect* 101:146–153.
- Lake, RS; Kropko, ML; Pezzutti, MR; et al. (1978) Chemical induction of unscheduled DNA synthesis in human skin epithelial cell cultures. *Water Res* 38:2091–2098.
- Langenbach, R; Hix, C; Oglesby, L; et al. (1983) Cell-mediated mutagenesis of Chinese hamster V79 cells and *Salmonella typhimurium*. *Ann NY Acad Sci* 407:258–266.

- Larsen, JC; Larsen, PB. (1998) Chemical carcinogens. In: Air pollution and health. Cambridge, UK: The Royal Society of Chemistry, pp. 33–56.
- Lavik, PS; Moore, PR; Rusch, HP; et al. (1942) Some additive effects of carcinogenic hydrocarbons. *Cancer Res* 2:189–192.
- LaVoie, EJ; Bedenko, V; Hirota, N; et al. (1979) A comparison of the mutagenicity, tumor-initiating activity and complete carcinogenicity of polynuclear aromatic hydrocarbons. In: Jones, PW; Leber, P, eds. Polynuclear aromatic hydrocarbons. Ann Arbor, MI: Ann Arbor Science Publishers, pp. 705–721.
- LaVoie, EJ; Tulley, L; Bedenko, V; et al. (1980) Mutagenicity, tumor initiating activity, and metabolism of tricyclic polynuclear aromatic hydrocarbons. In: Bjorseth, A; Dennis, AJ, eds. Polynuclear aromatic hydrocarbons: chemistry and biological effects. Columbus, OH: Battelle Press, pp. 1041–1057.
- LaVoie, EJ; Tulley, L; Bedenko, V; et al. (1981) Mutagenicity, tumor-initiating activity and metabolism of methylphenanthrenes. *Cancer Res* 41:3441–3447.
- LaVoie, EJ; Amin, S; Hecht, SS; et al. (1982) Tumour initiating activity of dihydrodiols of benzo[b]fluoranthene, benzo[j]fluoranthene, and benzo[k]fluoranthene. *Carcinogenesis* 3:49–52.
- LaVoie, EJ; Coleman, DT; Tonne, RL; et al. (1983) Mutagenicity, tumor initiating activity and metabolism of methylated anthracenes. In: Cooke, M; Dennis, AJ, eds. Proceedings of the seventh international symposium. Columbus, OH: Battelle Press, pp. 785–798.
- LaVoie, EJ; Coleman, DT; Rice, JE; et al. (1985) Tumor-initiating activity, mutagenicity, and metabolism of methylated anthracenes. *Carcinogenesis* 6:1483–1488.
- LaVoie, EJ; Braley, J; Rice, JE; et al. (1987) Tumorigenic activity of non-alternant polynuclear aromatic hydrocarbons in newborn mice. *Cancer Lett* 34:15–20.
- LaVoie, EJ; Cai, ZW; Meschter, CL; et al. (1994) Tumorigenic activity of fluoranthene, 2-methylfluoranthene and 3-methylfluoranthene in newborn CD-1 mice. *Carcinogenesis* 15:2131–2135.
- Li, CS; Lin, RH. (1996) Evaluation of low-dosage environmental mutagens with a long-term, cultured epithelial cell line. *Bull Environ Contam Toxicol* 56:919–925.
- Li, KM; Todorovic, R; Rogan, EG; et al. (1995) Identification and quantitation of dibenzo[a,l]pyrene--DNA adducts formed by rat liver microsomes in vitro: preponderance of depurinating adducts. *Biochemistry* 34(25):8043–8049.
- Li, D; Wang, M; Firozi, PF; et al. (2002) Characterization of a major aromatic DNA adduct detected in human breast tissues. *Environ Mol Mutagen* 39:193–200.
- Lubet, RA; Kiss, E; Gallagher, MM; et al. (1983) Induction of neoplastic transformation and DNA single-strand breaks in C3H/10T1/2 clone 8 cells by polycyclic hydrocarbons and alkylating agents. *J Natl Cancer Inst* 71:991–997.
- Machala, M; Vondracek, J; Blaha, L; et al. (2001) Aryl hydrocarbon receptor-mediated activity of mutagenic polycyclic aromatic hydrocarbons determined using in vitro reporter gene assay. *Mutat Res* 497:49–62.
- MacLeod, MC; Cohen, GM; Selkirk, JK. (1979) Metabolism and macromolecular binding of the carcinogen benzo[a]pyrene and its relatively inert isomer benzo(e)pyrene by hamster embryo cells. *Cancer Res* 39:3463–3470.
- Malcolm, HM; Dobson, S. (1994) The calculation of an environmental assessment level (EAL) for atmospheric PAHs using relative potencies. Department of the Environment, London, England; Report No. DoE/HMIP/RR/94/041.
- Mamber, SW; Bryson, V; Katz, SE. (1983) The *Escherichia coli* WP2/WP100 rec assay for detection of potential chemical carcinogens. *Mutat Res* 119:135–144.

Mane, SS; Purnell, DM; Hsu, IC. (1990) Genotoxic effects of five polycyclic aromatic hydrocarbons in human and rat mammary epithelial cells. *Environ Mol Mutagen* 15:78–82.

Marshall, CJ; Vousden, KH; Phillips, DH. (1984) Activation of c-Ha-ras-1 proto-oncogene by in vitro modification with a chemical carcinogen, benzo[a]pyrene diol-epoxide. *Nature* 310(5978):586–589.

Martin, CN; McDermid, AC. (1981) Testing of 42 coded compounds for their ability to induce unscheduled DNA repair synthesis in HeLa cells. *Prog Mutat Res* 1:533–537.

Martin, CN; McDermid, AC; Garner, RC. (1978) Testing of known carcinogens and noncarcinogens for their ability to induce unscheduled DNA synthesis in HeLa cells. *Cancer Res* 38:2621–2627.

Mass, MJ; Jeffers, AJ; Ross, JA; et al. (1993) Ki-ras oncogene mutations in tumors and DNA adducts formed by benz[j]aceanthrylene and benzo[a]pyrene in the lungs of strain A/J mice. *Mol Carcinog* 8:186–192.

Masuda, Y; Kagawa, R. (1972) A novel synthesis and carcinogenicity of dibenzo[a,l]pyrene. *Chem Pharm Bull* 20:2736–2737.

Matsuoka, A; Hayashi, M; Ishidate, MJ. (1979) Chromosomal aberration tests on 29 chemicals combined with S9 mix in vitro. *Mutat Res* 66:277–290.

Matthews, EJ; Kruhlak, NL; Cimino, MC; et al. (2006a) An analysis of genetic toxicity, reproductive and developmental toxicity, and carcinogenicity data: I. Identification of carcinogens using surrogate endpoints. *Regul Toxicol Pharmacol* 44:83–96.

Matthews, EJ; Kruhlak, NL; Cimino, MC; et al. (2006b) An analysis of genetic toxicity, reproductive and developmental toxicity, and carcinogenicity data: II. Identification of genotoxicants, reprotoxicants, and carcinogens using in silico methods. *Regul Toxicol Pharmacol* 44:97–110.

McCann, J; Choi, E; Yamasaki, E; et al. (1975) Detection of carcinogens as mutagens in the Salmonella/microsome test: assay of 300 chemicals. *Proc Natl Acad Sci USA* 72:5135–5139.

McCarroll, NE; Piper, CE; Keech, BH. (1981) An E coli microsuspension assay for the detection of DNA damage induced by direct-acting agents and promutagens. *Environ Mutagen* 3:429–444.

McClure, PR. (1996) Evaluation of a component-based relative potency approach to cancer risk assessment for exposure to PAHs. *Toxicologist* 30(1, Part 2):8.

McCoull, KD; Rindgen, D; Blair, IA; et al. (1999) Synthesis and characterization of polycyclic aromatic hydrocarbon o-quinone depurinating N7-guanine adducts. *Chem Res Toxicol* 12:237–246.

Meek, ME; Chan, PKL; Bartlett, S. (1994) Polycyclic aromatic hydrocarbons: evaluation of risks to health from environmental exposures in Canada. *Environ Carcinog Ecotoxicol Rev C* 12:443–452.

Melendez-Colon, VJ; Luch, A; Seidel, A; et al. (2000) Formation of stable DNA adducts and apurinic sites upon metabolic activation of bay and fjord region polycyclic aromatic hydrocarbons in human cell cultures. *Chem Res Toxicol* 13:10–17.

Mersch-Sundermann, V; Mochayedi, S; Kevekordes, S. (1992) Genotoxicity of polycyclic aromatic hydrocarbons in *Escherichia coli* PQ37. *Mutat Res* 278:1–9.

Miller, KP; Ramos, KS. (2001) Impact of cellular metabolism on the biological effects of benzo[a]pyrene and related hydrocarbons. *Drug Metab Rev* 33:1–35.

Milo, GE; Blakeslee, J; Yohn, DS; et al. (1978) Biochemical activation of aryl hydrocarbon hydroxylase activity, cellular distribution of polynuclear hydrocarbon metabolites, and DNA damage by polynuclear hydrocarbon products in human cells in vitro. *Cancer Res* 38:1638–1644.

Mishra, NK; Wilson, CM; Pant, KJ; et al. (1978) Simultaneous determination of cellular mutagenesis and transformation by chemical carcinogens in Fischer rat embryo cells. *J Toxicol Environ Health* 4:79–91.

Mohapatra, N; MacNair, P; Bryant, BJ; et al. (1987) Morphological transforming activity and metabolism of cyclopenta-fused isomers of benz[a]anthracene in mammalian cells. *Mutat Res* 188:323–334.

Muller, P; Leece, B; Raha, D. (1997) Scientific criteria document for multimedia standards development. Polycyclic aromatic hydrocarbons (PAHs). Part 1: Hazard identification and dose-response assessment. Ontario Ministry of the Environment, Standards Development Branch.

Murison, GL. (1988) Induction of sister-chromatid exchanges by direct and indirect agents in a human teratoma cell line. *Mutat Res* 203:347–354.

Myhr, BC; Caspary, WJ. (1988) Evaluation of the L5178Y mouse lymphoma cell mutagenesis assay: intralaboratory results for sixty-three coded chemicals tested at Litton Bionetics, Inc. *Environ Mol Mutag* 12 (Suppl 13):103–194.

Nagabhushan, M; Hussong, J; Polverini, PJ; et al. (1990) Inhibition of hamster buccal pouch epithelial cell replication during in vitro exposure to polycyclic aromatic hydrocarbons. *Proc Am Assoc Cancer Res* 31:86.

Nakatsuru, Y; Wakabayashi, K; Fujii-Kuriyama, Y; et al. (2004) Dibenzo[a,l]pyrene-induced genotoxic and carcinogenic responses are dramatically suppressed in aryl hydrocarbon receptor-deficient mice. *Int J Cancer* 112:179–183.

Neal, J; Rigdon, RH. (1967) Gastric tumors in mice fed benzo[a]pyrene: a quantitative study. *Tex Rep Biol Med* 25:553–557.

Nesnow, S; Triplett, LL; Slaga, TJ. (1983) Mouse skin tumor initiation-promotion and complete carcinogenesis bioassays: mechanisms and biological activities of emission samples. *Environ Health Perspect* 47:255–268.

Nesnow, S; Gold, A; Sangaiah, R; et al. (1984) Mouse skin tumor-initiating activity of benz[e]aceanthrylene and benz[l]aceanthrylene in Sencar mice. *Cancer Lett* 22:263–268.

Nesnow, S; Milo, G; Kurian, P; et al. (1990) Induction of anchorage-independent growth in human diploid fibroblasts by the cyclopenta-polycyclic aromatic hydrocarbon, benz[l]aceanthrylene. *Mutat Res* 244:221–225.

Nesnow, S; Ross, J; Mohapatra, N; et al. (1991) Genotoxicity and identification of the major DNA-adducts of aceanthrylene. In: Cooke M LKMJe, eds. *Polynuclear aromatic hydrocarbons: measurements, means, and metabolism*. Columbus, OH: Battelle Press, pp. 629–639.

Nesnow, S; Beck, S; Ball, LM; et al. (1993a) Morphological transformation of C3H10T1/2CL8 cells by cyclopenta-fused derivatives of benzo[a]pyrene and benzo[e]pyrene. *Cancer Lett* 74:25–30.

Nesnow, S; Ross, J; Nelson, G; et al. (1993b) Quantitative and temporal relationships between DNA adduct formation in target and surrogate tissues: implications for biomonitoring. *Environ Health Perspect* 101(Suppl 6) 3:37–42.

Nesnow, S; Ross, J; Beck, S; et al. (1994) Morphological transformation and DNA adduct formation by dibenz[a,h]anthracene and its metabolites in C3H10T1/2CL8 cells. *Carcinogenesis* 15:2225–2231.

Nesnow, S; Ross, JA; Stoner, GD; et al. (1995) Mechanistic linkage between DNA adducts, mutations in oncogenes and tumorigenesis of carcinogenic environmental polycyclic aromatic hydrocarbons in strain A/J mice. *Toxicology* 105:403–413.

Nesnow, S; Ross, JA; Stoner, GD; et al. (1996) Tumorigenesis of carcinogenic environmental polycyclic aromatic hydrocarbons in strain A/J mice: linkage to DNA adducts and mutations in oncogenes. *Polycyclic Aromatic Hydrocarbons* 10:259–266.

Nesnow, S; Davis, C; Nelson, G; et al. (1997) Comparison of the morphological transforming activities of dibenzo[a,l]pyrene and benzo[a]pyrene in C3H10T1/2CL8 cells and characterization of the dibenzo[a,l]pyrene-DNA adducts. *Carcinogenesis* 18:1973–1978.

Nesnow, S; Mass, MJ; Ross, JA; et al. (1998a) Lung tumorigenic interactions in strain A/J mice of five environmental polycyclic aromatic hydrocarbons. *Environ Health Perspect* 106(Suppl 6):1337–1346.

Nesnow, S; Ross, JA; Mass, MJ; et al. (1998b) Mechanistic relationships between DNA adducts, oncogene mutations, and lung tumorigenesis in strain A mice. *Exp Lung Res* 24:395–405.

Nikonova, TV. (1977) Transplacental effect of benz[a]pyrene and pyrene. *Bull Exp Biol Med* 84:1025–1027.

Nisbet, ICT; LaGoy, PK. (1992) Toxic equivalency factors (TEFs) for polycyclic aromatic hydrocarbons (PAHs). *Regul Toxicol Pharmacol* 16:290–300.

Norpoth, K; Kemena, A; Jacob, J; et al. (1984) The influence of 18 environmentally relevant polycyclic aromatic hydrocarbons and Clophen A50, as liver monooxygenase inducers, on the mutagenic activity of benz[a]anthracene in the Ames test. *Carcinogenesis* 5:747–752.

NTP (National Toxicology Program). (2000) Toxicology and carcinogenesis studies of naphthalene (CAS no. 91-20-3) in F344/N rats (inhalation studies). National Toxicology Program. U.S. Department of Health and Human Services, National Institutes of Health, Rockville, MD. Technical report series no. 500.

Nyholm, SH; Alexander, J; Lundanes, E; et al. (1996) Biotransformation of the cyclopenta-fused polycyclic aromatic hydrocarbon benz[j]aceanthrylene in isolated rat liver cells: identification of nine new metabolites. *Carcinogenesis* 17(5):1111–1120.

Okey, AB; Riddick, DS; Harper, PA. (1994) Molecular biology of the aromatic hydrocarbon (dioxin) receptor. *Trends Pharmacol Sci* 15(7):226–232.

Oshiro, Y; Balwierz, PS; Soelter, SG; et al. (1992) Evaluation of mouse peripheral blood micronucleus assay. *Environ Mol Mutag* 19(Suppl 20):47.

Pahlman, R; Pelkonen, O. (1987) Mutagenicity studies of different polycyclic aromatic hydrocarbons: the significance of enzymatic factors and molecular structure. *Carcinogenesis* 8:773–778.

Paika, IJ; Beauchesne, MT; Randall, M; et al. (1981) In vivo SCE analysis of 20 coded compounds. *Prog Mutat Res* 1:672–681.

Park, JH; Gopishetty, S; Szewczuk, LM; et al. (2005) Formation of 8-oxo-7,8-dihydro-2'-deoxyguanosine (8-oxo-dGuo) by PAH o-quinones: involvement of reactive oxygen species and copper(II)/copper(I) redox cycling. *Chem Res Toxicol* 18(6):1026–1037.

Park, JH; Troxel, AB; Harvey, RG; et al. (2006) Polycyclic aromatic hydrocarbon (PAH) o-quinones produced by the aldo-keto-reductases (AKRs) generate abasic sites, oxidized pyrimidines, and 8-oxo-dGuo via reactive oxygen species. *Chem Res Toxicol* 19(5):719–728.

Park, JH; Gelhaus, S; Vedantam, S; et al. (2008) The pattern of p53 mutations caused by PAH o-quinones is driven by 8-oxo-dGuo formation while the spectrum of mutations is determined by biological selection for dominance. *Chem Res Toxicol* 21(5):1039–1049.

Pataki, J; Huggins, C. (1969) Molecular site of substituents of benz[a]anthracene related to carcinogenicity. *Cancer Res* 29:506–509.

Pavanello, S; Favretto, D; Brugnone, F; et al. (1999) HPLC/fluorescence determination of anti-BPDE-DNA adducts in mononuclear white blood cells from PAH-exposed humans. *Carcinogenesis* 20(3):431–435.

Penman, BW; Kaden, DA; Liber, HL; et al. (1980) Perylene is a more potent mutagen than benzo[a]pyrene for *Salmonella typhimurium*. *Mutat Res* 77:271–277.

- Penning, TM; Burczynski, ME; Hung, CF; et al. (1999) Dihydrodiol dehydrogenases and polycyclic aromatic hydrocarbon activation: generation of reactive and redox active o-quinones. *Chem Res Toxicol* 12:1–18.
- Perry, PE; Thomson, EJ. (1981) Evaluation of the sister chromatid exchange method in mammalian cells as a screening system for carcinogens. *Prog Mutat Res* 1:560–569.
- Petry, T; Schmid, P; Schlatter, C. (1996) The use of toxic equivalency factors in assessing occupational and environmental health risk associated with exposure to airborne mixtures of polycyclic aromatic hydrocarbons (PAHs). *Chemosphere* 32:639–648.
- Pfeiffer, EH (1973) Investigations on the carcinogenic burden by air pollution in man. VII. Studies on the oncogenetic interaction of polycyclic aromatic hydrocarbons. *Zbl Bakt Hyg, J Abt Org B* 158:69–83.
- Pfeiffer, EH. (1977) Oncogenic interaction of carcinogenic and non-carcinogenic polycyclic aromatic hydrocarbons in mice. *IARC Sci Publ* 16:69–77.
- Pfeiffer, CA; Allen, E. (1948) Attempts to produce cancer in rhesus monkeys with carcinogenic hydrocarbons and estrogens. *Cancer Res* 8:97–127.
- Phillips, DH; Grover, PL; Sims, P. (1979) A quantitative determination of the covalent binding of a series of polycyclic hydrocarbons to DNA in mouse skin. *Int J Cancer* 23:201–208.
- Phillipson, CE; Ioannides, C. (1989) Metabolic activation of polycyclic aromatic hydrocarbons to mutagens in the Ames test by various animal species including man. *Mutat Res Mar* 211:147–151.
- Pienta, RJ; Poiley, JA; Leberherz, WB 3rd. (1977) Morphological transformation of early passage golden Syrian hamster embryo cells derived from cryopreserved primary cultures as a reliable in vitro bioassay for identifying diverse carcinogens. *Int J Cancer* 19:642–655.
- Platt, KL; Dienes, HP; Tommasone, M; et al. (2004) Tumor formation in the neonatal mouse bioassay indicates that the potent carcinogen dibenzo[def,p]chrysene (dibenzo[a,l]pyrene) is activated in vivo via its *trans*-11,12-dihydrodiol. *Chem Biol Interact* 148:27–36.
- Poncelet, F; Massanda, K; Fouassin, A; et al. (1978) Mutagenic study of some polycyclic aromatic hydrocarbons present in smoked fishes from Africa. *Arch Int Phys Biochem* 86:954–955.
- Popescu, NC; Turnbull, D; DiPaolo, JA. (1977) Sister chromatid exchange and chromosome aberration analysis with the use of several carcinogens and noncarcinogens: brief communication. *J Natl Cancer Inst* 59:289–293.
- Prahalad, AK; Ross, JA; Nelson, GB; et al. (1997) Dibenzo[a,l]pyrene-induced DNA adduction, tumorigenicity, and Ki-ras oncogene mutations in strain A/J mouse lung. *Carcinogenesis* 18:1955–1963.
- Probst, GS; McMahon, RE; Hill, LE; et al. (1981) Chemically-induced unscheduled DNA synthesis in primary rat hepatocyte cultures: a comparison with bacterial mutagenicity using 218 compounds. *Environ Mutagen* 3:11–32.
- Pufulete, M; Battershill, J; Boobis, A; et al. (2004) Approaches to carcinogenic risk assessment for polycyclic aromatic hydrocarbons: a UK perspective. *Regul Toxicol Pharmacol* 40:54–66.
- Puisieux, A; Lim, S; Groopman, J; et al. (1991) Selective targeting of p53 gene mutational hotspots in human cancers by etiologically defined carcinogens. *Cancer Res* 51(22):6185–6189.
- Ramesh, A; Walker, SA; Hood, DB; et al. (2004) Bioavailability and risk assessment of orally ingested polycyclic aromatic hydrocarbons. *Int J Toxicol* 23:301–333.
- Rask-Nielson, R. (1950) The susceptibility of the thymus, lung, subcutaneous and mammary tissues in strain St mice to direct application of small doses of four different carcinogenic hydrocarbons. *Br J Cancer* 4:108–116.

- Raveh, D; Huberman, E. (1983) A microtiter plate assay for the selection of 6-thioguanine-resistant mutants in Chinese hamster V79 cells in the presence of phorbol-12-myristate-13-acetate. *Mutat Res* 113:499–506.
- Raveh, D; Slaga, TJ; Huberman, E. (1982) Cell-mediated mutagenesis and tumor-initiating activity of the ubiquitous polycyclic hydrocarbon, cyclopenta[c,d]pyrene. *Carcinogenesis* 3:763–766.
- Reddy, MV; Gupta, RC; Randerath, E; et al. (1984) ³²P-Postlabeling test for covalent DNA binding of chemicals in vivo: application to a variety of aromatic carcinogens and methylating agents. *Carcinogenesis* 5:231–243.
- Rice, JE; Hosted, TJ, Jr.; LaVoie, EJ. (1984) Fluoranthene and pyrene enhance benzo[a]pyrene-DNA adduct formation in vivo in mouse skin. *Cancer Lett* 24:327–333.
- Rice, JE; Makowski, GS; Hosted, TJ, Jr.; et al. (1985) Methylene-bridged bay region chrysene and phenanthrene derivatives and their keto-analogs: mutagenicity in *Salmonella typhimurium* and tumor-initiating activity on mouse skin. *Cancer Lett* 27:199–206.
- Rice, JE; Jordan, K; Little, P; et al. (1988) Comparative tumor-initiating activity of methylene-bridged and bay-region methylated derivatives of benz[a]anthracene and chrysene. *Carcinogenesis* 9:2275–2278.
- Rigdon, RH; Neal, J. (1966) Gastric carcinomas and pulmonary adenomas in mice fed benzo[a]pyrene. *Tex Rep Biol Med* 24:195–207.
- Rigdon, RH; Neal, J. (1969) Relationship of leukemia to lung and stomach tumors in mice fed benzo[a]pyrene. *Proc Soc Exp Biol Med* 130:146–148.
- Rigdon, RH; Bengel, MC; Kirchoff, H; et al. (1969) Leukemia in mice fed benzo[a]pyrene: a clinical, pathologic and hematologic study. *Tex Rep Biol Med* 27:803–820.
- Robinson, DE; Mitchell, AD. (1981) Unscheduled DNA synthesis response of human fibroblasts, WI-38 cells, to 20 coded chemicals. *Prog Mutat Res* 1:517–527.
- Roe, FJC. (1962) Effect of phenanthrene on tumour-initiation by 3,4-benzopyrene. *Br J Cancer* 16:503–506.
- Roe, FJ; Waters, MA. (1967) Induction of hepatoma in mice by carcinogens of the polycyclic hydrocarbon type. *Nature* 214:299–300.
- Rogan, EG; Cavalieri, EL; Ramakrishna, NVS; et al. (1993) Mechanisms of benzo[a]pyrene and 7,12-dimethylbenz[a]anthracene activation: qualitative aspects of the stable and depurination DNA adducts obtained from radical cations and diol epoxides. In: *Polycyclic aromatic hydrocarbons: synthesis, properties, analytical measurements, occurrence and biological effects*. Bordeaux, France: Gordon and Breach Science Publishers, pp. 733–740.
- Rosenkranz, HS; Leifer, Z. (1980) Determining the DNA-modifying activity of chemicals using DNA polymerase-deficient *Escherichia coli*. In: *Chemical mutagens: principles and methods for their detection*. New York, NY: Plenum Press, pp. 109–147.
- Rosenkranz, HS; Poirier, LA. (1979) Evaluation of the mutagenicity and DNA-modifying activity of carcinogens and noncarcinogens in microbial systems. *J Natl Cancer Inst* 62:873–891.
- Ross, JA; Nelson, GB; Wilson, KH; et al. (1995) Adenomas induced by polycyclic aromatic hydrocarbons in strain A/J mouse lung correlate with time-integrated DNA adduct levels. *Cancer Res* 55:1039–1044.
- Rossmann, TG; Molina, M; Meyer, L; et al. (1991) Performance of 133 compounds in the lambda prophage induction endpoint of the microscreen assay and a comparison with *Salmonella typhimurium* mutagenicity and rodent carcinogenicity assays. *Mutat Res* 260:349–367.
- Roszinsky-Kocher, G; Basler, A; Rohrborn, G. (1979) Mutagenicity of polycyclic hydrocarbons. V. Induction of sister-chromatid exchanges in vivo. *Mutat Res* 66:65–67.

- Rugen, PJ; Stern, CD; Lamm, SH. (1989) Comparative carcinogenicity of the PAHs as a basis for acceptable exposure levels (AELs) in drinking water. *Regul Toxicol Pharmacol* 9:273–283.
- Rummel, AM; Trosko, JE; Wilson, MR; et al. (1999) Polycyclic aromatic hydrocarbons with bay-like regions inhibited gap junctional intercellular communication and stimulated MAPK activity. *Toxicol Sci* 49:232–240.
- Safe, S; Wormke, M. (2003) Inhibitory aryl hydrocarbon receptor-estrogen receptor alpha cross-talk and mechanisms of action. *Chem Res Toxicol* 16:807–816.
- Sagredo, C; Øvrebø, S; Haugen, A; et al. (2006) Quantitative analysis of benzo[a]pyrene biotransformation and adduct formation in AhR knockout mice. *Toxicol Lett* 167:173–182.
- Sakai, M; Yoshida, D; Mizusaki, S. (1985) Mutagenicity of polycyclic hydrocarbons and quinones on *Salmonella thyphimurium* TA97. *Mutat Res* 156:61–67.
- Salaman, MH; Roe, FJC. (1956) Further tests for tumour-initiating activity: N,N-di(2-chloroethyl)-p-amino-phenylbutic acid (CB1348) as an initiator of skin tumour formation in the mouse. *Br J Cancer* 10:363–378.
- Salamone, MF; Heddle, JA; Katz, M. (1979a) The mutagenic activity of thirty polycyclic aromatic hydrocarbons (PAH) and oxides in urban airborne particulates. *Environ Int* 2:37–43.
- Salamone, MF; Heddle, JA; Katz, M. (1979b) The use of the Salmonella/microsomal assay to determine mutagenicity in paired chemical mixtures. *Can J Genet Cytol* 21:101–107.
- Salamone, MF; Heddle, JA; Katz, M. (1981) Mutagenic activity of 41 compounds in the in vivo micronucleus assay. *Prog Mutat Res* 1:686–697.
- Sangaiah, R; Gold, A; Toney, GE; et al. (1983) Benz[j]aceanthrylene: a novel polycyclic aromatic hydrocarbon with bacterial mutagenic activity. *Mutat Res* 119:259–266.
- Sanner, T; Dybing, E. (2005) Comparison of carcinogenic and in vivo genotoxic potency estimates. *Basic Clin Pharmacol Toxicol* 96:131–139.
- Schmähl, D; Schmidt, KG; Habs, M. (1977) Syncarcinogenic action of polycyclic hydrocarbons in automobile exhaust gas condensates. *IARC Sci Publ* 16:53–59.
- Schmoldt, A; Jacob, J; Grimmer, G. (1981) Dose-dependent induction of rat liver microsomal aryl hydrocarbon monooxygenase by benzo[k]fluoranthene. *Cancer Lett* 13:249–257.
- Schneider, K; Roller, M; Kalberlah, F; et al. (2002) Cancer risk assessment for oral exposure to PAH mixtures. *J Appl Toxicol* 22:73–83.
- Scribner, JD. (1973) Brief communication: tumor initiation by apparently noncarcinogenic polycyclic aromatic hydrocarbons. *J Natl Cancer Inst* 50:1717–1719.
- Segeberback, D; Vodicka, P. (1993) Recoveries of DNA adducts of polycyclic aromatic hydrocarbons in the ³²P-postlabeling assay. *Carcinogenesis* 14:2463–2469.
- Shah, GM; Bhattacharya, RK. (1989) Alteration in hepatic nuclear RNA polymerase activity following benzo[a]pyrene administration in rat. *In Vivo* 3:125–127.
- Sharovskaia, I; Rokitskaia, TI; Kobliakov, VA. (2003) [Effect of some polycyclic aromatic hydrocarbons on gap junction intercellular communication in hepatoma Hep G2 cell culture]. *Tsitologiya* 45:51–58.
- Shen, YM; Troxel, AB; Vedantam, S; et al. (2006) Comparison of p53 mutations induced by PAH o-quinones with those caused by anti-benzo[a]pyrene diol epoxide in vitro: role of reactive oxygen and biological selection. *Chem Res Toxicol* 19(11):1441–1450.

- Sheu, CW; Dobras, SN; Rodriguez, I; et al. (1994) Transforming activity of selected polycyclic aromatic hydrocarbons and their nitro-derivatives in BALB/3T3 A31-1-1 cells. *Food Chem Toxicol* 32:611–615.
- Shubik, P; Pietra, G; Della Porta, G. (1960) Studies of skin carcinogenesis in the Syrian golden hamster. *Cancer Res* 20:100–105.
- Simmon, VF. (1979a) In vitro mutagenicity assays of chemical carcinogens and related compounds with *Salmonella typhimurium*. *J Natl Cancer Inst* 62:893–899.
- Simmon, VF. (1979b) In vitro assays for recombinogenic activity of chemical carcinogens and related compounds with *Saccharomyces cerevisiae* D3. *J Natl Cancer Inst* 62:901–910.
- Simmon, VF; Rosenkranz, HS; Zeiger, E; et al. (1979) Mutagenic activity of chemical carcinogens and related compounds in the intraperitoneal host-mediated assay. *J Natl Cancer Inst* 62:911–918.
- Sirianni, SR; Huang, CC. (1978) Sister chromatid exchange induced by promutagens/carcinogens in Chinese hamster cells cultured in diffusion chambers in mice. *Proc Soc Exp Biol Med* 158:269–274.
- Sjogren, M; Ehrenberg, L; Rannug, U. (1996) Relevance of different biological assays in assessing initiating and promoting properties of polycyclic aromatic hydrocarbons with respect to carcinogenic potency. *Mutat Res* 358:97–112.
- Slaga, TJ; Fischer, SM. (1983) Strain differences and solvent effects in mouse skin carcinogenesis experiments using carcinogens, tumor initiators and promoters. *Prog Exp Tumor Res* 26:85–109.
- Slaga, TJ; Hubermann, E; Selkirk, JK; et al. (1978) Carcinogenicity and mutagenicity of benz[a]anthracene diols and diol-epoxides. *Cancer Res* 38:1699–1704.
- Slaga, TJ; Jecker, L; Bracken, WM; et al. (1979) The effects of weak or noncarcinogenic polycyclic hydrocarbons on 7,12-dimethylbenz[a]anthracene and benzo[a]pyrene skin tumor-initiation. *Cancer Lett* 7:51–59.
- Slaga, TJ; Iyer, RP; Lyga, W; et al. (1980) Comparison of the skin tumor-initiating activities of dihydrodiols, diol-epoxides, and methylated derivatives of various polycyclic aromatic hydrocarbons. In: Bjorseth, A; Dennis, AJ, eds. *Polynuclear aromatic hydrocarbons: chemistry and biological effects*. Columbus, OH: Battelle Press, pp. 753–769.
- Slooff, W; Janus, JA; Matthijsen, AJCM; et al. (1989) Integrated criteria document PAHs (PDF includes addendum by Montizaan). National Institute of Public Health and the Environment (RIVM), Bilthoven, The Netherlands.
- Smith, LE; Denissenko, MF; Bennett, WP; et al. (2000) Targeting of lung cancer mutational hotspots by polycyclic aromatic hydrocarbons. *J Natl Cancer Inst* 92:803–811.
- Smolarek, TA; Baird, WM. (1984) Benzo[e]pyrene-induced alterations in the binding of benzo[a]pyrene to DNA in hamster embryo cell cultures. *Carcinogenesis* 5:1065–1069.
- Smolarek, TA; Moynihan, CG; Salmon, CP; et al. (1986) Benz[a]anthracene-induced alterations in the metabolic activation of benzo[a]pyrene by hamster embryo cell cultures. *Cancer Lett* 30:243–249.
- Smolarek, TA; Baird, WM; Fisher, EP; et al. (1987) Benzo[e]pyrene-induced alterations in the binding of benzo[a]pyrene and 7,12-dimethylbenz[a]anthracene to DNA in Sencar mouse epidermis. *Cancer Res* 47:3701–3706.
- Snell, KC; Stewart, HL. (1962) Pulmonary adenomatosis induced in DBA/2 mice by oral administration of dibenz[a,h]anthracene. *J Natl Cancer Inst* 28:1043–1049.
- Solt, DB; Polverini, PJ; Calderon, L. (1987) Carcinogenic response of hamster buccal pouch epithelium to 4 polycyclic aromatic hydrocarbons. *J Oral Pathol* 16:294–302.
- Staal, YCM; Hebels DGAJ; van Herwijnen, MHM; et al. (2007) Binary PAH-mixture cause additive or antagonistic effects on gene expression but synergistic effects on DNA adduct formation. *Carcinogenesis* 28:2632–2640.

- Stanton, MF; Miller, E; Wrench, C; et al. (1972) Experimental induction of epidermoid carcinoma in the lungs of rats by cigarette smoke condensate. *J Natl Cancer Inst* 49:867–877.
- Steiner, PF. (1955) Carcinogenicity of multiple chemicals simultaneously administered. *Cancer Res* 15:632–635.
- Steiner, PF; Falk, HL. (1951) Summation and inhibition effects of weak and strong carcinogenic hydrocarbons: 1:2-benzanthracene, chrysene, 1:2:5:6-dibenzanthracene, and 20-methylcholanthrene. *Cancer Res* 11:56–63.
- Straif K; Baan, R; Grosse, Y; et al. (2005) Carcinogenicity of polycyclic aromatic hydrocarbons. *Lancet* 6:931–932.
- Sugiyama, T. (1973) Chromosomal aberrations and carcinogenesis by various benz[a]anthracene derivatives. *Gann* 64:637–639.
- Tannheimer, SL; Ethier, SP; Caldwell, KK; et al. (1998) Benzo[a]pyrene- and TCDD-induced alterations in tyrosine phosphorylation and insulin-like growth factor signaling pathways in the MCF-10A human mammary epithelial cell line. *Carcinogenesis* 19:1291–1297.
- Teranishi, K; Hamada, K; Watanabe, H. (1975) Quantitative relationship between carcinogenicity and mutagenicity of polyaromatic hydrocarbons in *Salmonella typhimurium* mutants. *Mutat Res* 31:97–102.
- Thyssen, J; Althoff, J; Kimmerle, G; et al. (1980) Investigations on the carcinogenic burden of air pollution in man. XIX. Effect of inhaled benzo[a]pyrene in Syrian golden hamsters: a pilot study. *Zentralbl Bakteriol Hyg I Abt Orig B* 171:441–444.
- Thyssen, J; Althoff, J; Kimmerle, G; et al. (1981) Inhalation studies with benzo[a]pyrene in Syrian golden hamsters. *J Natl Cancer Inst* 66:575–577.
- Till, M; Riebinger, D; Schmitz, HJ; et al. (1999) Potency of various polycyclic aromatic hydrocarbons as inducers of CYP1A1 in rat hepatocyte cultures. *Chem Biol Interact* 117:135–150.
- Tong, C; Brat, SV; Williams, GM. (1981a) Sister-chromatid exchange induction by polycyclic aromatic hydrocarbons in an intact cell system of adult rat-liver epithelial cells. *Mutat Res* 91:467–473.
- Tong, C; Laspia, MF; Telang, S; et al. (1981b) The use of adult rat liver cultures in the detection of the genotoxicity of various polycyclic aromatic hydrocarbons. *Environ Mutagen* 3:477–487.
- Tong, C; Brat, VS; Telang, S; et al. (1983) Effects of genotoxic polycyclic aromatic hydrocarbons in rat liver culture systems. In: Cooke, M; Dennis, AJ, eds. *Polynuclear aromatic hydrocarbons: formation; metabolism, and measurement*. Columbus, OH: Battelle Press, pp. 1189–1203.
- Topping, DC; Martin, DH; Nettesheim, P. (1981) Determination of cocarcinogenic activity of benzo[e]pyrene for respiratory tract mucosa. *Cancer Lett* 11:315–321.
- Travis, CC; Saulsbury, AW; Richter Pack, SA. (1990) Prediction of cancer potency using a battery of mutation and toxicity data. *Mutagenesis* 5:213–219.
- Tsuchimoto, T; Matter, BE. (1981) Activity of coded compounds in the micronucleus test. *Prog Mutat Res* 1:705–711.
- Tweats, DJ. (1981) Activity of 42 coded compounds in a differential killing test using *Escherichia coli* strains WP2, WP67 (uvrA polA), and CM871 (uvrA lexA recA). *Prog Mutat Res* 1:199–209.
- Uno, S; Dalton, TP; Dragin, N; et al. (2006) Oral benzo[a]pyrene in *Cyp1* knockout mouse lines: CYP1A1 important in detoxication, CYP1B1 metabolism required for immune damage independent of total-body burden and clearance rate. *Mol Pharmacol* 69:1103–1114.
- U.S. EPA (U.S. Environmental Protection Agency). (1986) Guidelines for the health risk assessment of chemical mixtures. *Federal Register* 51(185):34014–34025.

U.S. EPA (U.S. Environmental Protection Agency). (1990) Drinking water criteria document for polycyclic aromatic hydrocarbons. Cincinnati, OH: Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office.

U.S. EPA (U.S. Environmental Protection Agency). (1993) Provisional guidance for quantitative risk assessment of polycyclic aromatic hydrocarbons. Cincinnati, OH: Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office.

U.S. EPA (U.S. Environmental Protection Agency). (2000) Supplementary guidance for conducting health risk assessment of chemical mixtures. EPA/630/R-00/002.

U.S. EPA (U.S. Environmental Protection Agency). (2002) Peer consultation workshop on approaches to polycyclic aromatic hydrocarbon (PAH) health assessment. Washington, DC: National Center for Environmental Assessment, Office of Research and Development. EPA/635/R-02/005.

U.S. EPA (U.S. Environmental Protection Agency). (2004) An examination of EPA risk assessment principles and practices. Staff paper prepared for the U.S. EPA by members of the Risk Assessment Task Force at the request of the EPA science advisor. Available online at <http://www.epa.gov/osa/ratf.htm> (accessed January 13, 2010).

U.S. EPA (U.S. Environmental Protection Agency). (2005a) Guidelines for carcinogen risk assessment. Risk Assessment Forum, Washington, DC: EPA/630/P-03/001B. Available online at <http://www.epa.gov/iris/backgr-d.htm> (accessed January 15, 2009).

U.S. EPA (U.S. Environmental Protection Agency). (2005b) Supplemental guidance for assessing susceptibility from early-life exposure to carcinogens. Risk Assessment Forum, Washington, DC; EPA/630/R-03/003F. Available online at <http://www.epa.gov/iris/backgr-d.htm> (accessed January 15, 2009).

U.S. EPA (U.S. Environmental Protection Agency). (2009) Integrated Risk Information System (IRIS). National Center for Environmental Assessment, Washington, DC. Available online at <http://www.epa.gov/iris> (accessed January 13, 2010).

Utesch, D; Glatt, H; Oesch, F. (1987) Rat hepatocyte-mediated bacterial mutagenicity in relation to the carcinogenic potency of benz[a]anthracene, benzo[a]pyrene, and twenty-five methylated derivatives. *Cancer Res* 47(6):1509–1515.

Vaca, C; Tornqvist, M; Rannug, U; et al. (1992) On the bioactivation and genotoxic action of fluoranthene. *Arch Toxicol* 66:538–545.

Valencia, R; Houtchens, K. (1981) Mutagenic activity of 10 coded compounds in the *Drosophila* sex-linked recessive lethal test. *Prog Mutat Res* 1:652–659.

Van Duuren, BL; Goldschmidt, BM. (1976) Cocarcinogenic and tumor-promoting agents in tobacco carcinogenesis. *J Natl Cancer Inst* 56:1237–1242.

Van Duuren, BL; Sivak, A; Segal, A; et al. (1966) The tumor-promoting agents of tobacco leaf and tobacco smoke condensate. *J Natl Cancer Inst* 37:519–526.

Van Duuren, BL; Sivak, A; Langseth, L; et al. (1968) Initiators and promoters in tobacco carcinogenesis. *Natl Cancer Inst Monogr* 28:173–80.

Van Duuren, BL; Sivak, A; Goldschmidt, BM; et al. (1970) Initiating activity of aromatic hydrocarbons in two-stage carcinogenesis. *J Natl Cancer Inst* 44:1167–1173.

Van Duuren, BL; Katz, C; Goldschmidt, BM; et al. (1973) Brief communication: cocarcinogenic agents in tobacco carcinogenesis. *J Natl Cancer Inst* 51:703–705.

Vesselinovitch, SD; Kyriazis, AP; Mihailovich, N; et al. (1975) Factors influencing and/or acceleration of lymphoreticula tumors in mice by benzo[a]pyrene treatment. *Cancer Res* 35:1963–1969.

- Vienneau, DS; DeBoni, U; Wells, PG. (1995) Potential genoprotective role for UDP-glucuronosyltransferases in chemical carcinogenesis: initiation of micronuclei by benzo[a]pyrene and benzo[e]pyrene in UDP-glucuronosyltransferase-deficient cultured rat skin fibroblasts. *Cancer Res* 55:1045–1051.
- Vijayalakshmi, KP; Suresh, CH. (2008) Theoretical studies on the carcinogenicity of polycyclic aromatic hydrocarbons. *J Comput Chem* 29:1108–1117.
- Wangenheim, J; Bolcsfoldi, G. (1988) Mouse lymphoma L5178Y thymidine kinase locus assay of 50 compounds. *Mutagenesis* 3:193–205.
- Warshawsky, D; Barkley, W. (1987) Comparative carcinogenic potencies of 7H-dibenzo[c,g]carbazole, dibenz[a,j]acridine and benzo[a]pyrene in mouse skin. *Cancer Lett* 37:337–344.
- Warshawsky, D; Barkley, W; Bingham, E. (1993) Factors affecting carcinogenic potential of mixtures. *Fundam Appl Toxicol* 20:376–382.
- Warshawsky, D; Livingston, GK; Fonouni-Fard, M; et al. (1995) Induction of micronuclei and sister chromatid exchanges by polycyclic and N-heterocyclic aromatic hydrocarbons in cultured human lymphocytes. *Environ Mol Mutagen* 26:109–118.
- Weinstein, D; Katz, ML; Kazmer, S. (1977) Chromosomal effects of carcinogens and noncarcinogens on WI-38 after short term exposures with and without metabolic activation. *Mutat Res* 46:297–304.
- Wenzel-Hartung, R; Brune, H; Grimmer, G; et al. (1990) Evaluation of the carcinogenic potency of four environmental polycyclic aromatic compounds following intrapulmonary application in rats. *Exp Pathol* 40:221–227.
- Weyand, EH; LaVoie, EJ. (1988) Comparison of PAH DNA adduct formation and tumor initiating activity in newborn mice. *Proc Am Assoc Cancer Res* 29:98.
- Weyand, EH; Wu, Y. (1995) Covalent binding of polycyclic aromatic hydrocarbon components of manufactured gas plant residue to mouse lung and forestomach DNA. *Chem Res Toxicol* 8:955–962.
- Weyand, EH; He, ZM; Ghodrati, F; et al. (1992) Effect of fluorene substitution on benzo[j]fluoranthene genotoxicity. *Chem Biol Interact* 84:37–53.
- Weyand, EH; Chen, YC; Wu, Y; et al. (1995) Differences in the tumorigenic activity of a pure hydrocarbon and a complex mixture following ingestion: benzo[a]pyrene vs. manufactured gas plant residue. *Chem Res Toxicol* 8:949–954.
- WHO (World Health Organization). (1998) Selected non-heterocyclic polycyclic aromatic hydrocarbons Environmental health criteria. Vol. 202. International Programme on Chemical Safety, Geneva, Switzerland.
- Willett, KL; Gardinali, PR; Sericano, JL; et al. (1997) Characterization of the H4IIE rat hepatoma cell bioassay for evaluation of environmental samples containing polynuclear aromatic hydrocarbons (PAHs). *Arch Environ Contam Toxicol* 32:442–448.
- Williams, GM; Laspia, MF; Dunkel, VC. (1982) Reliability of the hepatocyte primary culture/DNA repair test in testing of coded carcinogens and noncarcinogens. *Mutat Res* 97:359–370.
- Wislocki, PG; Bagan, ES; Lu, AY; et al. (1986) Tumorigenicity of nitrated derivatives of pyrene, benz[a]anthracene, chrysene and benzo[a]pyrene in the newborn mouse assay. *Carcinogenesis* 7:1317–1322.
- Wood, AW; Chang, RL; Levin, W; et al. (1979) Mutagenicity and tumorigenicity of phenanthrene and chrysene epoxides and diol epoxides. *Cancer Res* 39:4069–4077.
- Wood, AW; Levin, W; Chang, RL; et al. (1980) Mutagenicity and tumor-initiating activity of cyclopenta[c,d]pyrene and structurally related compounds. *Cancer Res* 40:642–649.

- Wynder, EL; Hoffmann, D. (1959a) The carcinogenicity of benzofluoranthenes. *Cancer* 12:1194–1199.
- Wynder, EL; Hoffmann, D. (1959b) A study of tobacco carcinogenesis: VII. The role of higher polycyclic hydrocarbons. *Cancer* 12:1079–1086.
- Wynder, EL; Hoffmann, D. (1961) Carcinogenicity of dibenzo[a,1]pyrene. *Nature* 192:1092–1093.
- Wynder, EL; Fritz, L; Furth, N. (1957) Effect of concentration of benzopyrene in skin carcinogenesis. *J Natl Cancer Inst* 19:361–370.
- Xu, D; Penning, TM; Blair, IA; et al. (2009) Synthesis of phenol and quinone metabolites of benzo[a]pyrene, a carcinogenic component of tobacco smoke implicated in lung cancer. *J Org Chem* 74:597–604.
- Xue, W; Warshawsky, D. (2005) Metabolic activation of polycyclic and heterocyclic aromatic hydrocarbons and DNA damage: a review. *Toxicol Appl Pharmacol* 206:73–93.
- Yu, C; Xu, S; Chen, S; et al. (2002) Investigation of photobleaching of hypocrellin B in non-polar organic solvent and in liposome suspension. *J Photochem Photobiol B* 68:73–78.
- Zijlstra, JA; Vogel, EW. (1984) Mutagenicity of 7,12-dimethylbenz[a]anthracene and some other aromatic mutagens in *Drosophila melanogaster*. *Mutat Res* 125:243–261.

APPENDIX A. SECONDARY SOURCES REVIEWED FOR IDENTIFICATION OF PRIMARY LITERATURE

ATSDR (Agency for Toxic Substances and Disease Registry). (1995) Toxicological profile for polycyclic aromatic hydrocarbons (PAHs). Atlanta, GA.

Bostrom, CC; Gerde, P; Hanberg, A; et al. (2002) Cancer risk assessment, indicators, and guidelines for polycyclic aromatic hydrocarbons in the ambient air. *Environ Health Perspect* 110(Suppl. 3):451–488.

California EPA (California Environmental Protection Agency). (2002) Air toxics hot spots program risk assessment guidelines Part I. Technical support document for describing available cancer potency factors. Office of Environmental Health Hazard Assessment.

California EPA (California Environmental Protection Agency). (2004) No Significant Risk Levels (NSRLs) for the Proposition 65 carcinogens benzo[b]fluoranthene, benzo[j]fluoranthene, chrysene, dibenzo[a,h]pyrene, dibenzo[a,i]pyrene, and 5-methyl chrysene by the oral route. Office of Environmental Health Hazard Assessment, Reproductive and Cancer Hazard Assessment Section.

CCME (Canadian Council of the Ministers of the Environment). (2003) Canadian soil quality guidelines for potentially carcinogenic and higher molecular weight polycyclic aromatic hydrocarbons (environmental and human health aspects). Scientific Supporting Document. UMA Group Ltd. Victoria, British Columbia.

Clement Associates. (1988) Comparative potency approach for estimating the cancer risk associated with exposure to mixtures of polycyclic aromatic hydrocarbons. Report No. 68-02-4403.

Clement Associates. (1990) Development of relative potency estimates for PAHs and hydrocarbon combustion product fractions compared to benzo[a]pyrene and their use in carcinogenic risk assessments. Draft Report, prepared for the U.S. EPA. September 30, 1990.

Collins, JF; Brown, JP; Alexeeff, GV; et al. (1998) Potency equivalency factors for some polycyclic aromatic hydrocarbons and polycyclic aromatic hydrocarbon derivatives. *Regul Toxicol Pharmacol* 28:45–54.

Health Canada. (1994) Canadian Environmental Protection Act; Priority substances list assessment report: polycyclic aromatic hydrocarbons. Government of Canada, Environment Canada.

IARC (International Agency for Research on Cancer). (1983) Polynuclear aromatic compounds. Part 1. Chemical, environmental and experimental data. In: IARC monographs on the evaluation of carcinogenic risk of chemicals to humans. Vol. 32. Lyon, France.

IARC (International Agency for Research on Cancer). (1984a) Polynuclear aromatic compounds. Part 2. Carbon black, mineral oils (lubricant base oils and derived products) and some nitroarenes. In: IARC monographs on the evaluation of carcinogenic risk of chemicals to humans. Lyon, France. pp. 87–168.

IARC (International Agency for Research on Cancer). (1984b) Polynuclear aromatic compounds. Part 3. Industrial exposures in aluminum production, coal gasification, coke production, and iron and steel founding. In: IARC monographs on the evaluation of carcinogenic risk of chemicals to humans. Lyon, France, pp. 37–111.

IARC (International Agency for Research on Cancer). (1985) Polynuclear aromatic compounds. Part 4. Bitumens, coal-tars and derived products, shale-oils and soots. In: IARC monographs on the evaluation of carcinogenic risk of chemicals to humans. Lyon, France, pp. 65–159.

IARC (International Agency for Research on Cancer). (1989) Occupational exposures in petroleum refining; crude oil and major petroleum fuels. In: IARC monographs on the evaluation of carcinogenic risk of chemicals to humans. Vol. 45. Lyon, France, pp. 239–270.

IARC (International Agency for Research on Cancer). (1996) Printing processes and printing inks, carbon black and some nitro compounds. In: IARC monographs on the evaluation of carcinogenic risks to humans. Vol. 65. Lyon, France.

IPCS/WHO (International Programme on Chemical Safety/World Health Organization). (1998) Selected non-heterocyclic polycyclic aromatic hydrocarbons. Environmental health criteria 202. International Programme on Chemical Safety.

Krewski, D; Thorslund, T; Withey, J. (1989) Carcinogenic risk assessment of complex mixtures. *Toxicol Ind Health* 5:851–867.

Larsen, JC; Larsen, PB. (1998) Chemical carcinogens. *Air pollution and health*. Cambridge, UK: The Royal Society of Chemistry, pp. 33–56.

Malcolm, HM; Dobson, S. (1994) The calculation of an environmental assessment level (EAL) for atmospheric PAHs using relative potencies. Report No. DoE/HMIP/RR/94/041. London, Department of the Environment.

McClure, P; Shoeny, R. (1995) Evaluation of a component-based relative potency approach to cancer risk assessment for exposure to PAH. In: Fifteenth international symposium on polycyclic aromatic compounds: chemistry, biology and environmental impact. Belgirate, Italy, 19–22 September 1995. Ispra, Joint Research Centre European Commission, pp. 161.

Meek, ME; Chan, PKL; Bartlett, S. (1994) Polycyclic aromatic hydrocarbons: evaluation of risks to health from environmental exposures in Canada. *Environ Carcinog Ecotoxicol Rev C* 12(2):443–452.

Muller, P. (1997) Scientific criteria document for multimedia standards development polycyclic aromatic hydrocarbons (PAH). Part I. Hazard identification and dose-response assessment. Ontario: Ontario Ministry of Environment and Energy, Standards Development Branch.

Nisbet, ICT; LaGoy, PK. (1992) Toxic equivalency factors (TEFs) for polycyclic aromatic hydrocarbons (PAHs). *Regul Toxicol Pharmacol* 16:290–300.

Petry, T; Schmid, P; Schlatter, C. (1996) The use of toxic equivalency factors in assessing occupational and environmental health risk associated with exposure to airborne mixtures of polycyclic aromatic hydrocarbons (PAHs). *Chemosphere* 32(4):639–648.

Rugen, PJ; Stern, CD; Lamm, SH. (1989) Comparative carcinogenicity of the PAHs as a basis for acceptable exposure levels (AELs) in drinking water. *Regul Toxicol Pharmacol* 9(3):273–283.

Schneider, K; Roller, M; Kalberlah, F; et al. (2002) Cancer risk assessment for oral exposure to PAH mixtures. *J Appl Toxicol* 22(1):73–83.

Sjogren, M; Ehrenberg, L; Rannug, U. (1996) Relevance of different biological assays in assessing initiating and promoting properties of polycyclic aromatic hydrocarbons with respect to carcinogenic potency. *Mutat Res* 358(1):97–112.

Slooff, W; Janus, JA; Matthijsen, AJCM; et al. (1989) Integrated criteria document PAHs (PDF includes addendum by Montizaan). Bilthoven, The Netherlands. National Institute of Public Health and the Environment (RIVM).

SRC (Syracuse Research Corporation). (1993) Estimating cancer risk from exposure to PAHs: a relative potency approach. SRC TR-93-045. Draft report prepared for U.S. EPA, Environmental Criteria and Assessment Office, Cincinnati, OH.

U.S. EPA (Environmental Protection Agency). (1990) Drinking water criteria document for polycyclic aromatic hydrocarbons. Cincinnati, OH: Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office.

U.S. EPA (Environmental Protection Agency). (1993) Provisional guidance for quantitative risk assessment of polycyclic aromatic hydrocarbons. Cincinnati, OH: Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office.

1 **APPENDIX B. BIBLIOGRAPHY OF STUDIES WITHOUT BENZO[A]PYRENE AS A**
2 **REFERENCE COMPOUND**
3
4
5
6

Table B-1. Bioassays with and without benzo[a]pyrene by PAH

PAH ^a	CASRN	Bioassays with benzo[a]pyrene						Bioassays without benzo[a]pyrene						
		Dermal		Intra-peritoneal	Sub-cutaneous	Oral	Other	Dermal		Intra-peritoneal	Sub-cutaneous	Oral	Other	
		Initiation	Complete					Initiation	Complete					
Acenanthrylene	202-03-09													
Acenaphthene	83-32-9													
Acenaphthylene	208-96-8													
Acephenanthrylene	201-06-9													
Acetyrene, 2,3-	25732-74-5	x	x											
Anthanthrene	191-26-4	x	x										x	
Anthracene	120-12-7	x	x		x								x	x
Benz[a]anthracene	56-55-3	x	x	x	x	x	x							
Benz[b]anthracene	92-24-9													
Benz[b,c]aceanthrylene, 11H-	202-94-8	x												
Benz[e]aceanthrylene	199-54-2													
Benz[j]aceanthrylene	202-33-5			x										
Benz[l]aceanthrylene	211-91-6	x												
Benzacenaphthylene	76774-50-0													
Benzo[a]fluoranthene	203-33-8													
Benzo[a]fluorene	238-84-6 or 30777-18-5													
Benzo[a]perylene	191-85-5													
Benzo[b]chrysene	214-17-5													
Benzo[b]fluoranthene	205-99-2	x	x	x										x
11H-Benzo[b]fluorene	243-17-4 or 30777-19-6													
Benzo[b]perylene	197-70-6													
Benzo[c]chrysene	194-69-4													
Benzo[c]fluorene	205-12-9 or 30777-20-9													
Benzo[c]phenanthrene	195-19-7													
Benzo[e]pyrene	192-97-2	x	x											x
Benzo[g]chrysene	196-78-1													
Benzo[g,h,i]fluoranthene	203-12-3	x	x											
Benzo[g,h,i]perylene	191-24-2	x	x											x
Benzo[j]fluoranthene	205-82-3	x	x	x										x
Benzo[k]fluoranthene	207-08-9	x	x	x										x
Benzophenanthrene	65777-08-4													
Chrysene	218-01-9	x	x	x	x									x
Coronene	191-07-1		x											
Cyclopenta[c,d]pyrene	27208-37-3	x	x	x										
Cyclopenta[d,e,f]chrysene, 4H-	202-98-2	x								x				
Cyclopenta[d,e,f]phenanthrene, 4H-	203-64-5									x				
Cyclopenta[h,i]acephenanthrylene	114959-37-4													

Table B-1. Bioassays with and without benzo[a]pyrene by PAH

PAH ^a	CASRN	Bioassays with benzo[a]pyrene						Bioassays without benzo[a]pyrene					
		Dermal		Intra-peritoneal	Sub-cutaneous	Oral	Other	Dermal		Intra-peritoneal	Sub-cutaneous	Oral	Other
		Initiation	Complete					Initiation	Complete				
Cyclopenta[h,i]aceanthrylene	131581-33-4												
Cyclopentaphenanthrene	219-08-9												
Cyclopenteno-1,2-benzanthracene, 5,6-	7099-43-6												
Dibenz[a,c]anthracene	215-58-7	x	x					x	x	x	x		
Dibenzo[a,e]fluoranthene	5385-75-1	x	x					x					
Dibenz[a,j]anthracene	224-41-9												
Dibenzo[b,e]fluoranthene	2997-45-7												
Dibenzo[a,c]fluorene, 13H-	201-65-0												
Dibenzo[a,e]pyrene	192-65-4	x	x					x					
Dibenzo[a,f]fluoranthene	203-11-2	x	x					x	x				
Dibenzo[a,g]fluorene, 13H-	207-83-0								x				
Dibenz[a,h]anthracene	53-70-3	x	x	x	x	x	x	x	x	x	x	x	x
Dibenzo[a,h]pyrene	189-64-0	x	x					x		x			
Dibenzo[a,i]pyrene	189-55-9	x	x					x	x	x	x		x
Dibenzo[a,l]pyrene	191-30-0	x	x	x				x	x	x	x	x	
Dibenzo[e,l]pyrene	192-51-8	x	x										
Dibenzo[h,rst]pentaphene	192-47-2												
Dibenz[k,mno]acephenanthrylene	153043-81-3												
Dibenzo[j,mno]acephenanthrylene	153043-82-4												
Dihydroaceanthrylene, 1,2-	641-48-5										x		
Fluoranthene	206-44-0	x	x	x						x			x
Fluorene	86-73-7												
Indeno[1,2,3-c,d]fluoranthene	193-43-1												
Indeno[1,2,3-c,d]pyrene	193-39-5	x	x	x									x
Naphtho[1,2-b]fluoranthene	111189-32-3												
Naphtho[1,2,3,-mno]acephenanthrylene	113779-16-1												
Naphtho[2,1-a]fluoranthene	203-20-3												
Naphtho[2,3-a]pyrene	196-42-9												
Naphtho[2,3-e]pyrene	193-09-9	x	x										
Pentacene	135-48-8												
Pentaphene	222-93-5												
Perylene	198-55-0	x	x										
Phenanthrene	85-01-8	x	x	x	x	x	x	x	x	x	x		x
Picene	213-46-7												
Pyrene	129-00-0	x	x	x									x
Tribenzofluoranthene 3,4-10,11-12,13-	13579-05-0												
Triphenylene	217-59-4		x										

^aPAHs in bold have at least one bioassay without benzo[a]pyrene and no bioassays with benzo[a]pyrene.

B.1. BIBLIOGRAPHY OF BIOASSAYS WITHOUT BENZO[A]PYRENE

Amin, S; Huie, K; Hecht, SS; (1985) Mutagenicity and tumor-initiating activity of methylated benzo[b]fluoranthenes. *Carcinogenesis* 6:1023–1025.

Amin, S; Hussain, N; Balanikas, G; et al. (1985) Mutagenicity and tumor initiating activity of methylated benzo[k] fluoranthenes. *Cancer Lett* 26:343–347.

Amin, S; Misra, B; Braley, J; et al. (1991) Comparative tumorigenicity in newborn mice of chrysene and 5-alkylchrysene-1,2-diol-3,4-epoxides. *Cancer Lett* 58:115–118.

Amin, S; Weyand, EH; Huie, K; et al. (1991) Effects of fluorene substitution on benzo[b]fluoranthene tumorigenicity and DNA adduct formation in mouse skin. In: Cooke, M; Loening, K; Merritt, J, eds. *Polynuclear aromatic hydrocarbons: measurements, means and metabolism*. Columbus, OH, Battelle Press, pp. 25–35.

Amin, S; Desai, D; Dai, W; et al. (1995) Tumorigenicity in newborn mice of fjord region and other sterically hindered diol epoxides of benzo[g]chrysene, dibenzo[a,l]pyrene (dibenzo[def,p]chrysene), 4H-cyclopenta[def]chrysene and fluoranthene. *Carcinogenesis* 16:2813–2817.

Barry, G; Cook, CW; Amin, S; et al. (1934) A comparison of the action of some polycyclic aromatic hydrocarbons in producing tumours of connective tissue. *Am J Cancer* 20:58–69.

Bhatt, TS; Coombs, MM. (1990) The carcinogenicity of cyclopenta[a]phenanthrene and chrysene derivatives in the Sencar mouse. *Polycycl Aromat Compd* 1:51–58.

Bock, FG; King, DW. (1959) A study of the sensitivity of the mouse forestomach toward certain polycyclic hydrocarbons. *J Natl Cancer Inst* 23:833–838.

Bottomley, AC; Twort, CC. (1934) The carcinogenicity of chrysene and oleic acid. *Am J Cancer* 21:781–786.

Boyland, E; Burrows, H. (1935) The experimental production of sarcoma in rats and mice by a colloidal aqueous solution of 1:2:5:6-dibenzanthracene. *J Pathol Bacteriol* 41:231–238.

Boyland, E; Sims, P. (1967) The carcinogenic activities in mice of compounds related to benz[a]anthracene. *Int J Cancer* 2:500–504.

Buening, MK; Levin, W; Karle, JM; et al. (1979) Tumorigenicity of bay-region epoxides and other derivatives of chrysene and phenanthrene in newborn mice. *Cancer Res* 39:5063–5068.

Buening, MK; Levin, W; Wood, A; et al. (1979) Tumorigenicity of the dihydrodiols of dibenz[a,h]anthracene on mouse skin and in newborn mice. *Cancer Res* 39:1310–1314.

Buters, JT; Mahadevan, B; Quintanilla-Martinez, L; et al. (2002) Cytochrome P450 1B1 determines susceptibility to dibenzo[a,l]pyrene-induced tumor formation. *Chem Res Toxicol* 15:1127–1135.

Cavalieri, EL; Rogan, EG; Higginbotham, S; et al. (1989) Tumor-initiating activity in mouse skin and carcinogenicity in rat mammary gland of dibenzo[a]pyrenes: the very potent environmental carcinogen dibenzo[a,l]pyrene. *J Cancer Res Clin Oncol* 115:67–72.

Chang, RL; Levin, W; Wood, AW; et al. (1981) Tumorigenicity of the diastereomeric bay-region benzo[e]pyrene 9,10-diol-11,12-epoxides in newborn mice. *Cancer Res* 41:915–918.

Chang, RL; Levin, W; Wood, AW; et al. (1982) Tumorigenicity of bay-region diol-epoxides and other benzo-ring derivatives of dibenzo[a,h]pyrene and dibenzo[a,i]pyrene on mouse skin and in newborn mice. *Cancer Res* 42:25–29.

Chang, RL; Levin, W; Wood, AW; et al. (1983) Tumorigenicity of enantiomers of chrysene 1,2-dihydrodiol and of the diastereomeric bay-region chrysene 1,2-diol-3,4-epoxides on mouse skin and in newborn mice. *Cancer Res* 43:192–196.

Chouroulinkov, I; Coulomb, H; MacNicoll, AD; et al. (1983) Tumour-initiating activities of dihydrodiols of dibenz[a,c]anthracene. *Cancer Lett* 19:21–26.

Danz, M; Hartmann, A; Otto, M; et al. (1991) Hitherto unknown additive growth effects of fluorene and 2-acetylaminofluorene on bile duct epithelium and hepatocytes in rats. *Arch Toxicol Suppl* 14:71–74.

Flesher, JW; Horn, J; Lehner, AF. (2002) Comparative carcinogenicity of picene and dibenz[a,h]anthracene in the rat. *Biochem Biophys Res Commun* 290:275–279.

Forbes, PD; Davies, RE; Urbach, F. (1976) Phototoxicity and photocarcinogenesis: comparative effects of anthracene and 8-methoxypsoralen in the skin of mice. *Food Cosmet Toxicol* 14:303–306.

Geddie, JE; Amin, S; Huie, K; et al. (1987) Formation and tumorigenicity of benzo[b]fluoranthene metabolites in mouse epidermis. *Carcinogenesis* 8:1579–1584.

Gill, HS; Kole, PL; Wiley, JC; et al. (1994) Synthesis and tumor-initiating activity in mouse skin of dibenzo[a,l]pyrene syn- and anti-fjord-region diolepoxides. *Carcinogenesis* 15:2455–2460.

Hecht, SS; LaVoie, E; Amin, S; et al. (1980) On the metabolic activation of the benzofluoranthenes. In: *Chemical analysis and biological fate: polynuclear aromatic hydrocarbons*. Columbus, OH: Battelle Press, pp. 417–433.

Hecht, SS; LaVoie, EJ; Bedenko, V; et al. (1981a) On the metabolic activation of dibenzo[a,i]pyrene and dibenzo[a,h]pyrene. In: *Chemical analysis and biological fate: polynuclear aromatic hydrocarbons*. Columbus, OH: Battelle Press, pp. 43–45.

Hecht, SS; LaVoie, EJ; Bedenko, V; et al. (1981b) Reduction of tumorigenicity and of dihydrodiol formation by fluorene substitution in the angular rings of dibenzo[a,i]pyrene. *Cancer Res* 41:4341–4345.

Hecht, SS; Amin, S; Lin, JM; et al. (1995) Mammary carcinogenicity in female CD rats of a diol epoxide metabolite of fluoranthene, a commonly occurring environmental pollutant. *Carcinogenesis* 16:1433–1435.

Hecht, SS; Rivenson, A; Amin, S; et al. (1996) Mammary carcinogenicity of diol epoxide metabolites of benzo[j]fluoranthene in female CD rats. *Cancer Lett* 106:251–255.

Hermann, M. (1981) Synergistic effects of individual polycyclic aromatic hydrocarbons on the mutagenicity of their mixtures. *Mutat Res* 90:399–409.

Hill, WT; Stanger, DW; Pizzo, A; et al. (1951) Inhibition of 9,10-dimethyl-1,2-benzanthracene skin carcinogenesis in mice by polycyclic hydrocarbons. *Cancer Res* 11:892–897.

Homburger, F; Treger, A. (1970) Transplantation technique for acceleration of carcinogenesis by benz[a]anthracene or 3,4,9,10-dibenzpyrene. *J Natl Cancer Inst* 44:357–360.

Homburger, F; Treger, A; Boger, E. (1971) Inhibition of murine subcutaneous and intravenous benzo[rs]t]pentaphene. *Carcinogenesis by sweet orange oils and d-limonene*. *Oncology* 25:1–10.

Jerina, DM; Sayer, JM; Yagi, H; et al. (1981) Highly tumorigenic bay-region diol epoxides from the weak carcinogen benzo[c]phenanthrene. *Adv Exp Med Biol* 136 Pt A:501–523.

Johnson, S. (1968) Effect of thymectomy on the induction of skin tumours by dibenzanthracene, and of breast tumours by dimethylbenzanthracene in mice of the IF strain. *Br J Cancer* 22:755–761.

Klein, M. (1952) Effect of croton oil on induction of tumors by 1,2-benzanthracene, deoxychloric or low doses of 20-methylcholanthrene in mice. *J Natl Cancer Inst* 13:333–341.

Klein, M. (1960) A comparison of the initiating and promoting actions of 9,10-dimethyl-1,2-benzanthracene and 1,2,5,6-dibenzanthracene in skin tumorigenesis. *Cancer Res* 20:1179–1183.

Klein, M. (1963) Susceptibility of strain B6AF1/J hybrid infant mice to tumorigenesis with 1,2-benzanthracene, deoxycholic acid, and 3-methylcholanthrene. II. Tumours called forth by painting the skin with dibenzpyrene. *Cancer Res* 23:1701–1707.

Kouri, RE; Connolly, GM; Nebert, DW; et al. (1983) Association between susceptibility to dibenzanthracene induced fibrosarcoma formation and the Ah locus. *Int J Cancer* 32:765–768.

Lacassagne, A; Buu-Hoi, NP; Zajdela, F; et al. (1968) The true dibenzo[a,l]pyrene, a new, potent carcinogen. *Naturwissenschaften* 55:43.

LaVoie, EJ; Tulley L; Bedenko, V; et al. (1980) Mutagenicity, tumor initiating activity, and metabolism of tricyclic polynuclear aromatic hydrocarbons. In: Bjorseth, A; Dennis, AJ, eds. *Polynuclear aromatic hydrocarbons: chemistry and biological effects*. Columbus, OH: Battelle Press, pp. 1041–1057.

LaVoie, EJ; Tulley-Freiler, L; Bedenko, V; et al. (1981) Comparative studies on the tumor initiating activity and metabolism of methylfluorenes and methylbenzofluorenes. In: Cooke, M; Dennis, AJ, eds. *Chemical analysis and biological fate: polynuclear hydrocarbons*. Columbus, OH: Battelle Press, pp. 417–427.

LaVoie, EJ; Coleman, DT; Tonne, RL; et al. (1983) Mutagenicity, tumor initiating activity and metabolism of methylated anthracenes. In: Cooke, M; Dennis, AJ, eds. *Proceedings of the Seventh International Symposium*. Columbus, OH: Battelle Press, pp. 785–798.

LaVoie, EJ; Cai, ZW; Meegalla, RL; et al. (1993a) Evaluation of the tumor-initiating activity of 4-, 5-, 6-, and 7-fluorobenzo[b]fluoranthene in mouse skin. *Chem Bio Interact* 89:129–139.

LaVoie, EJ; He, ZM; Meegalla, RL; et al. (1993b) Exceptional tumor-initiating activity of 4-fluorobenzo[j]-fluoranthene on mouse skin: comparison with benzo[j]-fluoranthene, 10-fluoro-benzo[j]fluoranthene, benzo[a]pyrene, dibenzo[a,l]pyrene and 7,12-dimethylbenz[a]anthracene. *Cancer Lett* 70:7–14.

LaVoie, EJ; He, ZM; Wu, Y; et al. (1994) Tumorigenic activity of the 4,5- and 9,10-dihydrodiols of benzo[j]fluoranthene and their syn- and anti-diol epoxides in newborn mice. *Cancer Res* 54:962–968.

Levin, W; Wood, AW; Chang, RL; et al. (1978) Evidence for bay region activation of chrysene 1,2-dihydrodiol to an ultimate carcinogen. *Cancer Res* 38:1831–1834.

Levin, W; Wood, AW; Chang, RL; et al. (1980) Exceptionally high tumor-initiating activity of benzo[c]phenanthrene bay-region diol-epoxides on mouse skin. *Cancer Res* 40:3910–3914.

Levin, W; Chang, RL; Wood, AW; et al. (1984) High stereoselectivity among the optical isomers of the diastereomeric bay-region diepoxides of benz[a]anthracene in the expression of tumorigenic activity in murine tumor models. *Cancer Res* 44:929–933.

Levin, W; Chang, RL; Wood, AW; et al. (1986) Tumorigenicity of optical isomers of the diastereomeric bay-region 3,4-diol-1,2-epoxides of benzo[c]phenanthrene in murine tumor models. *Cancer Res* 46:2257–2261.

Lijinsky, W; Garcia, H. (1972) Skin carcinogenesis tests of hydrogenated derivatives of anthanthrene and other polynuclear hydrocarbons. *Z Krebsforsch* 77:226–230.

Lijinsky, WH; Garcia, B; Terracini, B. (1965) Tumorigenic activity of hydrogenated derivatives of dibenz[a,h]anthracene. *J Natl Cancer Inst* 34:1–6.

Lijinsky, W; Garcia, H; Saffiotti, U. (1970) Structure-activity relationships among some polynuclear hydrocarbons and their hydrogenated derivatives. *J Natl Cancer Inst* 44:641–649.

Lorenz, E; Stewart, HL. (1947) Tumors of the alimentary tract induced in mice by feeding olive oil emulsions containing carcinogenic hydrocarbons. *J Natl Cancer Inst* 7:227–238.

- Lorenz, E; Stewart, HL. (1948) Tumors of alimentary tract in mice fed carcinogenic hydrocarbons in mineral-oil emulsions. *J Natl Cancer Inst* 9:173–180.
- Lubet, RA; Connolly, GM; Nebert, DW; et al. (1983) Dibenz[a,h]anthracene-induced subcutaneous tumors in mice. Strain sensitivity and the role of carcinogen metabolism. *Carcinogenesis* 4:513–517.
- Malament, DS; Shklar, G. (1981) Inhibition of DMBA carcinogenesis of hamster buccal pouch by phenanthrene and dimethylnaphthalene. *Carcinogenesis* 2:723–729.
- Mass, MJ; Abu-Shakra, A; Roop, BC; et al. (1996) Benzo[b]fluoranthene: tumorigenicity in strain A/J mouse lungs, DNA adducts and mutations in the Ki-ras oncogene. *Carcinogenesis* 17:1701–1704.
- Nakatsuru, Y; Wakabayashi, K; Fujii-Kuriyama, Y; et al. (2004) Dibenz[a,l]pyrene-induced genotoxic and carcinogenic responses are dramatically suppressed in aryl hydrocarbon receptor-deficient mice. *Int J Cancer* 112:179–183.
- Nesnow, S; Gold, A; Sangai, R; et al. (1993) Mouse skin tumor-initiating activity of benz[j]aceanthrylene in SENCAR mice. *Cancer Lett* 73:73–76.
- Nesnow, S; Ross, JA; Nelson, G; et al. (1994) Cyclopenta[cd]pyrene-induced tumorigenicity, Ki-ras codon 12 mutations and DNA adducts in strain A/J mouse lung. *Carcinogenesis* 15:601–606.
- O'Gara, RW; Kelly, MG; Brown, J; et al. (1965) Induction of tumors in mice given a minute single dose of dibenz[a,h]anthracene or 3-methylcholanthrene as newborns: a dose-response study. *J Natl Cancer Inst* 35(6):1027–1042.
- Platt, KL; Pfeiffer, EH; Glatt, HR; et al. (1983) Bacterial mutagenicity and carcinogenicity of potential metabolites of dibenz[a,h]anthracene. *J Cancer Res Clin Oncol* 105:A23.
- Platt, KL; Pfeiffer, E; Petrovic, P; et al. (1990) Comparative tumorigenicity of picene and dibenz[a,h]anthracene in the mouse. *Carcinogenesis* 11:1721–1726.
- Platt, KL; Dienes, HP; Tommasone, M; et al. (2004) Tumor formation in the neonatal mouse bioassay indicates that the potent carcinogen dibenzo[def,p]chrysene (dibenzo[a,l]pyrene) is activated in vivo via its trans-11,12-dihydrodiol. *Chem Biol Interact* 148:27–36.
- Pollia, JA. (1939) Investigations on the possible carcinogenic effect of anthracene and chrysene and some of their compounds. I. The effect of skin painting on the skin of mice. *J Ind Hyg Toxicol* 21(8):219–220.
- Pollia, JA. (1941) Investigation on the possible carcinogenic effect of anthracene and chrysene and some of their compounds. II. The effect of subcutaneous injection in rats. *J Ind Hyg Toxicol* 23:449–451.
- Prahalad, AK; Ross, JA; Nelson, GB; et al. (1997) Dibenz[a,l]pyrene-induced DNA adduction, tumorigenicity, and Ki-ras oncogene mutations in strain A/J mouse lung. *Carcinogenesis* 18:1955–1963.
- Ranadive, KJ; Karande, KA. (1963) Studies on 1,2,5,6-dibenzanthracene-induced mammary carcinogenesis in mice. *Br J Cancer* 17:272–280.
- Rice, JE; Coleman, DT; Hosted, TJJ; et al. (1985) On the metabolism, mutagenicity, and tumor-initiating activity of indeno[1,2,3-cd]pyrene. In: *Polynuclear aromatic hydrocarbons: mechanisms, methods and metabolism*. Columbus, OH: Battelle Press, pp. 1097–1109.
- Rice, JE; Hosted, TJ, Jr.; DeFloria, MC; et al. (1986) Tumor-initiating activity of major in vivo metabolites of indeno[1,2,3-cd]pyrene on mouse skin. *Carcinogenesis* 7:1761–1764.
- Rice, JE; Weyand, EH; Geddie, NG; et al. (1987) Identification of tumorigenic metabolites of benzo[j]fluoranthene formed in vivo in mouse skin. *Cancer Res* 47:6166–6170.

- Rice, JE; Weyand, EH; Burrill, C; et al. (1990) Fluorene probes for investigating the mechanism of activation of indeno[1,2,3-cd]pyrene to a tumorigenic agent. *Carcinogenesis* 11:1971–1974.
- Riegel, B; Watman, WB; Hill, WT. (1951) Delay of methylcholanthrene skin carcinogenesis in mice by 1,2,5,6-dibenzofluorene. *Cancer Res* 11:301–306.
- Salaman, MH; Roe, FJC. (1956) Further tests for tumour-initiating activity: N,N-di(2-chloroethyl)-paminophenylbutic acid (CB1348) as an initiator of skin tumour formation in the mouse. *Br J Cancer* 10:363–378.
- Sardella, DJ; Boger, E; Ghoshal, PK. (1981) Active sites in hexacyclic carcinogens probed by the fluorene substitution methodology. In: *Polynuclear aromatic hydrocarbons: chemical analysis and biological fate*. Columbus, OH: Battelle Press, pp. 529–538.
- Schmähl, D. (1955) [Testing of naphthalene and anthracene for carcinogenic effects in rats.] *Z Krebsforsch* 60:697–710. (German)
- Schoental, R. (1959) Carcinogenic activity of 3:4:9:10-dibenzopyrene. *Acta Unio Int Contra Cancrum* 15(1):216–219.
- Schoket, B; Hewer, A; Grover, PL; et al. (1988) Covalent binding of components of coal-tar, creosote and bitumen to the DNA of the skin and lungs of mice following topical application. *Carcinogenesis* 9:1253–1258.
- Scribner, JD. (1973) Brief communication: tumor initiation by apparently noncarcinogenic polycyclic aromatic hydrocarbons. *J Natl Cancer Inst* 50:1717–1719.
- Sellakumar, A; Shubik, P. (1974) Carcinogenicity of different polycyclic hydrocarbons in the respiratory tract of hamsters. *J Natl Cancer Inst* 53:1713–1719.
- Shear, MJ. (1938) Studies in carcinogenesis. V. Methyl derivatives of 1,2-benzanthracene. *Am J Cancer* 33:499–537.
- Shear, MJ; Leiter, J. (1941) Studies in carcinogenesis. XVI. Production of subcutaneous tumors in mice by miscellaneous polycyclic compounds. *J Natl Cancer Inst* 2:241–259.
- Siebert, D; Marquardt, H; Friesel, H; et al. (1981) Polycyclic aromatic hydrocarbons and possible metabolites: convertogenic activity in yeast and tumor initiating activity in mouse skin. *J Cancer Res Clin Oncol* 102:127–139.
- Slaga, TJ; Gleason, GL; Mills, C; et al. (1980) Comparison of the tumour-initiating activities of dihydrodiols and diol-epoxides of various polycyclic aromatic hydrocarbons. *Cancer Res* 40:1981–1984.
- Snell, KC; Stewart, HL. (1962) Pulmonary adenomatosis induced in DBA/2 mice by oral administration of dibenz[a,h]anthracene. *J Natl Cancer Inst* 28:1043–1049.
- Snell, KC; Stewart, HL. (1963) Induction of pulmonary adenomatoses in DBA/2 mice by the oral administration of dibenz[a,h]anthracene. *Acta Unio Int Contra Cancrum* 19:692–694.
- Stanton, MF; Miller, E; Wrench, C; et al. (1972) Experimental induction of epidermoid carcinoma in the lungs of rats by cigarette smoke condensate. *J Natl Cancer Inst* 49:867–877.
- Steiner, PE; Edgcomb, JH. (1952) Carcinogenicity of 1,2-benzanthracene. *Cancer Res* 12:657–659.
- Steiner, PF; Falk, HL. (1951) Summation and inhibition effects of weak and strong carcinogenic hydrocarbons: 1:2-Benzanthracene, chrysene, 1:2:5:6-dibenzanthracene, and 20-methylcholanthrene. *Cancer Res* 11:56–63.
- Stenbk, F; Sellakumar, A. (1974) Lung tumor induction by dibenz[a,i]pyrene in the Syrian golden hamster. *Z Krebsforsch* 82:175–182.
- Stevenson, JL; Von Haam, E. (1965) Carcinogenicity of benz[a]anthracene and benzo[c]phenanthrene derivatives. *Am Ind Hyg Assoc J* 26:475–478.

- Tawfic, HN. (1965) Studies on ear duct tumors in rats. Part II. Inhibitory effect of methylcholanthrene and 1,2-benzanthracene on tumor formation by 4-dimethylamino-stilbene. *Acta Pathol Jpn* 15:255–260.
- Van Duuren, BL; Langseth, L; Goldschmidt, BM. (1967) Carcinogenicity of epoxides, lactones and peroxy compounds. VI. Structure and carcinogenic activity. *J Natl Cancer Inst* 39:1217–1227.
- Van Duuren, BL; Sivak, A; Langseth, L; et al. (1968) Initiators and promoters in tobacco carcinogenesis. *Natl Cancer Inst Monogr* 28:173–180.
- Van Duuren, BL; Sivak, A; Goldschmidt, BM; et al. (1970) Initiating activity of aromatic hydrocarbons in two-stage carcinogenesis. *J Natl Cancer Inst* 44:1167–1173.
- Vulimiri, SV; Baer-Dubowska, W; Harvey, RG; et al. (1999) Analysis of highly polar DNA adducts formed in SENCAR mouse epidermis following topical application of dibenz[a,j]anthracene. *Chem Res Toxicol* 12:60–67.
- Wang, JS; Busby, WF, Jr. (1993) Induction of lung and liver tumors by fluoranthene in a preweanling CD-1 mouse bioassay. *Carcinogenesis* 14:1871–1874.
- Waravdekar, SS; Ranadive, KJ. (1958) Biologic testing of 3,4,9,10-dibenzpyrene. *J Natl Cancer Inst* 21:1151–1159.
- Weyand, EH; Amin, S; Huie, K; et al. (1989) Effects of fluorene substitution on the DNA binding and tumorigenicity of benzo[b]fluoranthene in mouse epidermis. *Chem Biol Interact* 71:279–290.
- Weyand, EH; Patel, S; LaVoie, EJ; et al. (1990) Relative tumor initiating activity of benzo[a]fluoranthene, benzo[b]fluoranthene, naphtho[1,2-b]fluoranthene and naphtho[2,1-a]fluoranthene on mouse skin. *Cancer Lett* 52:229–233.
- Weyand, EH; Cai, ZW; Wu, Y; et al. (1993) Detection of the major DNA adducts of benzo[b]fluoranthene in mouse skin: role of phenolic dihydrodiols. *Chem Res Toxicol* 6:568–577.
- White, FR; Eschenbrenner, AB. (1945) Note on the occurrence of hepatomas in rats following the ingestion of 1,2-benzoanthracene. *J Natl Cancer Inst* 6:19–21.
- Wislocki, PG; Buening, MK; Levin, W; et al. (1979) Tumorigenicity of the diastereomeric benz[a]anthracene 3,4-diol-1,2-epoxides and the (+)- and (-)-enantiomers of benz[a]anthracene 3,4-dihydrodiol in newborn mice. *J Natl Cancer Inst* 63:201–204.
- Wodinsky, I; Helinski, A; Kensler, CJ. (1964) Susceptibility of Syrian hamsters to induction of fibrosarcomas with a single injection of 3,4,9,10-dibenzpyrene. *Nature* 203:308–309.
- Wood, AW; Chang, RL; Levin, W; et al. (1979) Mutagenicity and tumorigenicity of phenanthrene and chrysene epoxides and diol epoxides. *Cancer Res* 39:4069–4077.
- Wynder, EL; Hoffmann, D. (1961) Carcinogenicity of dibenzo[a,l]pyrene. *Nature* 192:1092–1093.
- Zajdela, F; Perin-Roussel, O; Saguem, S. (1987) Marked differences between mutagenicity in Salmonella and tumour-initiating activities of dibenzo[a,e]fluoranthene proximate metabolites; initiation inhibiting activity of norharman. *Carcinogenesis* 8:461–464.

B.2. BIBLIOGRAPHY OF STUDIES ON CANCER-RELATED ENDPOINTS WITHOUT BENZO[A]PYRENE

Abe, S; Sasaki, M. (1977) Studies on chromosomal aberrations and sister chromatid exchanges induced by chemicals. *Proc Jpn Acad* 53:46–49.

Agarwal, SK; Sayer, JM; Yeh, HJC; et al. (1987) Chemical characterization of DNA adducts derived from the configurationally isomeric benzo[c]phenanthrene-3,4-diol 1,2-epoxides. *J Am Chem Soc* 109:2497–2504.

Agarwal, R; Canella, KA; Yagi, H; et al. (1996) Benzo[c]phenanthrene-DNA adducts in mouse epidermis in relation to the tumorigenicities of four configurationally isomeric 3,4-dihydrodiol 1,2-epoxides. *Chem Res Toxicol* 9:586–592.

Agarwal, R; Coffing, SL; Baird, WM; et al. (1997) Metabolic activation of benzo[g]chrysene in the human mammary carcinoma cell line MCF-7. *Cancer Res* 57:415–419.

Amin, S; Desai, D; Hecht, SS. (1993) Tumor-initiating activity on mouse skin of bay region diol-epoxides of 5,6-dimethylchrysene and benzo[c]phenanthrene. *Carcinogenesis* 14:2033–2037.

Arif, JM; Gupta, RC. (1997) Microsome-mediated bioactivation of dibenzo[a,l]pyrene and identification of DNA adducts by 32P-postlabeling. *Carcinogenesis* 18:1999–2007.

Arif, JM; Smith, WA; Gupta, RC. (1999) DNA adduct formation and persistence in rat tissues following exposure to the mammary carcinogen dibenzo[a,l]pyrene. *Carcinogenesis* 20:1147–1150.

Ayrton, AD; McFarlane, M; Walker, R; et al. (1990) Induction of the P-450 I family of proteins by polycyclic aromatic hydrocarbons: possible relationship to their carcinogenicity. *Toxicology* 60:173–186.

Babson, JR; Russo-Rodriguez, SE; Rastetter, WH; et al. (1986) In vitro DNA-binding of microsomally-activated fluoranthene: evidence that the major product is a fluoranthene N2-deoxyguanosine adduct. *Carcinogenesis* 7:859–865.

Babson, JR; Russo-Rodriguez, SE; Wattlely, RV; et al. (1986) Microsomal activation of fluoranthene to mutagenic metabolites. *Toxicol Appl Pharmacol* 85:355–366.

Baer-Dubowska, W; Nair, RV; Cortez, C; et al. (1995) Covalent DNA adducts formed in mouse epidermis from dibenz[a,j]anthracene: evidence for the formation of polar adducts. *Chem Res Toxicol* 8:292–301.

Ball, LM; Warren, SH; Sangaiah, R; et al. (1989) Bacterial mutagenicity of new cyclopenta-fused cata-annelated polycyclic aromatic hydrocarbons, and identification of the major metabolites of benz[j]acephenanthrylene formed by aroclor-treated rat liver microsomes. *Mutat Res* 224:115–25.

Barfknecht, TR; Andon, BM; Thilly, WG; et al. (1981) Soot and mutation in bacteria and human cells. In: Cooke, M; Dennis, AJ, eds. *Chemical analysis and biological fate: polynuclear aromatic hydrocarbons*, pp. 231–242.

Barrai, I; Barale, R; Scapoli, C; et al. (1992) The analysis of the joint effect of substances on reversion systems and the assessment of antimutagenicity. *Mutat Res* 267:173–182.

Barratt, RW; Tatum, EL (1958) Carcinogenic mutagens. *Ann NY Acad Sci* 71:1072–1084.

Bartczak, AW; Sangaiah, S; Ball, LM; et al. (1987) Synthesis and bacterial mutagenicity of the cyclopenta oxides of the four cyclopenta-fused isomers of benzanthracene. *Mutagenesis* 2:101–105.

Basler, A; Herbold, B; Peter, S; et al. (1977) Mutagenicity of polycyclic hydrocarbons. II. Monitoring genetical hazards of chrysene in vitro and in vivo. *Mutat Res* 48:249–254.

Baum, M; Amin, S; Guengerich, FP; et al. (2001) Metabolic activation of benzo[c]phenanthrene by cytochrome P450 enzymes in human liver and lung. *Chem Res Toxicol* 14:686–693.

Beach, AC; Gupta, RC. (1991) Analysis of cyclopenta(CP)-fused and 'pseudo-CP' polycyclic aromatic hydrocarbon (PAH)-DNA adducts by 32P-postlabeling. *Proc Am Assoc Cancer Res* 32:98.

Beach, AC; Gupta, RC. (1994) DNA adducts of the ubiquitous environmental contaminant cyclopenta[cd]pyrene. *Carcinogenesis* 15:1065–1072.

Beach, AC; Agarwal, SC; Lamberg, GR; et al. (1993) Reaction of cyclopenta[c,d]pyrene-3,4-epoxide with DNA and desoxynucleotides. *Carcinogenesis* 14:767–771.

Bos, RP; Prinsen, WJ; van Rooy, JG; et al. (1987) Fluoranthene, a volatile mutagenic compound, present in creosote and coal tar. *Mutat Res* 187:119–125.

Boutwell, RK. (1989) Model systems for defining initiation, promotion, and progression of skin neoplasms. *Prog Clin Biol Res* 298:3–15.

Bryant, MF; Kwanyuen, P; Atwater, AL; et al. (1991) Cytogenetic effects of benzo-b-fluoranthene in Sprague-Dawley rat peripheral blood lymphocytes after in vivo exposure (Abstract 33). *Environ Mol Mutag* 17 (Suppl 19):13.

Bu-Abbas, A; Ioannides, C; Walker, R. (1994) Evaluation of the antimutagenic potential of anthracene: in vitro and ex vivo studies. *Mutat Res* 309:101–107.

Budunova, IV; Mittleman, LA; Safaev, RD; et al. (1993) The carcinogen benzo[e]pyrene is metabolized by DM15 cells without an uncoupling effect on their gap junctions. *Cell Biol Toxicol* 9:131–140.

Carmichael, PL; Platt, KL; She, MN; et al. (1993) Evidence for the involvement of a bis-diol-epoxide in the metabolic activation of dibenz[a,h]anthracene to DNA-binding species in mouse skin. *Cancer Res* 53:944–948.

Cary, PD; Turner, CH; Cooper, CS; et al. (1980) Metabolic activation of benz[a]anthracene in hamster embryo cells: the structure of a guanosine-anti-BA-8,9-diol 10,11-oxide adduct. *Carcinogenesis* 1:505–512.

Casale, GP; Higginbotham, S; Johansson, SL; et al. (1997) Inflammatory response of mouse skin exposed to the very potent carcinogen dibenzo[a,l]pyrene: a model for tumor promotion. *Fundam Appl Toxicol* 36:71–78.

Casto, BC. (1973) Enhancement of adenovirus transformation by treatment of hamsters with ultraviolet irradiation, DNA base analogs, and dibenz[a,h]anthracene. *Cancer Res* 33:402–407.

Chakravarti, D; Mailander, P; Franzen, J; et al. (1998) Detection of dibenzo[a,l]pyrene-induced H-ras codon 61 mutant genes in preneoplastic Sencar mouse skin using a new PCR-RFLP method. *Oncogene* 16:3203–3210.

Chakravarti, D; Mailander, PC; Cavalieri, EL; et al. (2000) Evidence that error-prone DNA repair converts dibenzo[a,l]pyrene-induced depurinating lesions into mutations: formation, clonal proliferation and regression of initiated cells carrying H-ras oncogene mutations in early preneoplasia. *Mutat Res* 456:17–32.

Chaloupka, K; Santostefano, M; Goldfarb, IS; et al. (1994) Aryl hydrocarbon (Ah) receptor-independent induction of Cyp1a2 gene expression by acenaphthylene and related compounds in B6C3F1 mice. *Carcinogenesis* 15:2835–2840.

Chiarelli, MP; Chang, HF; Olsen, KW; et al. (2003) Structural differentiation of diastereomeric benzo[ghi]fluoranthene adducts of deoxyadenosine by matrix-assisted laser desorption/ionization time-of-flight mass spectrometry and postsourc decay. *Chem Res Toxicol* 16:1236–1241.

Chroust, K; Jowett, T; Farid-Wajidi, MF; et al. (2001) Activation or detoxification of mutagenic and carcinogenic compounds in transgenic *Drosophila* expressing human glutathione S-transferase. *Mutat Res* 498:169–179.

Cizmas, L; Zhou, GD; Safe, SH; et al. (2004) Comparative in vitro and in vivo genotoxicities of 7H-benzo[c]fluorene, manufactured gas plant residue (MGP), and MGP fractions. *Environ Mol Mutagen* 43:159–168.

- Clayson, DB; Iverson, F; Nera, EA; et al. (1990) The significance of induced forestomach tumors. *Annu Rev Pharmacol Toxicol* 30:441–463.
- Collin, G; H"ke, H. (1985) Anthracene. In: Elvers, B; Hawkins, S; Schulz, G, eds. *Ullmann's encyclopedia of industrial chemistry*. 5th ed., Volume A2. Weinheim, Verlagsgesellschaft, pp. 343–345.
- Collins, JF; Brown, JP; Alexeeff, GV; et al. (1998) Potency equivalency factors for some polycyclic aromatic hydrocarbons and polycyclic aromatic hydrocarbon derivatives. *Regul Toxicol Pharmacol* 28:45–54.
- Coombs, MM; Bhatt, TS, eds. (1987) Polycyclic aromatic compounds structurally related to steroids. In: *Cyclopenta[a]phenanthrenes*. New York, NY: Cambridge University Press, pp. 132–210.
- Coombs, MM; Dixon, C; Kissonerghis, AM; et al. (1976) Evaluation of the mutagenicity of compounds of known carcinogenicity, belonging to the benz[a]anthracene, chrysene, and cyclopenta[a]phenanthrene series, using Ames' test. *Cancer Res* 36:4525–4529.
- Dai, Q. (1980) Researches on chemical carcinogens and mechanism of chemical carcinogenesis. DI-region theory: a quantitative molecular orbital model of carcinogenic activity for polycyclic aromatic hydrocarbons. *Sci Sin* 23:453–470.
- Danz, M; Hartmann, A; Blaszyk, H. (1998) Mitogenic short-term effects on hepatocytes and adrenocortical cells: phenobarbital and reserpine compared to carcinogenic and non-carcinogenic fluorene derivatives. *Exp Toxicol Pathol* 50:416–424.
- Devanesan, P; Ariese, F; Jankowiak, R; et al. (1999) A novel method for the isolation and identification of stable DNA adducts formed by dibenzo[a,l]pyrene and dibenzo[a,l]pyrene 11,12-dihydrodiol 13,14-epoxides in vitro. *Chem Res Toxicol* 12:796–801.
- DeVito, MJ; Maier, WE; Diliberto, JJ; et al. (1993) Comparative ability of various PCBs, PCDFs, and TCDD to induce cytochrome P450 1A1 and 1A2 activity following 4 weeks of treatment. *Fundam Appl Toxicol* 20:125–130.
- Diamond, L; Cherian, K; Harvey, RG; et al. (1984) Mutagenic activity of methyl- and fluoro-substituted derivatives of polycyclic aromatic hydrocarbons in a human hepatoma (HepG2) cell-mediated assay. *Mutat Res* 136:65–72.
- Dipple, A; Pigott, MA; Agarwal, SK; et al. (1987) Optically active benzo[c]phenanthrene diol epoxides bind extensively to adenine in DNA. *Nature* 327:535–536.
- Dong, S; Fu, PP; Shirsat, RN; et al. (2002) UVA light-induced DNA cleavage by isomeric methylbenz[a]anthracenes. *Chem Res Toxicol* 15:400–407.
- Einolf, HJ; Amin, S; Yagi, H; et al. (1996) Benzo[c]phenanthrene is activated to DNA-binding diol epoxides in the human mammary carcinoma cell line MCF-7 but only limited activation occurs in mouse skin. *Carcinogenesis* 17:2237–2244.
- Einolf, HJ; Story, WT; Marcus, CB; et al. (1997) Role of cytochrome P450 enzyme induction in the metabolic activation of benzo[c]phenanthrene in human cell lines and mouse epidermis. *Chem Res Toxicol* 10:609–617.
- Ensell, MX; Hubbs, A; Zhou, G; et al. (1999) Neoplastic potential of rat tracheal epithelial cell lines induced by 1-nitropyrene and dibenzo[a,i]pyrene. *Mutat Res* 444:193–199.
- Ensell, MX; Whong, WZ; Heng, ZC; et al. (1998) In vitro and in vivo transformation in rat tracheal epithelial cells exposed to diesel emission particles and related compounds. *Mutat Res* 412:283–291.
- Fahmy, OG; Fahmy, MJ. (1973) Oxidative activation of benz[a]anthracene and methylated derivatives in mutagenesis and carcinogenesis. *Cancer Res* 33:2354–2361.
- Fuchs, J; Mlcoch, J; Platt, KL; et al. (1993) Characterization of highly polar bis-dihydrodiol epoxide--DNA adducts formed after metabolic activation of dibenz[a,h]anthracene. *Carcinogenesis* 14:863–867.

Gatehouse, D. (1980) Mutagenicity of 1,2 ring-fused acenaphthenes against *S. typhimurium* TA1537 and TA1538: structure-activity relationship. *Mutat Res* 78:121–135.

Giles, AS; Seidel, A; Phillips, DH. (1995) In vitro reaction with DNA of the fjord-region diol epoxides of benzo[g]chrysene and benzo[c]phenanthrene as studied by 32P-postlabeling. *Chem Res Toxicol* 8:591–599.

Giles, AS; Seidel, A; Phillips, DH. (1996) Covalent DNA adducts formed in mouse epidermis by benzo[g]chrysene. *Carcinogenesis* 17:1331–1336.

Glatt, H; Seidel, A; Bochnitschek, W; et al. (1986) Mutagenic and cell-transforming activities of triol-epoxides as compared to other chrysene metabolites. *Cancer Res* 46:4556–4565.

Glatt, H; Abu-Shqara, E; Harvey, RG; et al. (1994) Mutagenicity of K-region oxides and imines of chrysene, benzo[c]phenanthrene and benzo[g]chrysene in *Salmonella typhimurium*. *Mutat Res* 308:135–141.

Gold, A; Nesnow, S; Moore, M; et al. (1980) Mutagenesis and morphological transformation of mammalian cells by a non-bay-region polycyclic cyclopenta[cd]pyrene and its 3,4-oxide. *Cancer Res* 40:4482–4484.

Gorelick, NJ; Wogan, GN. (1989) Fluoranthene-DNA adducts: identification and quantification by an HPLC-32P-postlabeling method. *Carcinogenesis* 10:1567–1577.

Gorelick, NJ; Hutchins, DA; Tannenbaum, SR; et al. (1989) Formation of DNA and hemoglobin adducts of fluoranthene after single and multiple exposures. *Carcinogenesis* 10:1579–1587.

Goshman, LM; Heidelberger, C. (1967) Binding of tritium-labeled polycyclic hydrocarbons to DNA of mouse skin. *Cancer Res* 27:1678–1688.

Hall, M; Parker, DK; Hewer, AJ; et al. (1988) Further metabolism of diol-epoxides of chrysene and dibenz[a,c]anthracene to DNA binding species as evidenced by 32P-postlabeling analysis. *Carcinogenesis* 9:865–868.

Harvey, RG. (1996) Mechanisms of carcinogenesis of polycyclic aromatic compounds. *Polycycl Aromat Compd* 9:1–23.

Herner, HA; Trosko, JE; Masten, SJ. (2001) The epigenetic toxicity of pyrene and related ozonation byproducts containing an aldehyde functional group. *Environ Sci Technol* 35:3576–3583.

Hermann, M. (1981) Synergistic effects of individual polycyclic aromatic hydrocarbons on the mutagenicity of their mixtures. *Mutat Res* 90:399–409.

Hewer, A; Cooper, CS; Ribeiro, O; et al. (1981) The metabolic activation of dibenz[a,c]anthracene. *Carcinogenesis* 2:1345–1352.

Holme, JA; Bjorge, C; Soderlund, EJ; et al. (1993) Genotoxic effects of cyclopenta-fused polycyclic aromatic hydrocarbons in isolated rat hepatocytes and rabbit lung cells. *Carcinogenesis* 14:1125–1131.

Huberman, E; Kuroki, T; Marquardt, H; et al. (1972) Transformation of hamster embryo cells by epoxides and other derivatives of polycyclic hydrocarbons. *Cancer Res* 32:1391–1396.

Hughes, NC; Phillips, DH. (1993) 32P-postlabeling analysis of the covalent binding of benzo[ghi]perylene to DNA in vivo and in vitro. *Carcinogenesis* 14:127–133.

Ishidate, M; Odashima, S. (1977) Chromosome tests with 134 compounds on Chinese hamster cells *in vitro*: a screening for chemical carcinogens. *Mutat Res* 48:337–354.

Isu, Y; Nagashima, U; Aoyama, T; et al. (1996) Development of neural network simulator for structure--activity correlation of molecules (NECO). Prediction of endo/exo substitution of norbornane derivatives and of carcinogenic activity of PAHs from 13C-NMR shifts. *J Chem Inf Comput Sci* 36:286–293.

- Jankowiak, R; Ariese, F; Hewer, A; et al. (1998) Structure, conformations, and repair of DNA adducts from dibenzo[a,l]pyrene: 32P-postlabeling and fluorescence studies. *Chem Res Toxicol* 11:674–685.
- Jerina, DM; Lehr, RE. (1977) The bay-region theory: a quantum mechanical approach to aromatic hydrocarbon-induced carcinogenicity, pp. 709–720.
- Jerina, DM; Yagi, H; Lehr, RE; et al. (1978) The bay-region theory of carcinogenesis by polycyclic aromatic hydrocarbons, pp. 173–188.
- Juhasz, AL; Stanley, GA; Britz, ML. (2000) Microbial degradation and detoxification of high molecular weight polycyclic aromatic hydrocarbons by *Stenotrophomonas maltophilia* strain VUN 10,003. *Lett Appl Microbiol* 30:396–401.
- Kemena, A; Norpoth, KH; Jacob, J. (1988) Differential induction of the monooxygenase isoenzymes in mouse liver microsomes by polycyclic aromatic hydrocarbons. In: Cooke, M; Dennis, AJ, eds. *Polynuclear aromatic hydrocarbons: a decade of progress*. Columbus, OH: Battelle Press, pp. 449–460.
- Keohavong, P; Melacrinis, A; Shukla, R. (1995) In vitro mutational spectrum of cyclopenta[cd]pyrene in the human HPRT gene. *Carcinogenesis* 16:855–860.
- King, LC; Adams, L; Allison, J; et al. (1999) A quantitative comparison of dibenzo[a,l]pyrene-DNA adduct formation by recombinant human cytochrome P450 microsomes. *Mol Carcinog* 26:74–82.
- Knaap, AGAC; Goze, C; Simons, JWIM (1981) Mutagenic activity of seven coded samples in V79 Chinese hamster cells. *Prog Mutat Res* 1:608-613.
- Kumar, S; Kole, PL; Sikka, HC. (1990) Mutagenicity of dibenz[a,c]anthracene and its derivatives in *Salmonella typhimurium* TA100. *Mutat Res* 242:337–343.
- Laryea, A; Cosman, M; Lin, JM; et al. (1995) Direct synthesis and characterization of site-specific adenosyl adducts derived from the binding of a 3,4-dihydroxy-1,2-epoxybenzo[c]phenanthrene stereoisomer to an 11-mer oligodeoxyribonucleotide. *Chem Res Toxicol* 8:444–454.
- Lasley, J; Curti, S; Ross, J; et al. (1991) Morphological cell transformation and DNA adduction by benz[j]aceanthrylene and its presumptive reaction metabolites in C3H10T1/2CL8 cells. *Adv Exp Med Biol* 283:759–762.
- LaVoie, EJ; Hecht, SS; Amin, S; et al. (1980) Identification of mutagenic dihydrodiols as metabolites of benzo[j]fluoranthene and benzo[k]fluoranthene. *Cancer Res* 40:4528–4532.
- LaVoie, EJ; Tulley, L; Bedenko, V; et al. (1981) Mutagenicity of methylated fluorenes and benzofluorenes. *Mutat Res* 91:167–176.
- LaVoie, EJ; Hecht, SS; Bedenko, V; et al. (1982) Identification of the mutagenic metabolites of fluoranthene, 2-methylfluoranthene, and 3-methylfluoranthene. *Carcinogenesis* 3:841–846.
- Lecoq, S; Perin, F; Plessis, MJ; et al. (1989) Comparison of the in vitro metabolisms and mutagenicities of dibenz[a,c]anthracene, dibenz[a,h]anthracene and dibenz[a,j]anthracene: influence of norharman. *Carcinogenesis* 10:461–469.
- Lecoq, S; Ni She, M; Grover, PL; et al. (1991a) The in vitro metabolic activation of dibenz[a,h]anthracene, catalyzed by rat liver microsomes and examined by 32P-postlabeling. *Cancer Lett* 57:261–269.
- Lecoq, S; Ni She, M; Hewer, A; et al. (1991b) The metabolic activation of dibenz[a,h]anthracene in mouse skin examined by 32P-postlabeling: minor contribution of the 3,4-diol 1,2-oxides to DNA binding. *Carcinogenesis* 12:1079–1083.

Lecoq, S; Pfau, W; Grover, PL; et al. (1992) HPLC separation of ³²P-postlabelled DNA adducts formed from dibenz[a,h]anthracene in skin. *Chem Biol Interact* 85:173–185.

Levin, W; Wood, A; Chang, R; et al. (1982) Oxidative metabolism of polycyclic aromatic hydrocarbons to ultimate carcinogens. *Drug Metab Rev* 13:555–580.

Lewtas, J. (1985) Development of a comparative potency method for cancer risk assessment of complex mixtures using short-term in vivo and in vitro bioassays. *Toxicol Ind Health* 1:193–203.

Lewtas, J. (1988) Genotoxicity of complex mixtures: strategies for the identification and comparative assessment of airborne mutagens and carcinogens from combustion sources. *Fundam Appl Toxicol* 10:571–589.

Li, KM; Todorovic, R; Rogan, EG; et al. (1995) Identification and quantitation of dibenzo[a,l]pyrene--DNA adducts formed by rat liver microsomes in vitro: preponderance of depurinating adducts. *Biochemistry* 34:8043–8049.

Li, KM; Byun, J; Gross, ML; et al. (1999) Synthesis and structure determination of the adducts formed by electrochemical oxidation of dibenzo[a,l]pyrene in the presence of adenine. *Chem Res Toxicol* 12:749–757.

Lloyd, DR; Hanawalt, PC. (2002) p53 controls global nucleotide excision repair of low levels of structurally diverse benzo[g]chrysene-DNA adducts in human fibroblasts. *Cancer Res* 62:5288–5294.

Luch, A; Coffing, SL; Tang, YM; et al. (1998) Stable expression of human cytochrome P450 1B1 in V79 Chinese hamster cells and metabolically catalyzed DNA adduct formation of dibenzo[a,l]pyrene. *Chem Res Toxicol* 11:686–695.

Luch, A; Kishiyama, S; Seidel, A; et al. (1999) The K-region trans-8,9-diol does not significantly contribute as an intermediate in the metabolic activation of dibenzo[a,l]pyrene to DNA-binding metabolites by human cytochrome P450 1A1 or 1B1. *Cancer Res* 59:4603–4609.

Luch, A; Kudla, K; Seidel, A; et al. (1999) The level of DNA modification by (+)-syn-(11S,12R,13S,14R)- and (-)-anti-(11R,12S,13S,14R)-dihydrodiol epoxides of dibenzo[a,l]pyrene determined the effect on the proteins p53 and p21WAF1 in the human mammary carcinoma cell line MCF-7. *Carcinogenesis* 20:859–865.

Lupp, A; Tralls, M; Fuchs, U; et al. (1999) Transplantation of fetal liver tissue suspension into the spleens of adult syngenic rats: effects of various mitogens and cytotoxins on cytochrome P450 (P450) isoforms expression and on P450 mediated monooxygenase functions. *Exp Toxicol Pathol* 51:375–388.

Malaveille, C; Hautefeuille, A; Bartsch, H; et al. (1980) Liver microsome-mediated mutagenicity of dihydrodiols derived from dibenz[a,c]anthracene in *S. typhimurium* TA 100. *Carcinogenesis* 1:287–289.

Malaveille, C; Hautefeuille, A; Perin-Roussel, O; et al. (1984) Possible involvement of a vicinal, non-bay-region dihydrodiol-epoxide in the activation of dibenzo[a,e]fluoranthene into bacterial mutagens. *Carcinogenesis* 5:1263–1266.

Marquardt, H; Heidelberger, C. (1972) Influence of 'feeder cells' and inducers and inhibitors of microsomal mixed-function oxidases on hydrocarbon-induced malignant transformation of cells derived from C3H mouse prostate. *Cancer Res* 32:721–725.

Marquardt, H; Kuroki, T; Huberman, E; et al. (1972) Malignant transformation of cells derived from mouse prostate by epoxides and other derivatives of polycyclic hydrocarbons. *Cancer Res* 32:716–720.

Marrocchi, A; Minuti, L; Morozzi, G; et al. (1996) Synthesis and mutagenicity of some cyclopenta[c]phenanthrenes and indeno[c]phenanthrenes. *Carcinogenesis* 17:2009–2012.

Marsch, GA; Jankowiak, R; Small, GJ; et al. (1992) Evidence of involvement of multiple sites of metabolism in the in vivo covalent binding of dibenzo[a,h]pyrene to DNA. *Chem Res Toxicol* 5:765–772.

- Marshall, MV; He, ZM; Weyand, EH; et al. (1993) Mutagenic activity of the 4,5- and 9,10-dihydrodiols of benzo[j]fluoranthene and their syn- and anti-dihydrodiol epoxides in *Salmonella typhimurium*. *Environ Mol Mutagen* 22:34–45.
- Matijasevic, Z; Zeiger, E. (1985) Mutagenicity of pyrene in *Salmonella*. *Mutat Res* 142:149–152.
- Matsuoka, A; Sofuni, T; Miyata, N; et al. (1991) Clastogenicity of 1-nitropyrene, dinitropyrenes, fluorene and mononitrofluorenes in cultured Chinese hamster cells. *Mutat Res* 259:103–110.
- Meek, ME; Chan, PKL; Bartlett, S. (1994) Polycyclic aromatic hydrocarbons: evaluation of risks to health from environmental exposures in Canada. *Environ Carcinog Ecotoxicol Rev C* 12:443–452.
- Melendez-Colon, VJ; Smith, CA; Seidel, A; et al. (1997) Formation of stable adducts and absence of depurinating DNA adducts in cells and DNA treated with the potent carcinogen dibenzo[a,l]pyrene or its diol epoxides. *Proc Natl Acad Sci U S A* 94:13542–13547.
- Melendez-Colon, VJ; Luch, A; Seidel, A; et al. (1999) Comparison of cytochrome P450- and peroxidase-dependent metabolic activation of the potent carcinogen dibenzo[a,l]pyrene in human cell lines: formation of stable DNA adducts and absence of a detectable increase in apurinic sites. *Cancer Res* 59:1412–1416.
- Mlcoch, J; Fuchs, J; Oesch, F; et al. (1993) Characterization of DNA adducts at the bay region of dibenz[a,h]anthracene formed in vitro. *Carcinogenesis* 14:469–473.
- Mori, Y; Goto, S; Onodera, S; et al. (1993) Changes in mutagenic properties and chemical fate of benz[a]anthracene in chlorine-treated water with and without bromide ion. *Chemosphere* 27(11):2155–2162.
- Moyer, SR; Jurs, PC. (1990) An SRA study of the mutagenicity of PAH compounds in *Salmonella typhimurium*. In: Mendelsohn, ML; Albertini, J, eds. *Progress in clinical and biological research*. Vol. 340. *Mutation and the environment. Part B. Metabolism, testing methods, and chromosomes*. New York, NY: Wiley-Liss, pp. 1–10.
- Nair, RV; Gill, RD; Nettikumara, AN; et al. (1991) Characterization of covalently modified deoxyribonucleosides formed from dibenz[a,j]anthracene in primary cultures of mouse keratinocytes. *Chem Res Toxicol* 4:115–122.
- Nesnow, S; Leavitt, S; Easterling, R; et al. (1984) Mutagenicity of cyclopenta-fused isomers of benz[a]anthracene in bacterial and rodent cells and identification of the major rat liver microsomal metabolites. *Cancer Res* 44:4993–5003.
- Nesnow, S; Lasley, J; Curti, S; et al. (1991) Morphological transformation and DNA adduct formation by benz[j]aceanthrylene and its metabolites in C3H10T1/2CL8 cells: evidence for both cyclopenta-ring and bay-region metabolic activation pathways. *Cancer Res* 51:6163–6169.
- Nesnow, S; Davis, C; Padgett, W; et al. (1998) Metabolic activation of racemic and enantiomeric trans-8, 9-dihydroxy-8,9-dihydrodibenzo[a,l]pyrene (dibenzo[def,p]chrysene) to dibenzo[a,l]pyrene-bis-dihydrodiols by induced rat liver microsomes and a recombinant human P450 1A1 system: the role of the K-region-derived metabolic intermediates in the formation of dibenzo[a,l]pyrene-DNA adducts. *Chem Res Toxicol* 11:1596–1607.
- Newcomb, KO; Sangaiah, R; Gold, A; et al. (1993) Activation and metabolism of benz[j]aceanthrylene-9,10-dihydrodiol, the precursor to bay-region metabolism of the genotoxic cyclopenta-PAH benz[j]aceanthrylene. *Mutat Res* 287:181–190.
- Oesch, F; Bückler, M; Glatt, HR. (1981) Activation of phenanthrene to mutagenic metabolites and evidence for at least two different activation pathways. *Mutat Res* 81:1–10.
- Oshiro, Y; Balwierz, PS. (1982) Morphological transformation of C3H/10T1/2 CL8 cells by procarcinogens. *Environ Mutagen* 4:105–108.
- Otero-Lobato, MJ; Jenneskens, LW; Seinen, W. (2004) Bacterial mutagenicity of the three isomeric dicyclopenta-fused pyrenes: the effects of dicyclopenta topology. *Mutat Res* 559:105–119.

- Pal, K. (1981) The induction of sister-chromatid exchanges in Chinese hamster ovary cells by K-region epoxides and some dihydrodiols derived from benz[a]anthracene, dibenz[a,c]anthracene and dibenz[a,h]anthracene. *Mutat Res* 84:389–398.
- Palitti, F; Cozzi, R; Fiore, M; et al. (1986) An in vitro and in vivo study on mutagenic activity of fluoranthene: comparison between cytogenetic studies and HPLC analysis. *Mutat Res* 174:125–130.
- Perin-Roussel, O; Saguem, S; Ekert, B; et al. (1983) Binding to DNA of bay region and pseudo bay region diol-epoxides of dibenzo[a,e]fluoranthene and comparison with adducts obtained with dibenzo[a,e]fluoranthene or its dihydrodiols in the presence of microsomes. *Carcinogenesis* 4:27–32.
- Perin-Roussel, O; Croisy, A; Ekert, B; et al. (1984a) The metabolic activation of dibenzo[a,e]fluoranthene in vitro. Evidence that its bay-region and pseudo-bay-region diol-epoxides react preferentially with guanosine. *Cancer Lett* 22:289–298.
- Perin-Roussel, O; Ekert, B; Barat, N; et al. (1984b) DNA-protein crosslinks induced by exposure of cultured mouse fibroblasts to dibenzo[a,e]fluoranthene and its bay- and pseudo-bay region dihydrodiols. *Carcinogenesis* 5:379–383.
- Perin-Roussel, O; Barat, N; Zajdela, F. (1985) Formation and removal of dibenzo[a,e]fluoranthene-DNA adducts in mouse embryo fibroblasts. *Carcinogenesis* 6:1791–1796.
- Perin-Roussel, O; Barat, N; Zajdela, F. (1988) Non-random distribution of dibenzo[a,e]fluoranthene-induced DNA adducts in DNA loops in mouse fibroblast nuclei. *Carcinogenesis* 9:1383–1388.
- Perin-Roussel, O; Perin, F; Zajdela, F. (1990) 32P-post-labeling analysis of DNA adducts in mouse embryo fibroblasts treated with dibenzo[a,e]fluoranthene and its major metabolites. *Carcinogenesis* 11:301–306.
- Peter, S; Palme, GE; Röhrborn, G. (1979) Mutagenicity of polycyclic hydrocarbons. III. Monitoring genetic hazards of benz[a]anthracene. *Acta Morphol Acad Sci Hung* 27:199–204.
- Pfau, W; Hughes, NC; Grover, PL; et al. (1992) HPLC separation of 32P-postlabelled benzo[b]fluoranthene-DNA adducts. *Cancer Lett* 65:159–167.
- Pfau, W; Lecoq, S; Hughes, NC; et al. (1993) Separation of 32P-labelled nucleoside 3',5'-bisphosphate adducts by HPLC. *IARC Sci Publ* 124:233–242.
- Phillips, DH. (1997) Detection of DNA modifications by the 32P-postlabeling assay. *Mutat Res* 378:1–12.
- Platt, KL; Bucker, M; Golan, M; et al. (1982) The mutagenicity of dibenz[a,h]anthracene activated by phenobarbital-inducible mouse-liver mono-oxygenase is potentiated by the presence of hydrophilic residues at the K-region of the molecule. *Mutat Res* 96:1–13.
- Platt, KL; Schollmeier, M; Frank, H; et al. (1990) Stereoselective metabolism of dibenz[a,h]anthracene to trans-dihydrodiols and their activation to bacterial mutagens. *Environ Health Perspect* 88:37–41.
- Polcaro, C; Nicoletti, I; Ossicini, L; et al. (1988) Chromatographic and cytogenetic analysis of in vivo metabolites of fluoranthene. *J Chromatogr* 448:127–133.
- Pruess-Schwartz, D; Baird, WM; Yagi, H; et al. (1987) Stereochemical specificity in the metabolic activation of benzo[c]phenanthrene to metabolites that covalently bind to DNA in rodent embryo cell cultures. *Cancer Res* 47:4032–4037.
- Purchase, IFH; Longstaff, E; Ashby, J; et al. (1976) Evaluation of six short term tests for detecting organic chemical carcinogens and recommendations for their use. *Nature* 264:624–627.
- Ralston, SL; Lau, HH; Seidel, A; et al. (1994) The potent carcinogen dibenzo[a,l]pyrene is metabolically activated to fjord-region 11,12-diol 13,14-epoxides in human mammary carcinoma MCF-7 cell cultures. *Cancer Res* 54:887–890.

Ralston, SL; Seidel, A; Luch, A; et al. (1995) Stereoselective activation of dibenzo[a,l]pyrene to (-)-anti (11R,12S,13S,14R)- and (+)-syn(11S,12R,13S,14R)-11,12-diol-13,14-epoxides which bind extensively to deoxyadenosine residues of DNA in the human mammary carcinoma cell line MCF-7. *Carcinogenesis* 16:2899–2907.

Ralston, SL; Coffing, SL; Seidel, A; et al. (1997) Stereoselective activation of dibenzo[a,l]pyrene and its trans-11,12-dihydrodiol to fjord region 11,12-diol 13,14-epoxides in a human mammary carcinoma MCF-7 cell-mediated V79 cell mutation assay. *Chem Res Toxicol* 10:687–693.

RamaKrishna, NV; Padmavathi, NS; Cavalieri, EL; et al. (1993) Synthesis and structure determination of the adducts formed by electrochemical oxidation of the potent carcinogen dibenzo[a,i]pyrene in the presence of nucleosides. *Chem Res Toxicol* 6:554–560.

Rastetter, WH; Nachbar, RB; Russo-Rodriguez, S; et al. (1982) Fluoranthene: synthesis and mutagenicity of fluor diol epoxides. *J Org Chem* 47:4873–4878.

Reznikoff, CA; Bertram, JS; Brankow, DW; et al. (1973) Quantitative and qualitative studies of chemical transformation of cloned C3H mouse embryo cells sensitive to postconfluence inhibition of cell division. *Cancer Res* 33:3239–3249.

Rice, JE; Coleman, DT; Hosted, TJ, Jr.; et al. (1985) Identification of mutagenic metabolites of indeno-[1,2,3-cd]pyrene formed in vitro with rat liver enzymes. *Cancer Res* 45:5421–5425.

Rice, JE; Geddie, NG; Defloria, MC; et al. (1988) Structural requirements favoring mutagenic activity among methylated pyrenes in *S. typhimurium*. In: Cooke, M; Dennis, AJ, eds. *Polynuclear aromatic hydrocarbons: a decade of progress*. Columbus, OH: Battelle Press, pp. 773–785.

Ridler, P; Jennings, B. (1984) The binding of polycyclic aromatic hydrocarbon diol-epoxides to DNA. *Cancer Lett* 22:95–98.

Ross, JA; Nelson, GB; Holden, KL; et al. (1992) DNA adducts and induction of sister chromatid exchanges in the rat following benzo[b]fluoranthene administration. *Carcinogenesis* 13:1731–1734.

Rugen, PJ; Stern, CD; Lamm, SH. (1989) Comparative carcinogenicity of the PAHs as a basis for acceptable exposure levels (AELs) in drinking water. *Regul Toxicol Pharmacol* 9:273–283.

Safe, S. (1990) Polychlorinated biphenyls (PCBs), dibenzo-p-dioxins (PCDDs), dibenzofurans (PCDFs), and related compounds: environmental and mechanistic considerations which support the development of toxic equivalency factors (TEFs). *Crit Rev Toxicol* 21:51–88.

Saffiotti, U. (1969) Experimental respiratory tract carcinogenesis. *Prog Exp Tumor Res* 11:302–333.

Sangaiah, R; Gold, A; Newcomb, KO; et al. (1991) Synthesis and biological activity of bay-region metabolites of a cyclopenta-fused polycyclic aromatic hydrocarbon: benz[j]aceanthrylene. *J Med Chem* 34:546–549.

Schneider, K; Roller, M; Kalberlah, F; et al. (2002) Cancer risk assessment for oral exposure to PAH mixtures. *J Appl Toxicol* 22:73–83.

Slaga, TJ; Gleason, GL; Mills, C; et al. (1980) Comparison of the tumour-initiating activities of dihydrodiols and diol-epoxides of various polycyclic aromatic hydrocarbons. *Cancer Res* 40:1981–1984.

Snell, KC; Stewart, HL. (1962) Pulmonary adenomatosis induced in DBA/2 mice by oral administration of dibenz[a,h]anthracene. *J Natl Cancer Inst* 28:1043–1049.

Snell, KC; Stewart, HL. (1963) Induction of pulmonary adenomatoses in DBA/2 mice by the oral administration of dibenz[a,h]anthracene. *Acta Unio Int Contra Cancrum* 19:692–694.

Stanton, MF; Miller, E; Wrench, C; et al. (1972) Experimental induction of epidermoid carcinoma in the lungs of rats by cigarette smoke condensate. *J Natl Cancer Inst* 49:867–877.

Stocker, KJ; Howard, WR; Statham, J; et al. (1996) Assessment of the potential in vivo genotoxicity of fluoranthene. *Mutagenesis* 11:493–496.

Upham, BL; Weis, LM; Rummel, AM; et al. (1996) The effects of anthracene and methylated anthracenes on gap junctional intercellular communication in rat liver epithelial cells. *Fundam Appl Toxicol* 34:260–264.

U.S. EPA (Environmental Protection Agency). (1989) Health and environmental effects profile for benzo[g,h,i]perylene. Cincinnati, OH: Environmental Criteria and Assessment Office. EPA-600-X-87-395.

Wang, JS; Busby, WF; Wogan, GN. (1995) Tissue distribution of DNA adducts in pre-weanling BLU:Ha mice treated with a tumorigenic dose of fluoranthene. *Cancer Lett* 92:9–19.

Wang, JS; Busby, WF, Jr.; Wogan, GN. (1995) Formation and persistence of DNA adducts in organs of CD-1 mice treated with a tumorigenic dose of fluoranthene. *Carcinogenesis* 16:2609–2616.

Weis, LM; Rummel, AM; Masten, SJ; et al. (1998) Bay or baylike regions of polycyclic aromatic hydrocarbons were potent inhibitors of gap junctional intercellular communication. *Environ Health Perspect* 106:17–22.

Wester, PW; Kroes, R. (1988) Forestomach carcinogens: pathology and relevance to man. *Toxicol Pathol* 16:165–171.

Weyand, EH; Rice, JE; Hussain, N; et al. (1987a) Detection of DNA adducts of tumorigenic nonalternant polycyclic aromatic hydrocarbons by 32P-postlabeling. *Proc Am Assoc Cancer Res* 28:102.

Weyand, EH; Rice, JE; LaVoie, EJ. (1987b) 32P-postlabeling analysis of DNA adducts from non-alternant PAH using thin-layer and high performance liquid chromatography. *Cancer Lett* 37:257–266.

Weyand, EH; Geddie, N; Rice, JE; et al. (1988) Metabolism and mutagenic activity of benzo[k]fluoranthene and 3-, 8- and 9-fluorobenzo[k]fluoranthene. *Carcinogenesis* 9:1277–1281.

Weyand, EH; Bryla, P; Wu, Y; et al. (1993) Detection of the major DNA adducts of benzo[j]fluoranthene in mouse skin: nonclassical dihydrodiol epoxides. *Chem Res Toxicol* 6:117–124.

Whong, WZ; Stewart, JD; Cutler, D; et al. (1992) Comparative study of DNA adduct formation and cytogenic effects of two constituents in coke oven emissions with an in vivo rat lung cell system. *Environ Mol Mutag* 19(Suppl 20):70.

Whong, WZ; Stewart, JD; Cutler, D; et al. (1994) Induction of in vivo DNA adducts by 4 industrial by-products in the rat-lung-cell system. *Mutat Res* 312:165–172.

Wigley, CB; Newbold, RF; Amos, J; et al. (1979) Cell-mediated mutagenesis in cultured Chinese hamster cells by polycyclic hydrocarbons: mutagenicity and DNA reaction related to carcinogenicity in a series of compounds. *Int J Cancer* 23, 691–696.

Willett, KL; Randerath, K; Zhou, GD; et al. (1998) Inhibition of CYP1A1-dependent activity by the polynuclear aromatic hydrocarbon (PAH) fluoranthene. *Biochem Pharmacol* 55:831–839.

Williams, GM. (1977) Detection of chemical carcinogens by unscheduled DNA synthesis in rat liver primary cell cultures. *Cancer Res* 37:1845–1851.

Wood, AW; Levin, W; Ryan, D; et al. (1977) High mutagenicity of metabolically activated chrysene 1,2-dihydrodiol: evidence for bay region activation of chrysene. *Biochem Biophys Res Commun* 78:847–854.

Wood, AW; Levin, W; Thomas, PE; et al. (1978) Metabolic activation of dibenz[a,h]anthracene and its dihydrodiols to bacterial mutagens. *Cancer Res* 38:1967–1973.

Wood, AW; Chang, RL; Huang, MT; et al. (1980a) Mutagenicity of benzo[e]pyrene and triphenylene tetrahydroepoxides and diol-epoxides in bacterial and mammalian cells. *Cancer Res* 40:1985–1989.

Wood, AW; Chang, RL; Levin, W; et al. (1980b) Mutagenicity of the dihydrodiols and bay-region diol-epoxides of benzo[c]phenanthrene in bacterial and mammalian cells. *Cancer Res* 40:2876–2883.

Wood, AW; Chang, RL; Levin, W; et al. (1981) Mutagenicity of the bay-region diol-epoxides and other benzo-ring derivatives of dibenzo[a,h]pyrene and dibenzo[a,i]pyrene. *Cancer Res* 41:2589–2597.

Wood, AW; Chang, RL; Levin, W; et al. (1983) Mutagenicity of the enantiomers of the diastereomeric bay-region benz[a]anthracene 3,4-diol-1,2-epoxides in bacterial and mammalian cells. *Cancer Res* 43:5821–5825.

Wu, J; Zhu, BB; Yu, J; et al. (2003) In vitro and in vivo modulations of benzo[c]phenanthrene-DNA adducts by DNA mismatch repair system. *Nucleic Acids Res* 31:6428–6434.

Yamaguchi, K; Near, R; Shneider, A; et al. (1996) Fluoranthene-induced apoptosis in murine T cell hybridomas is independent of the aromatic hydrocarbon receptor. *Toxicol Appl Pharmacol* 139:144–152.

Zhong, BZ; Gu, ZW; Stewart, J; et al. (1995) Micronucleus formation induced by three polycyclic aromatic hydrocarbons in rat bone marrow and spleen erythrocytes following intratracheal instillation. *Mutat Res* 326:147–153.

1
2
3

APPENDIX C. DOSE-RESPONSE DATA FOR POTENCY CALCULATIONS

Table C-1. Dermal bioassays: dose-response information for incidence data

Record number	Reference	Study type	Species	Tumor type	PAH	Sex	Dose of PAH	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	Fisher's exact <i>p</i> -value	Cochran-Armitage trend test <i>p</i> -value	Comments
<i>Complete carcinogenicity studies</i>															
600	Habs et al., 1980	Complete	Mice	Sum of Papilloma, carcinoma, sarcoma	Acetone	F	0	µg/animal	0	35	0				
					DMSO	F	0	µg/animal	0	36	0				
					BaP	F	1.7	µg/animal	8	34	24		1.92×10^{-3}		
					BaP	F	2.8	µg/animal	24	35	69		1.67×10^{-11}		
					BaP	F	4.6	µg/animal	22	36	61		2.1×10^{-9}	2.15×10^{-9}	
					BbF	F	3.4	µg/animal	2	38	5		2.6×10^{-1}		
					BbF	F	5.6	µg/animal	5	34	15		2.3×10^{-2}		
					BbF	F	9.2	µg/animal	20	37	54		3.7×10^{-8}	1.33×10^{-9}	
					BjF	F	3.4	µg/animal	1	38	3		5.1×10^{-1}		
					BjF	F	5.6	µg/animal	1	35	3		4.9×10^{-1}		
					BjF	F	9.2	µg/animal	2	38	5		2.6×10^{-1}	1.77×10^{-1}	
					BkF	F	3.4	µg/animal	1	39	3		5.2×10^{-1}		
					BkF	F	5.6	µg/animal	0	38	0				
					BkF	F	9.2	µg/animal	0	38	0				
					CPcdP	F	1.7	µg/animal	0	34	0				
					CPcdP	F	6.5	µg/animal	0	35	0				
					CPcdP	F	27.2	µg/animal	3	38	8		1.3×10^{-1}	6.36×10^{-2}	
					IP	F	3.4	µg/animal	1	36	3		5×10^{-1}		
					IP	F	5.6	µg/animal	0	37	0				
					IP	F	9.2	µg/animal	0	37	0				
					CO	F	5.6	µg/animal	1	39	3		0.52		
					CO	F	15	µg/animal	2	40	5		0.27	1.83×10^{-1}	
13640	Cavalieri et al., 1983	Complete	Mice	Papilloma, adenoma, carcinoma	Acetone	F	0	nmol	0	29	0				
					BaP	F	2.2	nmol	2	30	7		0.25		
					BaP	F	6.6	nmol	2	28	7		0.24		

Table C-1. Dermal bioassays: dose-response information for incidence data

Record number	Reference	Study type	Species	Tumor type	PAH	Sex	Dose of PAH	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	Fisher's exact <i>p</i> -value	Cochran-Armitage trend test <i>p</i> -value	Comments
					BaP	F	20	nmol	17	30	57		4.32×10^{-7}	2.96×10^{-1}	
					CPcdP	F	22.2	nmol	2	29	7		0.25		
					CPcdP	F	66.6	nmol	2	29	7		0.25		
					CPcdP	F	200	nmol	24	29	83		9.25×10^{-12}	1.39×10^{-16}	
620	Hoffmann and Wynder 1966	Complete	Mice	Papilloma	Dioxane	F	0	%	0	20	0				
					BaP	F	0.05	%	17	20	85		1.28×10^{-8}		
					BaP	F	0.1	%	19	20	95		1.5×10^{-10}	8.7×10^{-10}	
					DBaeP	F	0.05	%	16	30	53		3.31×10^{-5}		
					DBaeP	F	0.1	%	9	17	53		1.95×10^{-4}	5.69×10^{-4}	
					DBahP	F	0.05	%	16	17	94		1.32×10^{-9}		
					DBahP	F	0.1	%	15	18	83		5.27×10^{-8}	1.29×10^{-7}	
					DBaiP	F	0.05	%	16	19	84		2.58×10^{-9}		
					DBaiP	F	0.1	%	16	19	84		2.58×10^{-9}	9.81×10^{-8}	
					DBaeF	F	0.05	%	17	19	89		3.35×10^{-9}		
					DBaeF	F	0.1	%	18	19	95		3.05×10^{-10}	1.13×10^{-9}	
17660	Cavalieri et al., 1977	Complete	Mice	Papilloma, kerato-acanthoma, carcinoma	Acetone	F	0	μmol/ap- plication	0	29	0				
					BaP	F	0.396	μmol/ap- plication	30	38	79		4.9×10^{-12}		
					DBahP	F	0.396	μmol/ap- plication	35	39	90		2.98×10^{-15}		
					AA	F	0.396	μmol/ap- plication	18	38	47		3.59×10^{-6}		
					BaA	F	0.396	μmol/ap- plication	1	39	3		0.66		

Table C-1. Dermal bioassays: dose-response information for incidence data

Record number	Reference	Study type	Species	Tumor type	PAH	Sex	Dose of PAH	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	Results of authors' statistical analysis (p-value)	Fisher's exact p-value	Cochran-Armitage trend test p-value	Comments
<i>Initiation studies</i>															
630	LaVoie et al., 1982	Initiation	Mice	Primarily squamous cell papilloma	Acetone/TPA	F	0	µg/mouse	0	20	0				
					BaP	F	30	µg/mouse	17	20	85		1.28×10^{-8}		
					BbF	F	10	µg/mouse	9	20	45		6.14×10^{-4}		
					BbF	F	30	µg/mouse	12	20	60		2.25×10^{-5}		
					BbF	F	100	µg/mouse	16	20	80		7.7×10^{-8}	1.46×10^{-5}	
					BjF	F	30	µg/mouse	6	20	30		0.01		
					BjF	F	100	µg/mouse	11	20	55		7.27×10^{-5}		
					BjF	F	1,000	µg/mouse	19	20	95		1.52×10^{-10}	4.67×10^{-8}	
					BkF	F	30	µg/mouse	1	20	5		0.01		
					BkF	F	100	µg/mouse	5	20	25		0.02		
					BkF	F	1,000	µg/mouse	15	20	75		3.85×10^{-7}	4.51×10^{-9}	
18570	Hecht et al., 1974	Initiation	Mice	Unspecified	Acetone	F	0	mg/mouse	0	20	0				Number of surviving not reported for controls; initial group size used here
					BaP	F	0.05	mg/mouse	6	20	30		0.01		
					CH	F	1	mg/mouse	11	19	58		4.51×10^{-5}		
24800	Nesnow et al., 1984	Initiation	Mice	Papilloma	Acetone	M	0	nmol	0	20	0				Data at 30 wks
					Acetone	F	0	nmol	1	19	5				
					BaP	M	200	nmol	13	18	67	<0.005			
					BaP	F	200	nmol	10	19	53	<0.005			
					BIAC	M	50	nmol	12	20	60	<0.005			
					BIAC	M	100	nmol	16	17	94	<0.005			
					BIAC	M	250	nmol	21	21	100	<0.005			
					BIAC	M	500	nmol	16	16	100	<0.005			

Table C-1. Dermal bioassays: dose-response information for incidence data

Record number	Reference	Study type	Species	Tumor type	PAH	Sex	Dose of PAH	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	Fisher's exact <i>p</i> -value	Cochran-Armitage trend test <i>p</i> -value	Comments
					BIAC	M	1,000	nmol	19	20	95	<0.005			
					BIAC	F	50	nmol	13	20	65	<0.005			
					BIAC	F	100	nmol	18	19	95	<0.005			
					BIAC	F	250	nmol	19	21	91	<0.005			
					BIAC	F	500	nmol	20	21	95	<0.005			
					BIAC	F	1,000	nmol	20	20	100	<0.005			
					BeAC	M	50	nmol	4	20	20				
					BeAC	M	100	nmol	4	20	20				
					BeAC	M	250	nmol	12	20	60	<0.005			
					BeAC	M	500	nmol	15	20	75	<0.005			
					BeAC	M	1,000	nmol	16	18	89	<0.005			
					BeAC	F	50	nmol	4	20	20				
					BeAC	F	100	nmol	7	19	37	<0.005			
					BeAC	F	250	nmol	10	19	53	<0.005			
					BeAC	F	500	nmol	8	18	44	<0.005			
					BeAC	F	1,000	nmol	18	20	90	<0.005			
21420	Slaga et al., 1980	Initiation	Mouse	Papilloma	Control	F	0	nmol	2	30	6				Different controls used for each chemical except DBacA and BeP
					Control	F	0	μmol	3	30	10				
					Control	F	0	μmol	3	30	10				
					Control	F	0	nmol	2	29	6				
					Control pooled	F	0	nmol	10	119	8				
					BaP	F	200	nmol	20	30	67		1.41×10^{-6}		
					BeP	F	2,000	nmol	5	29	17		0.33		
					CH	F	2,000	nmol	21	29	73		8.38×10^{-7}		
					DBacA	F	2,000	nmol	8	28	27		0.07		
					DBahA	F	100	nmol	15	29	50		3.52×10^{-6}		

Table C-1. Dermal bioassays: dose-response information for incidence data

Record number	Reference	Study type	Species	Tumor type	PAH	Sex	Dose of PAH	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	Fisher's exact <i>p</i> -value	Cochran-Armitage trend test <i>p</i> -value	Comments
15640	Raveh et al., 1982	Initiation	Mice	Papilloma	Control	F	0	µg	3	29	10				
					BaP	F	10	µg	17	29	58		1.11×10^{-4}		
					BaP	F	25	µg	21	28	76		5.96×10^{-7}		
					BaP	F	50	µg	24	28	87		5.43×10^{-9}		
					BaP	F	100	µg	27	27	100		5.50×10^{-13}		
					BaP	F	200	µg	26	26	100		1.03×10^{-12}	2.78×10^{-10}	
					CPcdP	F	10	µg	3	30	11		0.65		
					CPcdP	F	100	µg	11	29	39		0.01		
620	Hoffmann and Wynder 1966	Initiation	Mice	Papilloma	Croton oil control	F	0	mg/mouse	2	30	7				
					BaP	F	0.25	mg/mouse	24	30	80		3.80×10^{-9}		
					DBaeF	F	0.25	mg/mouse	18	30	60		9.40×10^{-6}		
					DBaeP	F	0.25	mg/mouse	10	27	37		0.006		
					DBelP	F	0.25	mg/mouse	0	29	0		0.25		
					DBahP	F	0.25	mg/mouse	21	29	72		1.30×10^{-7}		
					DBaiP	F	0.25	mg/mouse	12	30	40		0.002		
					AA	F	0.25	mg/mouse	2	29	7		0.68		
					BghiP	F	0.25	mg/mouse	2	27	7		0.65		
					N23eP	F	0.25	mg/mouse	9	30	30		0.02		
13650	Cavalieri et al., 1981b	Initiation	Mice	Papilloma	Acetone/TPA	F	0	µmol	3	29	10				
					BaP	F	0.2	µmol	12	30	40		0.009		
					CPcdP	F	0.2	µmol	1	30	3		0.29		
					CPcdP	F	0.6	µmol	9	29	31		0.05		
					CPcdP	F	1.8	µmol	6	29	21		0.24	0.14	
					ACEP	F	0.2	µmol	0	30	0		0.11		
					ACEP	F	0.6	µmol	1	30	3		0.29		

Table C-1. Dermal bioassays: dose-response information for incidence data

Record number	Reference	Study type	Species	Tumor type	PAH	Sex	Dose of PAH	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	Fisher's exact <i>p</i> -value	Cochran-Armitage trend test <i>p</i> -value	Comments
					ACEP	F	1.8	μmol	4	30	13		0.52	0.18	
15700	Rice et al., 1988	Initiation	Mice	Unspecified	Acetone	F	0	μmol	1	20	5				
					BaP	F	0.1	μmol	17	19	89	<0.005			
					CH	F	0.15	μmol	5	20	25	<0.05			
					CH	F	0.5	μmol	18	20	90	<0.005			
					CH	F	1.5	μmol	19	20	95	<0.005		6.39 × 10 ⁻⁹	
					CPdefC (4,5-MC)	F	0.15	μmol	13	20	65	<0.005			
					CPdefC (4,5-MC)	F	0.5	μmol	19	19	100	<0.005			
					CPdefC (4,5-MC)	F	1.5	μmol	19	19	100	<0.005		1.90 × 10 ⁻⁷	
					BbcAC (1,12-MBA)	F	0.5	μmol	15	20	75	<0.005			
					BbcAC (1,12-MBA)	F	2	μmol	18	20	90	<0.005			
					BbcAC (1,12-MBA)	F	4	μmol	18	20	90	<0.005		3.03 × 10 ⁻⁶	

1
2

Table C-2. Dermal bioassays: dose-response information for tumor multiplicity

Record number	Reference	Study type	Species	Tumor type	PAH	Sex	Dose of PAH	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	Results of SRC statistical analysis Fisher's exact <i>p</i> -value	Mean number tumors/animal	Comments
<i>Complete carcinogenicity</i>															
13640	Cavalieri et al., 1983	Complete	Mice	Papilloma, adenoma, carcinoma	Acetone	F	0	nmol	0	29	0			0	Number tumors per animal at risk calculated
					BaP	F	2.2	nmol	2	30	7		>0.05	0.07	
					BaP	F	6.6	nmol	2	28	7		>0.05	0.07	
					BaP	F	20	nmol	17	30	57		<0.001	1.5	
					CPcdP	F	22.2	nmol	2	29	7		>0.05	0.07	
					CPcdP	F	66.6	nmol	2	29	7		>0.05	0.07	
					CPcdP	F	200	nmol	24	29	83		<0.001	2.45	
13650	Cavalieri et al., 1981b	Complete	Mice	Primarily squamous cell carcinoma	Acetone	US	0	µmol/application	0	30	0			0	Number tumors per animal at risk calculated
					BaP	US	0.2	µmol/application	30	30	100		<0.001	1.5	
					CPcdP	US	0.2	µmol/application	17	30	57		<0.001	0.8	
					CPcdP	US	0.6	µmol/application	11	30	37		<0.001	0.5	
					CPcdP	US	1.8	µmol/application	7	30	23		0.0053	0.4	
					ACEP	US	0.2	µmol/application	0	30	0		>0.05	0	
					ACEP	US	0.6	µmol/application	1	30	3		>0.05	0.03	
					ACEP	US	1.8	µmol/application	1	30	3		>0.05	0.03	
<i>Initiation</i>															
630	LaVoie et al., 1982	Initiation	Mice	Primarily squamous cell papilloma	Acetone/TPA	F	0	µg/mouse	0	20	0			0	
					BaP	F	30	µg/mouse	17	20	85		<0.001	4.9	
					BbF	F	10	µg/mouse	9	20	45		<0.001	0.9	
					BbF	F	30	µg/mouse	12	20	60		<0.001	2.3	
					BbF	F	100	µg/mouse	16	20	80		<0.001	7.1	

Table C-2. Dermal bioassays: dose-response information for tumor multiplicity

Record number	Reference	Study type	Species	Tumor type	PAH	Sex	Dose of PAH	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	Results of SRC statistical analysis Fisher's exact <i>p</i> -value	Mean number tumors/animal	Comments
					BjF	F	30	µg/mouse	6	20	30		0.01	0.6	
					BjF	F	100	µg/mouse	11	20	55		<0.001	1.9	
					BjF	F	1,000	µg/mouse	19	20	95		<0.001	7.2	
					BkF	F	30	µg/mouse	1	20	5		>0.05	0.1	
					BkF	F	100	µg/mouse	5	20	25		0.02	0.4	
					BkF	F	1,000	µg/mouse	15	20	75		<0.001	2.8	
18570	Hecht et al., 1974	Initiation	Mice	Unspecified	Acetone	F	0	mg/animal	0	20	0			0	Number surviving not reported for controls; initial group size used here; number tumors per animal at risk calculated
					BaP	F	0.05	mg/animal	6	20	30		0.01	0.5	
					CH	F	1	mg/animal	11	19	61		<0.001	1	
21420	Slaga et al., 1980	Initiation	Mouse	Papilloma	Control	F	0	nmol	2	29	6			0.1	Different controls used for each chemical except DBacA and BeP
					Control	F	0	nmol	3	30	10			0.2	
					Control	F	0	nmol	3	30	10			0.1	
					Control	F	0	nmol	2	29	6			0.1	
					Control pooled	F	0	nmol	10	119	8			0.13	
					BaP	F	200	nmol	20	30	67		<0.001	2.2	
					BeP	F	2,000	nmol	5	29	17		>0.05	0.2	
					CH	F	2,000	nmol	21	29	73		<0.001	1.6	
					DBacA	F	2,000	nmol	8	28	27		>0.05	0.5	
					DBahA	F	100	nmol	15	29	50		<0.001	1.4	
15640	Raveh et al., 1982	Initiation	Mice	Papilloma	Control	F	0	µg	3	29	10			0.2	
					BaP	F	10	µg	17	29	58		<0.001	1.3	
					BaP	F	25	µg	21	28	76		<0.001	3.8	
					BaP	F	50	µg	24	28	87		<0.001	6.2	
					BaP	F	100	µg	27	27	100		<0.001	8.8	
					BaP	F	200	µg	26	26	100		<0.001	9	
					CPcdP	F	10	µg	3	30	11		>0.05	0.1	

Table C-2. Dermal bioassays: dose-response information for tumor multiplicity

Record number	Reference	Study type	Species	Tumor type	PAH	Sex	Dose of PAH	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	Results of SRC statistical analysis Fisher's exact <i>p</i> -value	Mean number tumors/animal	Comments
					CPcdP	F	100	µg	11	29	39		0.01	0.4	
					CPcdP	F	200	µg	16	28	57		<0.001	0.9	
13650	Cavalieri et al., 1981	Initiation	Mice	Papilloma	Acetone/TPA	F	0	µmol	3	29	10			0.14	
					BaP	F	0.2	µmol	12	30	40		0.009	1.2	
					CPcdP	F	0.2	µmol	1	30	3		>0.05	0.03	
					CPcdP	F	0.6	µmol	9	29	31		0.05	0.31	
					CPcdP	F	1.8	µmol	6	29	21		>0.05	0.31	
					ACEP	F	0.2	µmol	0	30	0		>0.05	0	
					ACEP	F	0.6	µmol	1	30	3		>0.05	0.03	
					ACEP	F	1.8	µmol	4	30	13		>0.05	0.13	
21410	Slaga et al., 1978	Initiation	Mice	Papilloma	Acetone/TPA	F	0	µmol	2	29	6			0.1	
					BaP	F	0.2	µmol	27	29	92		<0.001	5.3	
					BaA	F	2	µmol	17	30	57		<0.001	1.2	
16310	Weyand et al., 1992	Initiation	Mice	Unspecified	Acetone	US	0	µmol	1	21	5			0.05	
					BaP	US	0.01	µmol	24	24	100	<0.01		4.08	
					BjF	US	0.3	µmol	11	20	55	<0.01		1.75	
					BjF	US	1	µmol	21	24	88	<0.01		4.08	
					BjF	US	2	µmol	24	24	100	<0.01		7.17	
10200	El-Bayoumy et al., 1982	Initiation	Mice	Primarily squamous cell papilloma	Acetone	F	0	mg/mouse	1	20	5			0.1	
					BaP	F	0.05	mg/mouse	18	20	90	<0.01		7.1	
					CH	F	1	mg/mouse	20	20	100	<0.01		7.7	
					Pery	F	1	mg/mouse	1	20	5			0.1	
					Pyr	F	1	mg/mouse	4	20	20			0.2	
24300	Rice et al., 1985	Initiation	Mice	Unspecified	Acetone	F	0	mg/mouse	2	25	8			0.12	Mean number of tumors/animal digitally estimated from Figure 2 and rounded to even number tumors
					BaP	F	0.3	mg/mouse	24	25	96		<0.001	8.04	
					CH	F	1	mg/mouse	23	25	92		<0.001	5	

Table C-2. Dermal bioassays: dose-response information for tumor multiplicity

Record number	Reference	Study type	Species	Tumor type	PAH	Sex	Dose of PAH	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	Results of SRC statistical analysis Fisher's exact <i>p</i> -value	Mean number tumors/animal	Comments
					CPdefC	F	1	mg/mouse	24	24	100		<0.001	5.63	Number reported in text
13660	Cavalieri et al., 1991	Initiation	Mice	Primarily papilloma	Acetone	F	0	nmol	0	24	0			0	16-Wk experiment
					BaP	F	33.3	nmol	10	23	43		<0.001	0.65	
					BaP	F	100	nmol	17	24	71		<0.001	2.75	
					BaP	F	300	nmol	21	23	91		<0.001	5.22	
					DBaP	F	33.3	nmol	23	24	96		<0.001	6.75	
					DBaP	F	100	nmol	22	24	92		<0.001	7.92	
					DBaP	F	300	nmol	24	24	100		<0.001	8.5	
13660	Cavalieri et al., 1991	Initiation	Mice	Primarily papilloma	Acetone	F	0	nmol	0	24	0			0	27-Wk experiment
					BaP	F	4	nmol	1	24	4		>0.05	0.04	
					BaP	F	20	nmol	10	24	42		<0.001	0.75	
					BaP	F	100	nmol	22	24	92		<0.001	3.42	
					DBaP	F	4	nmol	22	24	92		<0.001	6.96	
					DBaP	F	20	nmol	20	24	83		<0.001	5.29	
					DBaP	F	100	nmol	20	24	83		<0.001	3.29	
16440	Wood et al., 1980	Initiation	Mice	Papilloma	Acetone	F	0	µmol	3	30	10			0.1	Number tumors per animal at risk calculated
					BaP	F	0.1	µmol	20	30	68	<0.05		2	
					BaP	F	0.4	µmol	22	30	73	<0.05		4.6	
					Pyr	F	0.1	µmol	4	30	14	>0.05		0.14	
					Pyr	F	0.4	µmol	3	30	10	>0.05		0.1	
					CPcdP	F	0.1	µmol	3	30	10	>0.05		0.1	
					CPcdP	F	0.4	µmol	6	30	21	>0.05		0.29	
18680	Hoffmann et al., 1972	Initiation	Mice	Papilloma	Acetone	F	0	mg	1	30	3			0.03	
					BaP	F	0.05	mg	19	29	66		<0.001	2.3	
					FA	F	1	mg	1	29	3		>0.05	0.03	
24800	Nesnow et al., 1984	Initiation	Mice	Papilloma	Acetone	M	0	nmol	0	20	0			0	
					Acetone	F	0	nmol	1	19	5			0.05	
					BaP	M	200	nmol	12	18	67		<0.001	1.4	
					BaP	F	200	nmol	10	19	53		0.0015	1.5	
					BeAC	M	50	nmol	4	20	20		>0.05	0.25	
					BeAC	F	50	nmol	4	20	20		>0.05	0.25	

Table C-2. Dermal bioassays: dose-response information for tumor multiplicity

Record number	Reference	Study type	Species	Tumor type	PAH	Sex	Dose of PAH	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	Results of SRC statistical analysis Fisher's exact <i>p</i> -value	Mean number tumors/animal	Comments
					BeAC	M	100	nmol	4	20	20		>0.05	0.4	
					BeAC	F	100	nmol	7	19	37		0.02	0.53	
					BeAC	M	250	nmol	12	20	60		<0.001	1.3	
					BeAC	F	250	nmol	10	19	53		<0.001	1.1	
					BeAC	M	500	nmol	15	20	75		<0.001	1.9	
					BeAC	F	500	nmol	8	18	44		0.007	1.2	
					BeAC	M	1,000	nmol	16	18	89		<0.001	3.1	
					BeAC	F	1,000	nmol	18	20	90		<0.001	2.2	
					BlAC	M	50	nmol	12	20	60		<0.001	1.4	
					BlAC	F	50	nmol	13	20	65		<0.001	1.1	
					BlAC	M	100	nmol	16	17	94		<0.001	2.3	
					BlAC	F	100	nmol	18	19	95		<0.001	3.1	
					BlAC	M	250	nmol	21	21	100		<0.001	8.4	
					BlAC	F	250	nmol	19	21	91		<0.001	4.7	
					BlAC	M	500	nmol	16	16	100		<0.001	10.8	
					BlAC	F	500	nmol	20	21	95		<0.001	6.6	
					BlAC	M	1,000	nmol	19	20	95		<0.001	8.7	
					BlAC	F	1,000	nmol	20	20	100		<0.001	10.8	

1

2

Table C-3. Intraperitoneal bioassays: dose-response information for incidence data

Record number	Reference	Species	Exposure route	Target organ	Tumor type	PAH	Sex	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor bearing animals	Results of authors' statistical analysis (p-value)	SRC Statistical Analysis		Comments
														Fisher's exact p-value	Cochran-Armitage trend test p-value	
17560	Busby et al., 1989	Mice	Intra-peritoneal	Lung	Adenoma + adenocarcinoma	DMSO	M	0	µg (total)	13	91	0.14				Stats reported for combined M and F only for each dose and treatment compared to control not individual sexes
				Lung	Adenoma + adenocarcinoma	DMSO	F	0	µg (total)	7	101	0.07				
				Lung	Adenoma + adenocarcinoma	BaP	M	59.5	µg (total)	13	28	0.46		7.2×10^{-4}		
				Lung	Adenoma + adenocarcinoma	BaP	F	59.5	µg (total)	19	27	0.70		3.96×10^{-11}		
				Lung	Adenoma + adenocarcinoma	Pyr	M	86.1	µg (total)	4	23	0.17		4.60×10^{-1}		
				Lung	Adenoma + adenocarcinoma	Pyr	F	86.1	µg (total)	1	28	0.04		4.50×10^{-1}		
				Lung	Adenoma + adenocarcinoma	Pyr	M	1,750	µg (total)	2	27	0.07		2.80×10^{-1}	3.13×10^{-1}	
				Lung	Adenoma + adenocarcinoma	Pyr	F	1,750	µg (total)	3	26	0.12		3.30×10^{-1}	3.50×10^{-1}	
				Lung	Adenoma + adenocarcinoma	FA	M	257.6	µg (total)	5	23	0.22		2.80×10^{-4}		
				Lung	Adenoma + adenocarcinoma	FA	F	257.6	µg (total)	9	29	0.31		1.65×10^{-3}		

Table C-3. Intraperitoneal bioassays: dose-response information for incidence data

Record number	Reference	Species	Exposure route	Target organ	Tumor type	PAH	Sex	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	SRC Statistical Analysis		Comments
														Fisher's exact <i>p</i> -value	Cochran-Armitage trend test <i>p</i> -value	
				Lung	Adenoma + adenocarcinoma	CH	M	6.3	µg (total)	2	27	0.07		2.80×10^{-1}		
				Lung	Adenoma + adenocarcinoma	CH	F	6.3	µg (total)	3	29	0.10		3.90×10^{-1}		
				Lung	Adenoma + adenocarcinoma	CH	M	210	µg (total)	3	20	0.15		5.85×10^{-1}	8.03×10^{-1}	
				Lung	Adenoma + adenocarcinoma	CH	F	210	µg (total)	0	29	0.00		1.60×10^{-1}	1.28×10^{-1}	
640	LaVoie et al., 1987	Mice	Intra-peritoneal	Lung	Adenoma	DMSO	M	0	µmol/mouse	0	17	0				
				Lung	Adenoma	DMSO	F	0	µmol/mouse	0	18	0				
				Lung	Adenoma	BaP	M	1.1	µmol/mouse	14	17	0.82	<0.005			
				Lung	Adenoma	BaP	F	1.1	µmol/mouse	9	14	0.64				
				Lung	Adenoma	BbF	M	0.5	µmol/mouse	2	15	0.13	>0.05			
				Lung	Adenoma	BbF	F	0.5	µmol/mouse	3	17	0.18	>0.05			
				Lung	Adenoma	BjF	M	1.1	µmol/mouse	11	21	0.52	<0.005			
				Lung	Adenoma	BjF	F	1.1	µmol/mouse	4	18	0.22	<0.05			
				Lung	Adenoma	BkF	M	2.1	µmol/mouse	1	16	0.06	>0.05			
				Lung	Adenoma	BkF	F	2.1	µmol/mouse	3	18	0.17	>0.05			

Table C-3. Intraperitoneal bioassays: dose-response information for incidence data

Record number	Reference	Species	Exposure route	Target organ	Tumor type	PAH	Sex	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	SRC Statistical Analysis		Comments
														Fisher's exact <i>p</i> -value	Cochran-Armitage trend test <i>p</i> -value	
				Lung	Adenoma	IP	M	2.1	μmol/mouse	1	11	0.09				
				Lung	Adenoma	IP	F	2.1	μmol/mouse	0	9	0				
				Liver	Adenoma + hepatoma	DMSO	M	0	μmol/mouse	1	17	0.06				Adenoma and hepatoma also reported separately; none of animals surviving 35 wks
				Liver	Adenoma + hepatoma	DMSO	F	0	μmol/mouse	0	18	0				
				Liver	Adenoma + hepatoma	BaP	M	1.1	μmol/mouse	13	17	0.76	<0.005			
				Liver	Adenoma + hepatoma	BaP	F	1.1	μmol/mouse	0	14	0				
				Liver	Adenoma + hepatoma	BbF	M	0.5	μmol/mouse	8	15	0.53	<0.005			
				Liver	Adenoma + hepatoma	BbF	F	0.5	μmol/mouse	0	17	0				
				Liver	Adenoma + hepatoma	BjF	M	1.1	μmol/mouse	11	21	0.52	<0.005			
				Liver	Adenoma + hepatoma	BjF	F	1.1	μmol/mouse	0	18	0				
				Liver	Adenoma + hepatoma	BkF	M	2.1	μmol/mouse	3	16	0.19	>0.05			
				Liver	Adenoma + hepatoma	BkF	F	2.1	μmol/mouse	0	18	0				
				Liver	Adenoma + hepatoma	IP	M	2.1	μmol/mouse	0	11	0				
				Liver	Adenoma + hepatoma	IP	F	2.1	μmol/mouse	0	9	0				
				Liver or lung	Adenoma + hepatoma	DMSO	M	0	μmol/mouse	1	17	0.06				

Table C-3. Intraperitoneal bioassays: dose-response information for incidence data

Record number	Reference	Species	Exposure route	Target organ	Tumor type	PAH	Sex	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	SRC Statistical Analysis		Comments
														Fisher's exact <i>p</i> -value	Cochran-Armitage trend test <i>p</i> -value	
				Liver or lung	Adenoma + hepatoma	DMSO	F	0	μmol/mouse	0	18	0				
				Liver or lung	Adenoma + hepatoma	BaP	M	1.1	μmol/mouse	13	17	0.76				
				Liver or lung	Adenoma + hepatoma	BaP	F	1.1	μmol/mouse	9	14	0.64				
				Liver or lung	Adenoma + hepatoma	BbF	M	0.5	μmol/mouse	8	15	0.53				
				Liver or lung	Adenoma + hepatoma	BbF	F	0.5	μmol/mouse	3	17	0.18				
				Liver or lung	Adenoma + hepatoma	BjF	M	1.1	μmol/mouse	17	21	0.81				
				Liver or lung	Adenoma + hepatoma	BjF	F	1.1	μmol/mouse	4	18	0.22				
				Liver or lung	Adenoma + hepatoma	BkF	M	2.1	μmol/mouse	3	16	0.19				
				Liver or lung	Adenoma + hepatoma	BkF	F	2.1	μmol/mouse	3	18	0.17				
				Liver or lung	Adenoma + hepatoma	IP	M	2.1	μmol/mouse	1	11	0.09				
				Liver or lung	Adenoma + hepatoma	IP	F	2.1	μmol/mouse	0	9	0				
7510	LaVoie et al., 1994	Mice	Intra-peritoneal	Lung	Total	DMSO	M	0	μmol/mouse	5	29	0.17				Survival to 1 yr
				Lung	Total	DMSO	F	0	μmol/mouse	4	34	0.12				
				Lung	Total	BaP	M	1.1	μmol/mouse	24	32	0.75	<0.001			
				Lung	Total	BaP	F	1.1	μmol/mouse	17	20	0.85	<0.001			

Table C-3. Intraperitoneal bioassays: dose-response information for incidence data

Record number	Reference	Species	Exposure route	Target organ	Tumor type	PAH	Sex	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor bearing animals	Results of authors' statistical analysis (p-value)	SRC Statistical Analysis		Comments
														Fisher's exact p-value	Cochran-Armitage trend test p-value	
				Lung	Total	FA	M	3.46	μmol/mouse	12	28	0.43	<0.05			
				Lung	Total	FA	F	3.46	μmol/mouse	11	31	0.35	<0.05			
				Lung	Total	FA	M	17.3	μmol/mouse	11	17	0.65	<0.005		2.84×10^{-3}	
				Lung	Total	FA	F	17.3	μmol/mouse	25	29	0.86	<0.001		2.18×10^{-9}	
				Liver	Foci + adenoma + carcinoma	DMSO	M	0	μmol/mouse	5	29	0.17				Foci, adenomas, carcinomas also reported separately
				Liver	Foci + adenoma + carcinoma	DMSO	F	0	μmol/mouse	2	34	0.06				
				Liver	Foci + adenoma + carcinoma	BaP	M	1.1	μmol/mouse	27	32	0.84	<0.001			
				Liver	Foci + adenoma + carcinoma	BaP	F	1.1	μmol/mouse	2	20	0.10	>0.05			
				Liver	Foci + adenoma + carcinoma	FA	M	3.46	μmol/mouse	18	28	0.64	<0.001			
				Liver	Foci + adenoma + carcinoma	FA	F	3.46	μmol/mouse	0	31	0				
				Liver	Foci + adenoma + carcinoma	FA	M	17.3	μmol/mouse	17	17	1.00	<0.001		5.10×10^{-7}	
				Liver	Foci + adenoma + carcinoma	FA	F	17.3	μmol/mouse	2	29	0.07			5.47×10^{-1}	

Table C-3. Intraperitoneal bioassays: dose-response information for incidence data

Record number	Reference	Species	Exposure route	Target organ	Tumor type	PAH	Sex	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	SRC Statistical Analysis		Comments
														Fisher's exact <i>p</i> -value	Cochran-Armitage trend test <i>p</i> -value	
24590	Nesnow et al., 1998b	Mice	Intra-peritoneal	Lung	NS	Control	M	0	mg/kg	6	20	0.30				Data provided by S. Nesnow
				Lung	NS	BaP	M	5	mg/kg	6	20	0.30		>0.05		
				Lung	NS	BaP	M	10	mg/kg	7	17	0.41		>0.05		
				Lung	NS	BaP	M	50	mg/kg	19	19	1.00		<0.001		
				Lung	NS	BaP	M	100	mg/kg	16	16	1.00		0.0018		
				Lung	NS	BaP	M	200	mg/kg	24	24	1.00		<0.001		
				Lung	NS	BbF	M	10	mg/kg	9	18	0.50		>0.05		
				Lung	NS	BbF	M	50	mg/kg	16	20	0.80		>0.05		
				Lung	NS	BbF	M	100	mg/kg	20	20	1.00		<0.001		
				Lung	NS	BbF	M	200	mg/kg	19	19	1.00		<0.001		
				Lung	NS	CPcdP	M	10	mg/kg	8	20	0.40		>0.05		
				Lung	NS	CPcdP	M	50	mg/kg	20	20	1.00		<0.001		
				Lung	NS	CPcdP	M	100	mg/kg	19	19	1.00		<0.001		
				Lung	NS	CPcdP	M	200	mg/kg	19	19	1.00		<0.001		
				Lung	NS	DBahA	M	1.25	mg/kg	12	18	0.67		<0.05		
				Lung	NS	DBahA	M	2.5	mg/kg	18	19	0.95		0.0053		
				Lung	NS	DBahA	M	5	mg/kg	20	20	1.00		<0.001		
				Lung	NS	DBahA	M	10	mg/kg	19	19	1.00		<0.001		
24590	Nesnow et al., 1998b	Mice	Intra-peritoneal	Lung	NS	Control	M	0	mg/kg	15	30	0.50				Data provided by S. Nesnow
				Lung	NS	DBalP	M	0.3	mg/kg	13	33	0.39		>0.05		
				Lung	NS	DBalP	M	1.5	mg/kg	33	34	0.97		<0.001		
				Lung	NS	DBalP	M	3	mg/kg	35	35	1.00		<0.001		
				Lung	NS	DBalP	M	6	mg/kg	30	30	1.00		<0.001		
24801	Weyand et al., 2004	Mouse	Intra-peritoneal	Lung	Adenoma	Tri-caprylin	F	0	mg/kg	14	29	0.48				

Table C-3. Intraperitoneal bioassays: dose-response information for incidence data

Record number	Reference	Species	Exposure route	Target organ	Tumor type	PAH	Sex	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	SRC Statistical Analysis		Comments
														Fisher's exact <i>p</i> -value	Cochran-Armitage trend test <i>p</i> -value	
						BaP	F	100	mg/kg	27	30	0.90		0.0005		
						BcFE	F	100	mg/kg	26	28	0.92		0.0002		
22510	Wislocki et al., 1986	Mice	Intra-peritoneal	Liver	Adenoma + carcinoma	DMSO	M	0	nmol	2	28	0.07				Animals surviving through weaning
				Liver	Adenoma + carcinoma	DMSO	F	0	nmol	0	31	0				0
				Liver	Adenoma + carcinoma	DMSO	M	0	nmol	5	45	0.11				This group started 10 wks after other groups
				Liver	Adenoma + carcinoma	DMSO	F	0	nmol	0	34	0				This group started 10 wks after other groups
				Liver	Adenoma + carcinoma	DMSO pooled	M	0	nmol	7	73	0.09				
				Liver	Adenoma + carcinoma	DMSO pooled	F	0	nmol	0	65	0				
				Liver	Adenoma + carcinoma	BaP	M	560	nmol	18	37	0.49	<0.05			
				Liver	Adenoma + carcinoma	BaP	F	560	nmol	0	27	0				
				Liver	Adenoma + carcinoma	CH	M	700	nmol	10	35	0.29	<0.05			This group started 10 wks after other groups
				Liver	Adenoma + carcinoma	CH	F	700	nmol	0	33	0				This group started 10 wks after other groups
				Liver	Adenoma + carcinoma	CH	M	2,800	nmol	14	34	0.41	<0.05		6×10^{-3}	
				Liver	Adenoma + carcinoma	CH	F	2,800	nmol	0	24	0			1	
				Liver	Adenoma + carcinoma	BaA	M	2,800	nmol	31	39	0.79	<0.05			

Table C-3. Intraperitoneal bioassays: dose-response information for incidence data

Record number	Reference	Species	Exposure route	Target organ	Tumor type	PAH	Sex	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	SRC Statistical Analysis		Comments
														Fisher's exact <i>p</i> -value	Cochran-Armitage trend test <i>p</i> -value	
				Liver	Adenoma + carcinoma	BaA	F	2,800	nmol	0	32	0				
				Lung	Adenoma + carcinoma	DMSO	M	0	nmol	1	28	0.04				
				Lung	Adenoma + carcinoma	DMSO	F	0	nmol	0	31	0				
				Lung	Adenoma + carcinoma	DMSO	M	0	nmol	4	45	0.09				This group started 10 wks after other groups
				Lung	Adenoma + carcinoma	DMSO	F	0	nmol	2	34	0.06				This group started 10 wks after other groups
				Lung	Adenoma + carcinoma	DMSO pooled	M	0	nmol	5	73	0.07				
				Lung	Adenoma + carcinoma	DMSO pooled	F	0	nmol	2	65	0.03				
				Lung	Adenoma + carcinoma	BaP	M	560	nmol	13	37	0.35	<0.05			
				Lung	Adenoma + carcinoma	BaP	F	560	nmol	13	27	0.48	<0.05			
				Lung	Adenoma + carcinoma	CH	M	700	nmol	6	35	0.17				This group started 10 wks after other groups
				Lung	Adenoma + carcinoma	CH	F	700	nmol	2	33	0.06				This group started 10 wks after other groups
				Lung	Adenoma + carcinoma	CH	M	2,800	nmol	7	34	0.21	<0.05		1.1 × 10 ⁻¹	
				Lung	Adenoma + carcinoma	CH	F	2,800	nmol	1	24	0.04			5.6 × 10 ⁻¹	
				Lung	Adenoma + carcinoma	BaA	M	2,800	nmol	6	39	0.15				

Table C-3. Intraperitoneal bioassays: dose-response information for incidence data

Record number	Reference	Species	Exposure route	Target organ	Tumor type	PAH	Sex	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	SRC Statistical Analysis		Comments
														Fisher's exact <i>p</i> -value	Cochran-Armitage trend test <i>p</i> -value	
				Lung	Adenoma + carcinoma	BaA	F	2,800	nmol	6	32	0.19	<0.05			
				Lymphatic system	Lymphoma	DMSO	M	0	nmol	1	28	0.04				
				Lymphatic system	Lymphoma	DMSO	F	0	nmol	1	31	0.03				
				Lymphatic system	Lymphoma	DMSO	M	0	nmol	0	45	0				This group started 10 wks after other groups
				Lymphatic system	Lymphoma	DMSO	F	0	nmol	0	34	0				This group started 10 wks after other groups
				Lymphatic system	Lymphoma	BaP	M	560	nmol	2	37	0.05				
				Lymphatic system	Lymphoma	BaP	F	560	nmol	4	27	0.15				
				Lymphatic system	Lymphoma	CH	M	700	nmol	3	35	0.09	<0.05			This group started 10 wks after other groups
				Lymphatic system	Lymphoma	CH	F	700	nmol	1	33	0.03				This group started 10 wks after other groups
				Lymphatic system	Lymphoma	CH	M	2,800	nmol	0	34	0			2.2×10^{-1}	
				Lymphatic system	Lymphoma	CH	F	2,800	nmol	0	24	0			3.9×10^{-1}	

Table C-3. Intraperitoneal bioassays: dose-response information for incidence data

Record number	Reference	Species	Exposure route	Target organ	Tumor type	PAH	Sex	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	SRC Statistical Analysis		Comments
														Fisher's exact <i>p</i> -value	Cochran-Armitage trend test <i>p</i> -value	
				Lymphatic system	Adenoma + carcinoma	BaA	M	2,800	nmol	1	39	0.03				
				Lymphatic system	Adenoma + carcinoma	BaA	F	2,800	nmol	3	32	0.09				

1
2

Table C-4. Intraperitoneal bioassays: dose-response information for tumor multiplicity

Record number	Reference	Species	Exposure route	Target organ	Tumor type	PAH	Sex	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	Results of authors' statistical analysis (p-value)	Results of SRC statistical analysis (Fisher's exact p-value)	Mean number tumors/animal	SD of mean	Results of SRC statistical analysis (t-test p-value)	Comments
17560	Busby et al., 1989	Mice	Intra-peritoneal	Lung	Adenoma+adenocarcinoma	DMSO	M	0	µg (total)	13	91	0.14			0.15	0.38		Stats reported for combined M and F
				Lung	Adenoma+adenocarcinoma	DMSO	F	0	µg (total)	7	101	0.07			0.08	0.30		
				Lung	Adenoma+adenocarcinoma	BaP	M	59.5	µg (total)	13	28	0.46		<0.001	0.71	1.01	<0.001	
				Lung	Adenoma+adenocarcinoma	BaP	F	59.5	µg (total)	19	27	0.70		<0.001	1.19	1.09	<0.001	
				Lung	Adenoma+adenocarcinoma	Pyr	M	86.1	µg (total)	4	23	0.17		>0.05	0.17	0.38	>0.05	
				Lung	Adenoma+adenocarcinoma	Pyr	F	86.1	µg (total)	1	28	0.04		>0.05	0.04	0.21	>0.05	
				Lung	Adenoma+adenocarcinoma	Pyr	M	1,750	µg (total)	2	27	0.07		>0.05	0.07	0.26	>0.05	
				Lung	Adenoma+adenocarcinoma	Pyr	F	1,750	µg (total)	3	26	0.12		>0.05	0.12	0.31	>0.05	
				Lung	Adenoma+adenocarcinoma	FA	M	257.6	µg (total)	5	23	0.22		>0.05	0.22	0.43	>0.05	
				Lung	Adenoma+adenocarcinoma	FA	F	257.6	µg (total)	9	29	0.31		0.00165	0.41	0.70	<0.0001	
				Lung	Adenoma+adenocarcinoma	CH	M	6.3	µg (total)	2	27	0.07		>0.05	0.07	0.26	>0.05	
				Lung	Adenoma+adenocarcinoma	CH	F	6.3	µg (total)	3	29	0.10		>0.05	0.1	0.32	>0.05	
				Lung	Adenoma+adenocarcinoma	CH	M	210	µg (total)	3	20	0.15		>0.05	0.15	0.36	>0.05	
				Lung	Adenoma+adenocarcinoma	CH	F	210	µg (total)	0	29	0.00		>0.05	0	0.00	>0.05	
7510	LaVoie et al., 1994	Mice	Intra-peritoneal	Lung	Total	DMSO	M	0	µmol/mouse	5	29	0.17			0.17			Survived to 1 yr
				Lung	Total	DMSO	F	0	µmol/mouse	4	34	0.12			0.15			
				Lung	Total	BaP	M	1.1	µmol/mouse	24	32	0.75	<0.001		4.3			
				Lung	Total	BaP	F	1.1	µmol/mouse	17	20	0.85	<0.001		3.55			
				Lung	Total	FA	M	3.46	µmol/mouse	12	28	0.43	<0.05		0.64			

Table C-4. Intraperitoneal bioassays: dose-response information for tumor multiplicity

Record number	Reference	Species	Exposure route	Target organ	Tumor type	PAH	Sex	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	Results of authors' statistical analysis (p-value)	Results of SRC statistical analysis (Fisher's exact p-value)	Mean number tumors/animal	SD of mean	Results of SRC statistical analysis (t-test p-value)	Comments
				Lung	Total	FA	F	3.46	µmol/mouse	11	31	0.35	<0.05		0.35			
				Lung	Total	FA	M	17.3	µmol/mouse	11	17	0.65	<0.005		1.12			
				Lung	Total	FA	F	17.3	µmol/mouse	25	29	0.86	<0.001		2.45			
				Liver	Foci + adenoma + carcinoma	DMSO	M	0	µmol/mouse	5	29	0.17			0.41			
				Liver	Foci + adenoma + carcinoma	DMSO	F	0	µmol/mouse	2	34	0.06			0.06			Tumor count appears to be error in publication
				Liver	Foci + adenoma + carcinoma	BaP	M	1.1	µmol/mouse	27	32	0.84	<0.001		4.53			
				Liver	Foci + adenoma + carcinoma	BaP	F	1.1	µmol/mouse	2	20	0.10	>0.05		0.3			
				Liver	Foci + adenoma + carcinoma	FA	M	3.46	µmol/mouse	18	28	0.64	<0.001		1.86			
				Liver	Foci + adenoma + carcinoma	FA	F	3.46	µmol/mouse	0	31	0			0			
				Liver	Foci + adenoma + carcinoma	FA	M	17.3	µmol/mouse	17	17	1.00	<0.001		7.53			
				Liver	Foci + adenoma + carcinoma	FA	F	17.3	µmol/mouse	2	29	0.07			0.07			
22510	Wislocki et al., 1986	Mice	Intra-peritoneal	Liver	Adenoma + carcinoma	DMSO	M	0	nmol	2	28	0.07			0.07			Animals surviving through weaning
				Liver	Adenoma + carcinoma	DMSO	F	0	nmol	0	31	0			0			
				Liver	Adenoma + carcinoma	DMSO	M	0	nmol	5	45	0.11			0.11			This group started 10 wks after other groups
				Liver	Adenoma + carcinoma	DMSO	F	0	nmol	0	34	0			0			This group started 10 wks after other groups
				Liver	Adenoma + carcinoma	DMSO pooled	M	0	nmol	7	73	0.09			0.096			
				Liver	Adenoma + carcinoma	DMSO pooled	F	0	nmol	0	65	0			0			
				Liver	Adenoma + carcinoma	BaP	M	560	nmol	18	37	0.49	<0.05		1.46			

Table C-4. Intraperitoneal bioassays: dose-response information for tumor multiplicity

Record number	Reference	Species	Exposure route	Target organ	Tumor type	PAH	Sex	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	Results of authors' statistical analysis (p-value)	Results of SRC statistical analysis (Fisher's exact p-value)	Mean number tumors/animal	SD of mean	Results of SRC statistical analysis (t-test p-value)	Comments
				Liver	Adenoma + carcinoma	BaP	F	560	nmol	0	27	0	>0.05		0			
				Liver	Adenoma + carcinoma	Pyr	M	200	nmol	0	29	0	>0.05		0			
				Liver	Adenoma + carcinoma	Pyr	F	200	nmol	0	31	0	>0.05		0			
				Liver	Adenoma + carcinoma	Pyr	M	700	nmol	3	25	0.12	>0.05		0.12			This group started 10 wks after other groups
				Liver	Adenoma + carcinoma	Pyr	F	700	nmol	0	49	0	>0.05		0			This group started 10 wks after other groups
				Liver	Adenoma + carcinoma	Pyr	M	2,800	nmol	3	14	0.21	>0.05		0.21			
				Liver	Adenoma + carcinoma	Pyr	F	2,800	nmol	0	18	0	>0.05		0			
				Liver	Adenoma + carcinoma	CH	M	700	nmol	10	35	0.29	<0.05		0.86			This group started 10 wks after other groups
				Liver	Adenoma + carcinoma	CH	F	700	nmol	0	33	0	>0.05		0			This group started 10 wks after other groups
				Liver	Adenoma + carcinoma	CH	M	2,800	nmol	14	34	0.41	<0.05		1.03			
				Liver	Adenoma + carcinoma	CH	F	2,800	nmol	0	24	0	>0.05		0			
				Liver	Adenoma + carcinoma	BaA	M	2,800	nmol	31	39	0.79	<0.05		2.38			
				Liver	Adenoma + carcinoma	BaA	F	2,800	nmol	0	32	0	>0.05		0			
13610	Busby et al., 1984	Mice	Intra-peritoneal	Lung	Adenoma + carcinoma	DMSO	M	0	mg (total)	1	27	0.04			0.04	0.21		
				Lung	Adenoma + carcinoma	DMSO	F	0	mg (total)	4	28	0.14			0.14	0.37		
				Lung	Adenoma + carcinoma	BaP	M	0.28	mg (total)	24	25	0.96		<0.001	4.32	3.5	<0.001	
				Lung	Adenoma + carcinoma	BaP	F	0.28	mg (total)	25	27	0.93		<0.001	3.7	3.10	<0.001	
				Lung	Adenoma + carcinoma	BaP	M	1.4	mg (total)	16	20	0.80		<0.001	10.15	13.0	<0.001	No model fit
				Lung	Adenoma + carcinoma	BaP	F	1.4	mg (total)	21	24	0.88		<0.001	4.25	4.70	<0.001	No model fit
				Lung	Adenoma + carcinoma	FA	M	0.7	mg (total)	7	31	0.23		0.0412	0.29	0.84	>0.05	
				Lung	Adenoma + carcinoma	FA	F	0.7	mg (total)	3	20	0.15		>0.05	0.15	0.49	>0.05	

Table C-4. Intraperitoneal bioassays: dose-response information for tumor multiplicity

Record number	Reference	Species	Exposure route	Target organ	Tumor type	PAH	Sex	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	Results of authors' statistical analysis (p-value)	Results of SRC statistical analysis (Fisher's exact p-value)	Mean number tumors/animal	SD of mean	Results of SRC statistical analysis (t-test p-value)	Comments	
				Lung	Adenoma + carcinoma	FA	M	3.5	mg (total)	20	27	0.74		<0.001	1.52	1.66	<0.001	Nonconstant variance	
				Lung	Adenoma + carcinoma	FA	F	3.5	mg (total)	8	21	0.38		>0.05	0.52	0.82	0.0343	NS incidence; nonconstant variance	
24590	Nesnow et al., 1998b	Mice	Intra-peritoneal	Lung	NS	Control	M	0	mg/kg	6	20	0.30			0.53	0.72		Pooled controls from data provided by Nesnow	
				Lung	NS	BaP	M	5	mg/kg	6	20	0.30		>0.05	0.45	0.80	>0.05		
				Lung	NS	BaP	M	10	mg/kg	7	17	0.41		>0.05	0.53	0.78	>0.05		
				Lung	NS	BaP	M	50	mg/kg	19	19	1.00		<0.001	4.37	2.74	<0.001		
				Lung	NS	BaP	M	100	mg/kg	16	16	1.00		0.0018	12.75	4.28	<0.001		
				Lung	NS	BaP	M	200	mg/kg	24	24	1.00		<0.001	32.96	10.23	<0.001		
				Lung	NS	BbF	M	10	mg/kg	9	18	0.50		>0.05	0.67	0.75	>0.05		
				Lung	NS	BbF	M	50	mg/kg	16	20	0.80		<0.05	2.00	1.82	0.0022		
				Lung	NS	BbF	M	100	mg/kg	20	20	1.00		<0.001	5.30	3.21	<0.001		
				Lung	NS	BbF	M	200	mg/kg	19	19	1.00		<0.001	6.95	3.52	<0.001		
				Lung	NS	CPcdP	M	10	mg/kg	8	20	0.40		>0.05	0.55	0.80	>0.05		
				Lung	NS	CPcdP	M	50	mg/kg	20	20	1.00		<0.001	4.75	2.12	<0.001		
				Lung	NS	CPcdP	M	100	mg/kg	19	19	1.00		<0.001	32.21	15.15	<0.001		
				Lung	NS	CPcdP	M	200	mg/kg	19	19	1.00		<0.001	97.68	28.68	<0.001		
				Lung	NS	DBahA	M	1.25	mg/kg	12	18	0.67		<0.05	1.44	1.46	0.0229		
				Lung	NS	DBahA	M	2.5	mg/kg	18	19	0.95		0.0053	3.05	1.90	<0.001		
				Lung	NS	DBahA	M	5	mg/kg	20	20	1.00		<0.001	13.05	5.99	<0.001		
				Lung	NS	DBahA	M	10	mg/kg	19	19	1.00		<0.001	32.16	10.78	<0.001		
24590	Nesnow et al., 1998b	Mice	Intra-peritoneal	Lung	NS	Control	M	0	mg/kg	15	30	0.50			0.67	0.80			
				Lung	NS	DBaP	M	0.3	mg/kg	13	33	0.39		>0.05	0.42	0.56	>0.05		
				Lung	NS	DBaP	M	1.5	mg/kg	33	34	0.97		<0.001	4.32	2.86	<0.001		
				Lung	NS	DBaP	M	3	mg/kg	35	35	1.00		<0.001	7.49	3.79	<0.001		
				Lung	NS	DBaP	M	6	mg/kg	30	30	1.00		<0.001	16.10	7.26	<0.001		
11190	Mass et al., 1993	Mice	Intra-peritoneal	Lung	NS	Control	M	0	mg/kg	19	34	0.56			0.85	0.9			
					NS	BaP	M	20	mg/kg	10	16	0.63		>0.05	1	1	>0.05		
					NS	BaP	M	50	mg/kg	15	16	0.94		0.0065	3.9	2.9	<0.001		
					NS	BaP	M	100	mg/kg	14	14	1.00		0.0017	5.9	3.3	<0.001		
					NS	BjAC	M	20	mg/kg	12	12	1.00		0.0036	60.3	14.6	<0.001		
					NS	BjAC	M	50	mg/kg	13	13	1.00		0.0025	140.6	21.5	<0.001		
					NS	BjAC	M	100	mg/kg	14	14	1.00		0.0017	97.6	28.2	<0.001		
24801	Weyand et al., 2004	Mice	Intra-peritoneal	Lung	Adenoma	Tri-caprylin	F	0	mg/kg						0.6	0.75			
				Lung	Adenoma	BaP	F	100	mg/kg	14	29	0.48							
				Lung	Adenoma	BaP	F	100	mg/kg	27	30	0.9		0.0005	6.7	5.26	<0.01		
				Lung	Adenoma	BcFE	F	100	mg/kg	26	28	0.92		0.0002	4	2.8	<0.01		

Table C-5. Lung implantation bioassays: dose-response information for incidence data

Record number	Reference	Species	Target organ	Tumor type	PAH	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	SRC statistical analysis		Comments
											Fisher's exact <i>p</i> -value	Cochran-Armitage trend test <i>p</i> -value	
17940	Deutsch-Wenzel et al., 1983	Rat	Lung	Epidermoid carcinoma	Untreated control	0	mg	0	35	0.00			
					Vehicle control	0	mg	0	35	0.00			
					BaP	0.1	mg	4	35	0.11	5.70×10^{-2}		
					BaP	0.3	mg	21	35	0.60	6.02×10^{-9}		
					BaP	1	mg	33	35	0.94	5.93×10^{-18}	1.57×10^{-17}	
					BbF	0.1	mg	0	35	0.00			
					BbF	0.3	mg	1	35	0.03	5×10^{-1}		
					BbF	1	mg	9	35	0.26	1×10^{-3}	5.12×10^{-7}	
					BeP	0.2	mg	0	35	0.00			
					BeP	1	mg	0	30	0.00			
					BeP	5	mg	1	35	0.03	5×10^{-1}	9.49×10^{-2}	
					BjF	0.2	mg	1	35	0.03	5×10^{-1}		
					BjF	1	mg	3	35	0.09	1.2×10^{-1}		
					BjF	5	mg	18	35	0.51	1.96×10^{-7}	1.28×10^{-11}	
					BkF	0.16	mg	0	35	0.00			
					BkF	0.83	mg	3	31	0.10	1×10^{-1}		
					BkF	4.15	mg	12	27	0.44	8.05×10^{-6}	1.03×10^{-9}	
					IP	0.16	mg	3	35	0.09	1.20×10^{-1}		
					IP	0.83	mg	8	35	0.23	2×10^{-3}		
					IP	4.15	mg	21	35	0.60	6.02×10^{-9}	2.09×10^{-10}	
					AA	0.16	mg	1	35	0.03	5×10^{-1}		
					AA	0.83	mg	19	35	0.54	6.4×10^{-8}	1.13×10^{-10}	
					BghiP	0.16	mg	0	35	0.00			
					BghiP	0.83	mg	1	35	0.03	1.2×10^{-1}		
					BghiP	4.15	mg	4	34	0.12	5.4×10^{-2}	2.47×10^{-3}	
			Lung	Pleomorphic sarcoma	Untreated control	0	mg	0	35	0.00			
					Vehicle control	0	mg	0	35	0.00			

Table C-5. Lung implantation bioassays: dose-response information for incidence data

Record number	Reference	Species	Target organ	Tumor type	PAH	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	SRC statistical analysis		Comments
											Fisher's exact <i>p</i> -value	Cochran-Armitage trend test <i>p</i> -value	
					BaP	0.1	mg	6	35	0.17	1.2×10^{-2}		
					BaP	0.3	mg	2	35	0.06	2.5×10^{-1}		
					BaP	1	mg	0	35	0.00		1.36×10^{-1}	
					BbF	0.1	mg	1	35	0.03	1.2×10^{-1}		
					BbF	0.3	mg	2	35	0.06	2.5×10^{-1}		
					BbF	1	mg	4	35	0.11	$6. \times 10^{-2}$	7.55×10^{-3}	
					BeP	0.2	mg	0	35	0.00			
					BeP	1	mg	1	30	0.03			
					BeP	5	mg	0	35	0.00			
					BjF	0.2	mg	0	35	0.00			
					BjF	1	mg	0	35	0.00			
					BjF	5	mg	0	35	0.00			
					BkF	0.16	mg	0	35	0.00			
					BkF	0.83	mg	0	31	0.00			
					BkF	4.15	mg	0	27	0.00			
					IP	0.16	mg	1	35	0.03	1.2×10^{-1}		
					IP	0.83	mg	0	35	0.00			
					IP	4.15	mg	0	35	0.00			
					AA	0.16	mg	0	35	0.00			
					AA	0.83	mg	0	35	0.00			
					BghiP	0.16	mg	0	35	0.00			
					BghiP	0.83	mg	0	35	0.00			
					BghiP	4.15	mg	0	34	0.00			
			Lung	Carcinoma+sarcoma	Untreated control	0	mg	0	35	0.00			
					Vehicle control	0	mg	0	35	0.00			
					BaP	0.1	mg	10	35	0.29	4.63×10^{-4}		
					BaP	0.3	mg	23	35	0.66	4.7×10^{-10}		
					BaP	1	mg	33	35	0.94	5.9×10^{-19}	3.66×10^{-9}	

Table C-5. Lung implantation bioassays: dose-response information for incidence data

Record number	Reference	Species	Target organ	Tumor type	PAH	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	SRC statistical analysis		Comments
											Fisher's exact <i>p</i> -value	Cochran-Armitage trend test <i>p</i> -value	
					BbF	0.1	mg	1	35	0.03	1.2×10^{-1}		
					BbF	0.3	mg	3	35	0.09	1.2×10^{-1}		
					BbF	1	mg	13	35	0.37	3.1×10^{-5}	9.63×10^{-8}	
					BeP	0.2	mg	0	35	0.00			
					BeP	1	mg	1	30	0.03			
					BeP	5	mg	1	35	0.03	1.2×10^{-1}	3.23×10^{-1}	
					BjF	0.2	mg	1	35	0.03	1.2×10^{-1}		
					BjF	1	mg	3	35	0.09	1.20×10^{-1}		
					BjF	5	mg	18	35	0.51	1.96×10^{-7}	1.28×10^{-11}	
					BkF	0.16	mg	0	35	0.00			
					BkF	0.83	mg	3	31	0.10	1×10^{-1}		
					BkF	4.15	mg	12	27	0.44	8.05×10^{-4}	1.03×10^{-9}	
					IP	0.16	mg	4	35	0.11	6×10^{-2}		
					IP	0.83	mg	8	35	0.23	2×10^{-3}		
					IP	4.15	mg	21	35	0.60	6.02×10^{-9}	7.56×10^{-10}	
					AA	0.16	mg	1	35	0.03			
					AA	0.83	mg	19	35	0.54	6.4×10^{-8}	1.13×10^{-10}	
					BghiP	0.16	mg	0	35	0.00			
					BghiP	0.83	mg	1	35	0.03			
					BghiP	4.15	mg	4	34	0.12	5.4×10^{-2}	2.47×10^{-3}	
22000	Wenzel-Hartung et al., 1990	Rat	Lung	Carcinoma	Untreated control	0	mg/animal	0	35	0.00			ED ₁₀ , relative potencies reported
					Vehicle control	0	mg/animal	0	35	0.00			
					BaP	0.03	mg/animal	3	35	0.09	1.2×10^{-1}		
					BaP	0.1	mg/animal	11	35	0.31	1.93×10^{-4}		
					BaP	0.3	mg/animal	27	35	0.77	$1.29E \times 10^{-12}$	8.85×10^{-15}	

Table C-5. Lung implantation bioassays: dose-response information for incidence data

Record number	Reference	Species	Target organ	Tumor type	PAH	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	SRC statistical analysis		Comments
											Fisher's exact <i>p</i> -value	Cochran-Armitage trend test <i>p</i> -value	
					PH	1	mg/animal	0	35	0.00			
					PH	3	mg/animal	0	35	0.00			
					PH	10	mg/animal	1	35	0.03	5×10^{-1}	1	
					CH	1	mg/animal	5	35	0.14	2.7×10^{-2}		
					CH	3	mg/animal	10	35	0.29	4.63×10^{-4}	7.96×10^{-4}	
					DBahA	0.1	mg/animal	20	35	0.57	2.01×10^{-8}		

1
2

1

Table C-6. Oral bioassays: dose-response information for incidence data

Record number	Reference	Species	Target organ	Tumor type	PAH	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	SRC statistical analysis		Comments
											Fisher's exact <i>p</i> -value	Cochran-Armitage trend test <i>p</i> -value	
24801	Weyand et al., 2004	Mouse	Lung	Adenoma	Control	0	µg/mouse/day	7	29	0.24			
					BaP	230	µg/mouse/day	21	27	0.77	>0.0001		
					BcFE	13.6	µg/mouse/day	13	28	0.46	0.0684		
					BcFE	197	µg/mouse/day	29	29	1	>0.0001		
			Fore-stomach	Squamous cell carcinoma	Control	0	µg/mouse/day	0	29	0			
					BaP	230	µg/mouse/day	10	27	0.36			
					BcFE	13.6	µg/mouse/day	0	28	0			
					BcFE	197	µg/mouse/day	0	29	0			

2

Table C-7. Oral bioassays: dose-response information for tumor multiplicity

Reference	Species	Exposure route	Target organ	Tumor type	PAH	Sex	Dose	Dose units	Number of animals with tumors	Number of animals in group	% Tumor-bearing animals	Results of authors' statistical analysis (<i>p</i> -value)	Results of SRC statistical analysis (Fisher's exact <i>p</i> -value)	Mean number tumors/animal	SD of mean	Results of SRC statistical analysis (t-test <i>p</i> -value)	Comments
24801	Weyand et al., 2004	Mouse	Lung	Adenoma	Control	F	0	µg/mouse/day	7	29	0.24			0.31	0.59		
					BaP	F	230	µg/mouse/day	21	27	0.77		>0.0001	1.4	1.14	>0.0001	
					BcFE	F	13.6	µg/mouse/day	13	28	0.46		0.0684	0.57	0.69	0.13	
					BcFE	F	197	µg/mouse/day	29	29	1		>0.0001	46	15.1	>0.0001	

Table C-8. In vitro bacterial mutagenicity: data use

Record number	Reference	Data source	Data points	Basis for RPF approach	Comments
17030	Andrews et al., 1978	Figure 1	Dose (μg) and number of revertant colonies for DBacA, DBajA, DBahA, AA, BghiP, BeP, BaP	Point estimate	TA100 with Ar S9
23830	Baker et al., 1980	Table 2	Use data for guinea pig-MC S9 only (column D); dose in $\mu\text{g}/\text{plate}$ and number of revertant colonies; BaP, DBaiP, BaA, DBacA, DBahA	Point estimate Table 2	TA100 with guinea pig-MC S9; Table 1 data not used, different S9 mix used for each of three experiments
23660	Bartsch et al., 1980	Appendix table	Use data for BaA and BaP; dose in $\mu\text{mol}/\text{plate}$ and mutagenic activity in revertants/ μmol	Point estimate	TA100 rat MC S9
17380	Bos et al., 1988	Table 1	Use TA100 strain only; dose ($\mu\text{g}/\text{plate}$) and number of revertant colonies/plate for PH, Pyr, BaP	Derive point estimate for BaP (use PH control as background); continuous model PH and Pyr using the BaP response as the BMR	TA100 with rat Ar S9
17590	Carver et al., 1986	Figure 1	Use curves for BaP, BaA, BghiF, and Pery; use 400 μL S9 per plate (last data point on x-axis); each curve is different dose in $\mu\text{g}/\text{plate}$, use hamster data; revertants per plate is y-axis	Point estimate; use highest dose in hamster, except for perylene (use 10 $\mu\text{g}/\text{plate}$); this is maximal response in hamsters	TA100 with hamster Ar S9; multidose data but not SD was reported
17630	Cavalieri et al., 1981a	Figure 1	Dose-response curves for BaP, CPcdP (CPEP in figure), and ACEP (CPAP in figure); dose as μM , response as mutant fraction $\times 105$	Model as quantal data (mutant fraction reported)	TM677 with Ar S9
9620	Chang et al., 2002	Figure 7	Dose-response curves for BghiF, BcPH, and BaP; dose ($\mu\text{g}/\text{plate}$) and revertants/plate	Point estimate; use 5 $\mu\text{g}/\text{plate}$ dose for BghiF and BaP; use 10 $\mu\text{g}/\text{plate}$ for BcPH	TA100 with rat Ar S9; SD not available from graph (reported for some data points, but not all)
24030	De Flora et al., 1984	Table 2	Table provides potency estimates as revertants/nmol for BaA, Pery, BaP, and BeP	Calculate the RPF ratio using the potency estimates provided	Determine strain used to calculate potencies; rat Ar S9
18050	Eisenstadt and Gold, 1978	Figure 2B	Use TA100 data for BaP and CPcdP (open circles); dose is 1 μg for CPcdP and 2 μg for BaP (legend); use the same S9 concentration (20 $\mu\text{L}/\text{plate}$)	Point estimate; single point data (20 μL S9/plate)	TA100 with rat Ar S9; μL S9 that maximizes the BaP response does not produce maximal response for CPcdP

Table C-8. In vitro bacterial mutagenicity: data use

Record number	Reference	Data source	Data points	Basis for RPF approach	Comments
18180	Florin et al., 1980	Table III	Use TA100 data for BaA, CH, and BaP, use TA98 data for Pery, CO, and BaP; dose is indicated as optimal dose ($\mu\text{mol}/\text{plate}$) and number revertants/plate	Point estimate; please note that reported response includes subtraction of spontaneous revertants (control); need to use formula for added risk; make sure to flag in comments	Note that data for both TA100 and TA98 strains were used; BaP results were provided for each; rat MC S9
24080	Gibson et al., 1978	Table 1 (BaP) Table 3 (PAHs)	Use data for TA98; in Table 1 use Expt. No.1 for BaP; in Table 3 use data for DBahA, Tphen, BaA, BghiP, CH, FE, Pyr; dose as $\mu\text{g}/\text{plate}$, response as increase in revertants	Point estimate; use the dose associated with the maximum response (if reported as a range, do not use); controls were reported as negative (no mutagenic or toxic response)	TA98 with non-enzymatic induction (gamma irradiation); multidose data but not SD reported
14080	Gold and Eisenstadt, 1980	Table 2	Use data for 3-MC induction at 50 μL S9/plate; dose is 4 nmol for BaP and CPcdP, results as revertants/plate	Point estimate	TA100 using 50 μL of rat MC S9; important to note that maximal response for CPcdP occurred at much lower dose of S9 (5 $\mu\text{L}/\text{plate}$)
18650	Hermann, 1981	Table 1	Table provides potency estimates as revertants/nmol for BbA, BaA, CH, FA, Tphen, BeP, DBacA, DBahA, BbF, Pery, DBalP, DBaiP, AA, CO; potency of BaP in legend as 100 revertants/nmol	Calculate the RPF ratio using the potency estimates provided	TA98 with rat Ar S9; potency estimates were calculated from the linear portion of the dose-response curve
10670	Johnsen et al., 1997	Figure 2	Use data for PCB microsomes for BaP, BjAC, BIAC; dose as $\mu\text{g}/\text{plate}$, response as revertants	Model to derive BMDsd1; need to extract SDs from graph; control response is 113 ± 9 revertants per plate (see legend); add control response to each response for modeling (it was subtracted prior to graphing)	TA98 with PCB microsomes
19000	Kaden et al., 1979	Table 1	RPFs calculated for AN, ANL, Pyr, BbFE, CPcdP, BaA, CH, Tphen, FA, BeP, Pery, BghiP, AA, DBacA, DBahA, DBbeF	Not applicable	TM677 with Ar S9 and PB S9
24680	Lafleur et al., 1993	Figures 3 and 4	Use dose-response curves for BaP, BghiF, CPcdP, CPhiACEA (CPAA), ACEA (AA), CPhiAPA (CPAP), APA (AP); dose as $\mu\text{g}/\text{mL}$, response as mutant fraction ($\times 10^5$)	Model as quantal data (mutant fraction reported)	Forward mutation to 8-azaguanine resistance in TM677 with rat AR S9
19320	LaVoie et al., 1979	Table VI	Use data for TA98 for BaP, BeP, and Pery; 10 μg dose and response as revertants/plate	Point estimate; use 20 μg for BaP; 10 μg for BeP; and 20 μg for Pery	TA98 with rat Ar S9; for BeP and Pery the maximal response was in TA100

Table C-8. In vitro bacterial mutagenicity: data use

Record number	Reference	Data source	Data points	Basis for RPF approach	Comments
23650	McCann et al., 1975	Table 1	Table provides potency estimates as revertants/nmol for DBaiP, BaP, BeP, DBacA, DBahA, CH, BaA	Calculate the RPF ratio using the potency estimates provided	Multiple strains, rat Ar S9
20220	Pahlman and Pelkonen, 1987	Table 1	Use data for rat-MC induced (last column); potency estimates are provided as revertants/nmol for BaA, CH, Tphen, DBacA, DBahA	Calculate the RPF ratio using the potency estimates provided	TA100 with rat MC S9
20450	Phillipson and Ioannides, 1989	Figures 2 and 3	Use the curve for hamster S9 (open triangles); data for BaP, DBaiP, BaA, and DBahA, dose as µg/plate, revertants/plate	Point estimate; use 10 µg/plate for BaP, DBahA; 20 µg/plate BaA, DBaiP	TA100 with hamster S9; multidose data but not SD reported
21000	Sakai et al., 1985	Table 3	Use data for TA97 +S9 for FE, AC, PH, FA, Ch, Pyr, BaP, BeP, Pery, BghiP, CO; dose µg, response as revertants per plate	Point estimate; use 10 µg for AC, PH, FA, BaP, BeP; use 5 µg for FE; use 20 µg for CH, Pyr, BghiP; use 4 µg for Pery; use 100 µg for CO	TA97 with rat Ar S9; multidose data but not SD reported
11860	Sangaiah et al., 1983	Figure 2	Use data for BjAC and BaP; dose as µg/plate, response as revertants/plate	Point estimate; use 10 µg/plate for BjAC; use 6 µg/plate for BaP	TA98 with rat Ar S9; multidose data but not SD was reported
21360	Simmon, 1979a	Table 1	Use data for TA100 for BaA, BaP, BeP; dose as µg, response as revertants/plate after subtracting background	Point estimate	TA100 with rat Ar S9
21640	Teranishi et al., 1975	Table I and Figure 3	Use data for TA1538 for DBaiP and BaP; use data in Figure 3 for TA 1538, PB and DBahA-induced S9 (open circles) for DBaeP	Point estimate	TA1538 with rat PB S9 for DBaiP; TA1538 with PB and DBahA S9 for DBaeP
16180	Utesch et al., 1987	Figures 2 and 3	Use data for homogenized hepatocytes (open circles) for BaA and BaP; dose as µg/plate, response as revertants/plates	Point estimate; use 12.5 µg/plate for BaP; use 25 µg/plate for BaA	TA100 with homogenized hepatocytes from Ar-treated rats; multidose data but not SD reported
16440	Wood et al., 1980	Chart 3A	Use dose-response curves for BaP and CPcdP; dose as nmol, response as revertants/plate	Point estimate; use 15 nmol for BaP and CPcdP	TA98 with purified microsomal P450; multidose data but not SD reported

Table C-9. In vitro bacterial mutagenicity: dose-response data

Record number	Reference	Cell type	Activation system	PAH	Dose	Dose units	Response	Response units	n	Units	% Response	SD	SE	Comments
17030	Andrews et al., 1978	TA100	ArS9	Control	0	µg	150	Revertant colonies						
				BaP	250	µg	1,681	Revertant colonies						
				DBacA	10	µg	2,957	Revertant colonies						
				DBajA	10	µg	843	Revertant colonies						
				DBahA	25	µg	617	Revertant colonies						
				AA	250	µg	1,796	Revertant colonies						
				BghiP	100	µg	793	Revertant colonies						
				BeP	1,000	µg	643	Revertant colonies						
23830	Baker et al., 1980	TA100	Guinea pig-MC	Control	0	µg/plate	134	Revertant colonies				18		
				BaP	2.5	µg/plate	1,278	Revertant colonies	10			97		
				DBaiP	5	µg/plate	737	Revertant colonies	10			73		
				BaA	10	µg/plate	947	Revertant colonies	10			47		
				DBacA	2.5	µg/plate	1,738	Revertant colonies	10			88		
				DBahA	5	µg/plate	1,331	Revertant colonies	10			98		
23660	Bartsch et al., 1980	TA100	Rat MC S9	BaP	0.027	µmol/plate	29,000	Revertants/plate						Control response subtracted
				BaA	0.067	µmol/plate	6,000	Revertants/plate						Control response subtracted
17380	Bos et al., 1988	TA100	Rat ArS9	BaP	7.5	µg/plate	824	Revertants/plate	3	Replicates		21	12	
				Control	0	µg/plate	85	Revertants/plate	3	Replicates		12	7	

Table C-9. In vitro bacterial mutagenicity: dose-response data

Record number	Reference	Cell type	Activation system	PAH	Dose	Dose units	Response	Response units	n	Units	% Response	SD	SE	Comments
				PH	1	µg/plate	108	Revertants/plate	3	Replicates		10	6	
				PH	5	µg/plate	167	Revertants/plate	3	Replicates		5	3	
				PH	25	µg/plate	240	Revertants/plate	3	Replicates		10	6	
				Control	0	µg/plate	86	Revertants/plate	3	Replicates		7	4	
				Pyr	1	µg/plate	93	Revertants/plate	3	Replicates		9	5	
				Pyr	5	µg/plate	164	Revertants/plate	3	Replicates		23	13	
				Pyr	25	µg/plate	279	Revertants/plate	3	Replicates		10	6	
17590	Carver et al., 1986	TA100	Hamster ArS9	Control	0	µg/plate	140	Revertants/plate						Control curves difficult to digitize; control value estimated from BaP graph and used for all
				BaP	1	µg/plate	141	Revertants/plate						Continuous data, no SD
				BaP	10	µg/plate	482	Revertants/plate						
				BaP	50	µg/plate	1,035	Revertants/plate						
				BaA	15	µg/plate	346	Revertants/plate						
				BaA	40	µg/plate	892	Revertants/plate						
				BaA	50	µg/plate	1,263	Revertants/plate						
				BghiF	10	µg/plate	333	Revertants/plate						
				BghiF	25	µg/plate	727	Revertants/plate						

Table C-9. In vitro bacterial mutagenicity: dose-response data

Record number	Reference	Cell type	Activation system	PAH	Dose	Dose units	Response	Response units	n	Units	% Response	SD	SE	Comments
				BghiF	50	µg/plate	985	Revertants/plate						
				Perylene	5	µg/plate	195	Revertants/plate						
				Perylene	10	µg/plate	993	Revertants/plate						
				Perylene	15	µg/plate	922	Revertants/plate						
17630	Cavalieri et al., 1981a	TM677	Ar S9	Control	0	µM	5	Mutants	1 × 10 ⁵	Survivors	0.000050			Control value estimated
				BaP	10	µM	15	Mutants	1 × 10 ⁵	Survivors	0.000150			
				BaP	20	µM	26	Mutants	1 × 10 ⁵	Survivors	0.000256			
				BaP	40	µM	84	Mutants	1 × 10 ⁵	Survivors	0.000839			
				BaP	60	µM	131	Mutants	1 × 10 ⁵	Survivors	0.001308			
				CPcdP	20	µM	34	Mutants	1 × 10 ⁵	Survivors	0.000337			
				CPcdP	40	µM	133	Mutants	1 × 10 ⁵	Survivors	0.001330			
				ACEP	10	µM	11	Mutants	1 × 10 ⁵	Survivors	0.000110			
				ACEP	40	µM	25	Mutants	1 × 10 ⁵	Survivors	0.000248			
				ACEP	120	µM	55	Mutants	1 × 10 ⁵	Survivors	0.000551			
9620	Chang et al., 2002	TA100	Rat ArS9	Control	0	µg/plate	326	Revertants/plate						SD not consistently plotted; extracted only point estimate data
				BaP	5	µg/plate	2,543	Revertants/plate						
				BghiF	5	µg/plate	1,630	Revertants/plate						

Table C-9. In vitro bacterial mutagenicity: dose-response data

Record number	Reference	Cell type	Activation system	PAH	Dose	Dose units	Response	Response units	n	Units	% Response	SD	SE	Comments
				BcPH	10	µg/plate	1,043	Revertants/plate						
24030	De Flora et al., 1984	Rat AR S9		BaP			185	Revertants/nmol (potency)						
				BaA			12	Revertants/nmol (potency)						
				Pery			21	Revertants/nmol (potency)						
				BeP			1.6	Revertants/nmol (potency)						
18050	Eisenstadt and Gold, 1978	TA100	Rat ArS9	BaP	2	µg	1,705	Revertants/plate						Background subtracted from data reported
				CPcdP	1	µg	134	Revertants/plate						
18180	Florin et al., 1980	TA100	Rat MC S9	BaP	0.0030	µmol/plate	255	Revertants/plate						Background subtracted from data reported
		TA100		BaA	0.10	µmol/plate	326	Revertants/plate						Only peak response reported
		TA100		CH	0.0050	µmol/plate	196	Revertants/plate						
		TA98		BaP	0.0030	µmol/plate	235	Revertants/plate						
		TA98		Pery	0.025	µmol/plate	91	Revertants/plate						
		TA98		CO	0.070	µmol/plate	82	Revertants/plate						
24080	Gibson et al., 1978	TA98	[⁶⁰ Co] gamma radiation, for 7 d (2.5 × 10 ⁷ rad)	Control	0	µg/plate	0	Increase in revertants						Continuous data, no SD

Table C-9. In vitro bacterial mutagenicity: dose-response data

Record number	Reference	Cell type	Activation system	PAH	Dose	Dose units	Response	Response units	n	Units	% Response	SD	SE	Comments
				BaP	10	µg/plate	1.5	Increase in revertants						
				BaP	20	µg/plate	3	Increase in revertants						
				BaP	50	µg/plate	10	Increase in revertants						
				BaP	100	µg/plate	15	Increase in revertants						
				BaP	200	µg/plate	21	Increase in revertants						
				BaP	300	µg/plate	35	Increase in revertants						
				BaA	150	µg/plate	1.8	Increase in revertants						
				BaA	250	µg/plate	6.4	Increase in revertants						
				BghiP	400	µg/plate	4.2	Increase in revertants						
				CH	500	µg/plate	6.1	Increase in revertants						
				CH	1,000	µg/plate	6.7	Increase in revertants						
				FE	200	µg/plate	1.1	Increase in revertants						
				FE	360	µg/plate	2.2	Increase in revertants						
				Pyr	160	µg/plate	28	Increase in revertants						
14080	Gold and Eisenstadt, 1980	TA100	50 µL rat MC S9	BaP	4	nmol	1,103	Revertants/plate						Background subtracted from data reported
				CPcdP	4	nmol	281	Revertants/plate						
18650	Hermann, 1981	TA98	Rat Ar S9	BaP			100	Revertants/nmol (potency)						

Table C-9. In vitro bacterial mutagenicity: dose-response data

Record number	Reference	Cell type	Activation system	PAH	Dose	Dose units	Response	Response units	n	Units	% Response	SD	SE	Comments
				BbA			8	Revertants/nmol (potency)						
				BaA			4	Revertants/nmol (potency)						
				CH			2	Revertants/nmol (potency)						
				FA			3	Revertants/nmol (potency)						
				Tphen			13	Revertants/nmol (potency)						
				BeP			15	Revertants/nmol (potency)						
				DBacA			42	Revertants/nmol (potency)						
				DBahA			8	Revertants/nmol (potency)						
				BbF			15	Revertants/nmol (potency)						
				Pery			31	Revertants/nmol (potency)						
				DBalP			21	Revertants/nmol (potency)						
				DBaiP			38	Revertants/nmol (potency)						
				AA			62	Revertants/nmol (potency)						

Table C-9. In vitro bacterial mutagenicity: dose-response data

Record number	Reference	Cell type	Activation system	PAH	Dose	Dose units	Response	Response units	n	Units	% Response	SD	SE	Comments
				CO			60	Revertants/nmol (potency)						
10670	Johansen et al., 1997	TA98	PCB micro-somes	Control	0	µg/plate	113	Revertants/plate	3			8.54		Control response added back to each response for modeling
				BaP	10	µg/plate	128	Revertants/plate	3			3.66		
				BaP	20	µg/plate	123	Revertants/plate	3			13.41		
				BjAC	10	µg/plate	192	Revertants/plate	3			10.98		
				BjAC	20	µg/plate	213	Revertants/plate	3			9.76		
				BIAC	10	µg/plate	204	Revertants/plate	3			13.41		
				BIAC	20	µg/plate	207	Revertants/plate	3			43.90		
19000	Kaden et al., 1979	TM677	ArS9 and PB S9	BaP			1	RPF						Mutagenic activity relative to that of the 80 µmol BaP-positive control performed simultaneously with test compound
				AN	NA		0.010	RPF						
				ANL	NA		0.070	RPF						
				Pyr	NA		0.070	RPF						
				BbFE	NA		0.080	RPF						
				CPcdP	NA		1.5	RPF						
				BaA	NA		0.14	RPF						
				CH	NA		0.20	RPF						
				Tphen	NA		0.070	RPF						
				FA	NA		1.0	RPF						
				BeP	NA		0.11	RPF						

Table C-9. In vitro bacterial mutagenicity: dose-response data

Record number	Reference	Cell type	Activation system	PAH	Dose	Dose units	Response	Response units	n	Units	% Response	SD	SE	Comments
				Pery	NA		6	RPF						
				BghiP	NA		0.080	RPF						
				AA	NA		0.080	RPF						
				DBacA	NA		0.77	RPF						
				DBahA	NA		0.080	RPF						
				DBbeF	NA		0.88	RPF						
24680	Lafleur et al., 1993	TM677	Rat AR S9	BaP	0	µg/mL	7	Mutants	100,000	Survivors	0.000070			
				BaP	0.5	µg/mL	8	Mutants	100,000	Survivors	0.000080			
				BaP	1	µg/mL	10	Mutants	100,000	Survivors	0.000101			
				BaP	2	µg/mL	18	Mutants	100,000	Survivors	0.000175			
				BaP	4	µg/mL	22	Mutants	100,000	Survivors	0.000220			
				BaP	8	µg/mL	33	Mutants	100,000	Survivors	0.000327			
				BghiF	0	µg/mL	11	Mutants	100,000	Survivors	0.00011			
				BghiF	1	µg/mL	10	Mutants	100,000	Survivors	0.00010			
				BghiF	3	µg/mL	14	Mutants	100,000	Survivors	0.00014			
				BghiF	10	µg/mL	55	Mutants	100,000	Survivors	0.00055			
				CPcdP	0	µg/mL	12	Mutants	100,000	Survivors	0.000120			
				CPcdP	0.5	µg/mL	15	Mutants	100,000	Survivors	0.000146			
				CPcdP	1	µg/mL	13	Mutants	100,000	Survivors	0.000130			
				CPcdP	2	µg/mL	17	Mutants	100,000	Survivors	0.000172			
				CPcdP	4	µg/mL	27	Mutants	100,000	Survivors	0.000274			

Table C-9. In vitro bacterial mutagenicity: dose-response data

Record number	Reference	Cell type	Activation system	PAH	Dose	Dose units	Response	Response units	n	Units	% Response	SD	SE	Comments
				CPcdP	8	µg/mL	60	Mutants	100,000	Survivors	0.000597			
				CPhiACE A	0	µg/mL	8	Mutants	100,000	Survivors	0.000084			
				CPhiACE A	0.5	µg/mL	10	Mutants	100,000	Survivors	0.000103			
				CPhiACE A	1	µg/mL	16	Mutants	100,000	Survivors	0.000157			
				CPhiACE A	2	µg/mL	29	Mutants	100,000	Survivors	0.000286			
				CPhiACE A	4	µg/mL	67	Mutants	100,000	Survivors	0.000670			
				CPhiAPA	0	µg/mL	9	Mutants	100,000	Survivors	0.000090			
				CPhiAPA	10	µg/mL	12	Mutants	100,000	Survivors	0.000117			
				CPhiAPA	30	µg/mL	21	Mutants	100,000	Survivors	0.000210			
				CPhiAPA	100	µg/mL	26	Mutants	100,000	Survivors	0.000263			
				ACEA	0	µg/mL	9	Mutants	100,000	Survivors	0.000092			
				ACEA	10	µg/mL	21	Mutants	100,000	Survivors	0.000214			
				ACEA	35	µg/mL	69	Mutants	100,000	Survivors	0.000686			
				APA	0	µg/mL	16	Mutants	100,000	Survivors	0.000160			
				APA	10	µg/mL	37	Mutants	100,000	Survivors	0.000375			
				APA	30	µg/mL	42	Mutants	100,000	Survivors	0.000416			
				APA	100	µg/mL	22	Mutants	100,000	Survivors	0.000220			
19320	LaVoie et al., 1979	TA98	Rat Ar S9	BaP	10	µg	450	Revertants/ plate						Background subtracted from data reported

Table C-9. In vitro bacterial mutagenicity: dose-response data

Record number	Reference	Cell type	Activation system	PAH	Dose	Dose units	Response	Response units	n	Units	% Response	SD	SE	Comments
				BaP	20	µg	480	Revertants/plate						
				BeP	10	µg	20	Revertants/plate						
				BeP	20	µg	20	Revertants/plate						
				Pery	20	µg	70	Revertants/plate						
23650	McCann et al., 1975	Multiple strains	Rat Ar S9	BaP	NA		121	Revertants/nmol (potency)						Paper states that comparison of potency estimates should be done with caution (non-linear dose-response), see table footnotes
				DBaIP	NA		20	Revertants/nmol (potency)						
				BeP	NA		0.6	Revertants/nmol (potency)						
				DBaCA	NA		175	Revertants/nmol (potency)						
				DBaHA	NA		11	Revertants/nmol (potency)						
				CH	NA		38	Revertants/nmol (potency)						
				BaA	NA		11	Revertants/nmol (potency)						
20220	Pahlman and Pelkonen, 1987	TA100	Rat MC S9	BaP	NA		272	Revertants/nmol (potency)						

Table C-9. In vitro bacterial mutagenicity: dose-response data

Record number	Reference	Cell type	Activation system	PAH	Dose	Dose units	Response	Response units	n	Units	% Response	SD	SE	Comments
				BaA	NA		10.4	Revertants/nmol (potency)						
				CH	NA		9.7	Revertants/nmol (potency)						
				Tphen	NA		4	Revertants/nmol (potency)						
				DBacA	NA		35	Revertants/nmol (potency)						
				DBahA	NA		4.4	Revertants/nmol (potency)						
20450	Phillipson and Ioannides, 1989	TA100	Hamster S9	BaP	0	µg/plate	0.000	Revertants/plate						
				BaP	5	µg/plate	68.833	Revertants/plate						
				BaP	10	µg/plate	118.948	Revertants/plate						
				BaP	15	µg/plate	99.744	Revertants/plate						
				BaP	20	µg/plate	96.101	Revertants/plate						
				BaA	0	µg/plate	0.000	Revertants/plate						
				BaA	20	µg/plate	109.877	Revertants/plate						
				BaA	40	µg/plate	115.248	Revertants/plate						
				BaA	60	µg/plate	114.430	Revertants/plate						
				BaA	100	µg/plate	98.846	Revertants/plate						
				DBaiP	0	µg/plate	0.000	Revertants/plate						

Table C-9. In vitro bacterial mutagenicity: dose-response data

Record number	Reference	Cell type	Activation system	PAH	Dose	Dose units	Response	Response units	n	Units	% Response	SD	SE	Comments
				DBaiP	20	µg/plate	64.638	Revertants/plate						
				DBaiP	40	µg/plate	75.747	Revertants/plate						
				DBaiP	60	µg/plate	80.394	Revertants/plate						
				DBaiP	100	µg/plate	63.880	Revertants/plate						
				DBahA	0	µg/plate	0.000	Revertants/plate						
				DBahA	10	µg/plate	50.899	Revertants/plate						
				DBahA	20	µg/plate	56.886	Revertants/plate						
				DBahA	30	µg/plate	52.419	Revertants/plate						
				DBahA	50	µg/plate	34.980	Revertants/plate						
21000	Sakai et al., 1985	TA97	Rat Ar S9	Control	0	µg	177	Revertants/plate						
				BaP	1	µg	1,208	Revertants/plate						
				BaP	5	µg	1,432	Revertants/plate						
				BaP	10	µg	1,742	Revertants/plate						
				Control	0	µg	189	Revertants/plate						
				FE	5	µg	254	Revertants/plate						
				FE	10	µg	240	Revertants/plate						
				FE	50	µg	240	Revertants/plate						
				FE	250	µg	232	Revertants/plate						

Table C-9. In vitro bacterial mutagenicity: dose-response data

Record number	Reference	Cell type	Activation system	PAH	Dose	Dose units	Response	Response units	n	Units	% Response	SD	SE	Comments
				Control	0	µg	189	Revertants/plate						
				AC	5	µg	360	Revertants/plate						
				AC	10	µg	509	Revertants/plate						
				AC	50	µg	293	Revertants/plate						
				AC	250	µg	279	Revertants/plate						
				Control	0	µg	189	Revertants/plate						
				PH	5	µg	454	Revertants/plate						
				PH	10	µg	534	Revertants/plate						
				PH	50	µg	321	Revertants/plate						
				PH	250	µg	T	Revertants/plate						
				Control	0	µg	177	Revertants/plate						
				FA	5	µg	652	Revertants/plate						
				FA	10	µg	1,012	Revertants/plate						
				FA	50	µg	1,042	Revertants/plate						
				FA	250	µg	518	Revertants/plate						
				Control	0	µg	177	Revertants/plate						
				CH	5	µg	640	Revertants/plate						
				CH	10	µg	815	Revertants/plate						

Table C-9. In vitro bacterial mutagenicity: dose-response data

Record number	Reference	Cell type	Activation system	PAH	Dose	Dose units	Response	Response units	n	Units	% Response	SD	SE	Comments
				CH	20	µg	888	Revertants/plate						
				CH	50	µg	723	Revertants/plate						
				Control	0	µg	177	Revertants/plate						
				Pyr	2	µg	929	Revertants/plate						
				Pyr	4	µg	1,582	Revertants/plate						
				Pyr	6	µg	2,057	Revertants/plate						
				Pyr	10	µg	2,577	Revertants/plate						
				Pyr	20	µg	2,832	Revertants/plate						
				Pyr	50	µg	2,296	Revertants/plate						
				Control	0	µg	177	Revertants/plate						
				BeP	5	µg	944	Revertants/plate						
				BeP	10	µg	1,100	Revertants/plate						
				BeP	50	µg	606	Revertants/plate						
				BeP	250	µg	640	Revertants/plate						
				Control	0	µg	177	Revertants/plate						
				Pery	1	µg	1,516	Revertants/plate						
				Pery	2	µg	2,236	Revertants/plate						
				Pery	4	µg	2,784	Revertants/plate						

Table C-9. In vitro bacterial mutagenicity: dose-response data

Record number	Reference	Cell type	Activation system	PAH	Dose	Dose units	Response	Response units	n	Units	% Response	SD	SE	Comments
				Pery	10	µg	2,550	Revertants/plate						
				Pery	50	µg	1,808	Revertants/plate						
				Control	0	µg	177	Revertants/plate						
				BghiP	10	µg	896	Revertants/plate						
				BghiP	20	µg	991	Revertants/plate						
				BghiP	50	µg	896	Revertants/plate						
				BghiP	250	µg	612	Revertants/plate						
				Control	0	µg	177	Revertants/plate						
				CO	5	µg	362	Revertants/plate						
				CO	10	µg	400	Revertants/plate						
				CO	50	µg	405	Revertants/plate						
				CO	100	µg	490	Revertants/plate						
				CO	200	µg	479	Revertants/plate						
11860	Sangaiah et al., 1983	TA98	Rat Ar S9	Control	0	µg/plate	35.43	Revertants/plate						
				BaP	2	µg/plate	177.37	Revertants/plate						
				BaP	3	µg/plate	266.02	Revertants/plate						
				BaP	6	µg/plate	419.68	Revertants/plate						
				BaP	10	µg/plate	312.76	Revertants/plate						

Table C-9. In vitro bacterial mutagenicity: dose-response data

Record number	Reference	Cell type	Activation system	PAH	Dose	Dose units	Response	Response units	n	Units	% Response	SD	SE	Comments
				BaP	30	µg/plate	358.41	Revertants/plate						
				BaP	50	µg/plate	350.92	Revertants/plate						
				BaP	100	µg/plate	323.12	Revertants/plate						
				Control	0	µg/plate	53.15	Revertants/plate						
				BjAC	2	µg/plate	124.15	Revertants/plate						
				BjAC	3	µg/plate	331.10	Revertants/plate						
				BjAC	6	µg/plate	674.11	Revertants/plate						
				BjAC	10	µg/plate	993.21	Revertants/plate						
				BjAC	30	µg/plate	1,027.06	Revertants/plate						
				BjAC	50	µg/plate	883.45	Revertants/plate						
				BjAC	100	µg/plate	1,021.36	Revertants/plate						
21360	Simmon, 1979a	TA100	Rat Ar S9	BaP	5	µg	1,141	Revertants/plate						Background subtracted from data reported
				BaA	50	µg	280	Revertants/plate						
				BeP	50	µg	57	Revertants/plate						
21640	Teranishi et al., 1975	TA1538	Rat PB S9	Control	0	µg/plate	38	Revertant colonies/plate						
				BaP	50	µg/plate	77	Revertant colonies/plate						

Table C-9. In vitro bacterial mutagenicity: dose-response data

Record number	Reference	Cell type	Activation system	PAH	Dose	Dose units	Response	Response units	n	Units	% Response	SD	SE	Comments
				DBaiP	50	µg/plate	102	Revertant colonies/plate						
		TA1538	Rat PB and DBahA S9	Control	0	µg/plate	25	Revertant colonies/plate						
				BaP	50	µg/plate	279	Revertant colonies/plate						
				DBaEP	50	µg/plate	88	Revertant colonies/plate						
16180	Utesch et al., 1987	TA100	With homogenized hepatocytes from Ar-treated rats	Control	0	µg/plate	159	Revertants/plates						
				BaP	6.3	µg/plate	998	Revertants/plate						
				BaP	12.5	µg/plate	1,079	Revertants/plate						
				BaP	25	µg/plate	1,178	Revertants/plate						
				BaP	50	µg/plate	1,141	Revertants/plate						
				BaP	100	µg/plate	1,114	Revertants/plate						
				Control	0	µg/plate	199	Revertants/plate						
				BaA	6.3	µg/plate	861	Revertants/plate						
				BaA	12.5	µg/plate	2,583	Revertants/plate						
				BaA	25	µg/plate	3,546	Revertants/plate						
				BaA	50	µg/plate	3,786	Revertants/plate						

Table C-9. In vitro bacterial mutagenicity: dose-response data

Record number	Reference	Cell type	Activation system	PAH	Dose	Dose units	Response	Response units	n	Units	% Response	SD	SE	Comments
				BaA	100	µg/plate	3,406	Revertants/plate						
16440	Wood et al., 1980	TA98	Purified microsomal P450	Control	0	nmol	0	Revertants/plate						Background subtracted from data reported
				BaP	3.75	nmol	45	Revertants/plate						
				BaP	7.5	nmol	63	Revertants/plate						
				BaP	15	nmol	99	Revertants/plate						
				BaP	30	nmol	103	Revertants/plate						
				Control	0	nmol	0	Revertants/plate						
				CPcdP	3.75	nmol	303	Revertants/plate						
				CPcdP	7.5	nmol	491	Revertants/plate						
				CPcdP	15	nmol	685	Revertants/plate						
				CPcdP	30	nmol	776	Revertants/plate						

1

Table C-10. In vitro mammalian mutagenicity: data use

Record number	Reference	Data source	Data points	Basis for RPF approach	Comments
16920	Amacher and Paillet, 1982	Figure 1	Use lines for BaP (open circles) and BaA (closed triangles); dose is $\mu\text{g/mL}$ and response is mutation frequency (MF)/ 10^6 survivors	Model; quantal data	Thymidine kinase assay (resistance to trifluorothymidine) in mouse lymphoma cells (L5178Y) with Syrian golden hamster S9 mix or cocultivated hamster hepatocytes
16940	Amacher and Turner, 1980	Figure 3	Use bars for SM2 S9 activation for BaP and BaA; dose is 1.25×10^{-5} M for BaP and 3.22×10^{-5} M for BaA; response is IMF/ 10^4 survivors	Point estimate	Thymidine kinase assay (resistance to trifluorothymidine) in mouse lymphoma cells (L5178Y) with mouse S9 mix
16910	Amacher et al., 1980	Table 3	Use dose-response data for BaA and BaP; dose as concentration (M), response as mutants per 10^4 survivors	Model; quantal data	Thymidine kinase assay (resistance to trifluorothymidine) in mouse lymphoma cells (L5178Y) with mouse S9 mix
17140	Barfknecht et al., 1982	Figure 2 (BaP, FA); Figure 4 (BaA, CH, Tphen); Figure 6 (CPcdP)	Dose is μM and mutant fraction $\times 10^6$	Model; quantal data	Thymidine kinase assay (resistance to trifluorothymidine) in human lymphoblast cells with rat Ar S9 mix
14250	Hass et al., 1982	Table 1	Dose-response data for DBaIP, DBaHP, and BaP; dose is $\mu\text{g/mL}$; use response data for TG mutants only (mutants/ 10^6 cells); control value is 4 ± 1 mutants/ 10^6 cells	Model; quantal data	Hypoxanthine-guanine phosphoribosyl transferase assay (resistance to 6-thioguanine) in V79 Chinese hamster cells with rat MC S9
18740	Huberman and Sachs, 1976	Table 2	Use data for BaP, DBaCA, DBaHA; 8-azaguanine resistance only; use $1 \mu\text{g/mL}$ dose for all (*), response as mutants per 10^5 survivors	Point estimate	Hypoxanthine-guanine phosphoribosyl transferase assay (resistance to 8-azaguanine) in V79 Chinese hamster cells with hamster embryo cells
18990	Jotz and Mitchell, 1981	Table 2	Use data for BaP and Pyr with metabolic activation; subtract negative control, dose as $\mu\text{g/mL}$, response as MF $\times 10^{-6}$	Point estimate	Thymidine kinase assay (resistance to trifluorothymidine) in mouse lymphoma cells (L5178Y) with rat Ar S9
24720	Kligerman et al., 1986	Figure 1	Use dose-response data for BaP and BIAC; dose as $\mu\text{g/mL}$, response as mutant frequency/ 10^6 survivors; average data from two experiments	Model; quantal data	Thymidine kinase assay (resistance to trifluorothymidine) in mouse lymphoma cells (L5178Y) with rat Ar S9

Table C-10. In vitro mammalian mutagenicity: data use

Record number	Reference	Data source	Data points	Basis for RPF approach	Comments
19180	Krahn and Heidelberger, 1977	Table II	Use data for BaP, DBaA, DBaC, and BaA; cell survival at 40% control (column 3), controls are 100% survival group (column 1); use 3-MC S9 data only; dose as nmol/mL, response as 6-TG/10 ⁵ cells	Point estimate	Hypoxanthine-guanine phosphoribosyl transferase assay (resistance to 6-thioguanine) in V79 Chinese hamster cells with hamster embryo cells
24680	Lafleur et al., 1993	Figures 5 and 6	Use dose-response curves for BaP, CPcdP (CPP), CPhiACEA (CPAA), ACEA (AA); dose as µg/mL, response as mutant fraction (ppm)	Model as quantal data (mutant fraction reported)	Thymidine kinase assay (resistance to trifluorothymidine) in MCL-3 cells (human B-lymphoblastoid cells)
7550	Li and Lin, 1996	Text	Mutant frequency of controls 2×10^{-5} ; 10 ng/mL BaP = 5×10^{-5} ; BaA = 5.6×10^{-5}	Point estimate	Hypoxanthine-guanine phosphoribosyl transferase assay (resistance to 6-thioguanine) in HS1 HeLa cells (human epithelial cells)
11450	Nesnow et al., 1984	Chart 9	Use data for BaP, BlAC, BeAC, and BjAC; dose as µg/mL, response as 6TG-resistant mutants/10 ⁶ survivors	Model; quantal data	Hypoxanthine-guanine phosphoribosyl transferase assay (resistance to 6-thioguanine) in V79 Chinese hamster cells with rat AR S9
15630	Raveh and Huberman, 1983	Table 1	Use data for CPcdP and BaP, with PMA only; dose in µg/mL, response in mutants/10 ⁵ cells	Model; quantal data	Hypoxanthine-guanine phosphoribosyl transferase assay (resistance to 6-thioguanine) in V79 Chinese hamster cells with hamster embryo cells
15640	Raveh et al., 1982	Figure 4	Use dose-response data for CPcdP and BaP (ouabain resistance only); dose in µg/mL, response in mutants/10 ⁶ cells	Model; quantal data	Hypoxanthine-guanine phosphoribosyl transferase assay (resistance to ouabain) in V79 Chinese hamster cells with hamster embryo cells
21410	Slaga et al., 1978	Table 3	Use dose-response data for BaA and BaP; dose as µM, response as ouabain resistant mutants/10 ⁴ survivors	Model; quantal data	Hypoxanthine-guanine phosphoribosyl transferase assay (resistance to ouabain) in V79 Chinese hamster cells with hamster embryo cells
16190	Vaca et al., 1992	Figure 5	Dose-response data for FA and BaP; dose as µM, response as 6-Tg resistant cells/100,000	Model; quantal data	Hypoxanthine-guanine phosphoribosyl transferase assay (resistance to 6-thioguanine) in UV-sensitive CHO cells with rat Ar S9
21900	Wangenheim and Bolcsfoldi, 1988	Table 1	Use +S9 dose-response data for Pyr, BaP, and FE; dose as mol/L, response as mutation frequency	Model; quantal data	Thymidine kinase assay (resistance to trifluorothymidine) in mouse lymphoma cells (L5178Y) with rat Ar S9

Table C-10. In vitro mammalian mutagenicity: data use

Record number	Reference	Data source	Data points	Basis for RPF approach	Comments
24670	Durant et al., 1999	Table 1	Use dose-response data for BaPery, BbPery, DBaeF, DBafF, DBahP, DBaiP, DBelP, N23aP, N23eP; positive control is reported as 1,000 ng/mL BaP (reported separately for each PAH)	Model; quantal data	Thymidine kinase assay (resistance to trifluorothymidine) in human h1Alv2 cells

Table C-11. In vitro mammalian mutagenicity: dose-response data

Record number	Reference	PAH	Dose	Dose units	Mutants	In number	Units	% Response	Comments
16920	Amacher and Paillet, 1982	Control	0	µg/mL	39	1 × 10 ⁶	Survivors	0.000039	
		BaP	2.5	µg/mL	119	1 × 10 ⁶	Survivors	0.00012	
		BaP	5	µg/mL	170	1 × 10 ⁶	Survivors	0.00017	
		BaP	7.5	µg/mL	196	1 × 10 ⁶	Survivors	0.00020	
		BaP	10	µg/mL	267	1 × 10 ⁶	Survivors	0.00027	
		Control	0	µg/mL	20	1 × 10 ⁶	Survivors	0.000020	
		BaA	2.5	µg/mL	65	1 × 10 ⁶	Survivors	0.000065	
		BaA	5	µg/mL	62	1 × 10 ⁶	Survivors	0.000062	
		BaA	10	µg/mL	88	1 × 10 ⁶	Survivors	0.000088	
		BaA	15	µg/mL	89	1 × 10 ⁶	Survivors	0.000089	
16940	Amacher and Turner, 1980	Control	0	M	0.4	1 × 10 ⁴	Survivors	0.000040	Control without S9 treatment
		BaP	1.25 × 10 ⁻⁵	M	2.85	1 × 10 ⁴	Survivors	0.000285	
		BaA	3.22 × 10 ⁻⁵	M	3.12	1 × 10 ⁴	Survivors	0.000312	
16910	Amacher et al., 1980	Control	0	M	0.680	1 × 10 ⁴	Survivors	0.000068	
		BaP	5.30 × 10 ⁻⁶	M	1.360	1 × 10 ⁴	Survivors	0.000136	
		BaP	7.00 × 10 ⁻⁶	M	1.790	1 × 10 ⁴	Survivors	0.000179	
		BaP	9.40 × 10 ⁻⁶	M	1.470	1 × 10 ⁴	Survivors	0.000147	
		BaP	1.25 × 10 ⁻⁵	M	1.870	1 × 10 ⁴	Survivors	0.000187	
		BaP	1.67 × 10 ⁻⁵	M	2.600	1 × 10 ⁴	Survivors	0.000260	
		BaP	2.23 × 10 ⁻⁵	M	2.490	1 × 10 ⁴	Survivors	0.000249	
		BaP	2.97 × 10 ⁻⁵	M	2.650	1 × 10 ⁴	Survivors	0.000265	
		BaP	3.96 × 10 ⁻⁵	M	3.970	1 × 10 ⁴	Survivors	0.000397	
		Control	0	M	0.770	1 × 10 ⁴	Survivors	0.000077	
		BaA	1.36 × 10 ⁻⁵	M	0.810	1 × 10 ⁴	Survivors	0.000081	
		BaA	1.81 × 10 ⁻⁵	M	0.840	1 × 10 ⁴	Survivors	0.000084	
		BaA	2.42 × 10 ⁻⁵	M	1.000	1 × 10 ⁴	Survivors	0.000100	
		BaA	3.22 × 10 ⁻⁵	M	1.230	1 × 10 ⁴	Survivors	0.000123	
		BaA	4.30 × 10 ⁻⁵	M	1.470	1 × 10 ⁴	Survivors	0.000147	
		BaA	5.47 × 10 ⁻⁵	M	NS	1 × 10 ⁴	Survivors		NS = no survivors
		BaA	7.65 × 10 ⁻⁵	M	NS	1 × 10 ⁴	Survivors		

Table C-11. In vitro mammalian mutagenicity: dose-response data

Record number	Reference	PAH	Dose	Dose units	Mutants	In number	Units	% Response	Comments
		BaA	1.02×10^{-4}	M	NS	1×10^4	Survivors		
17140	Barfknecht et al., 1982	Control	0	μM	0	1×10^6	Survivors	0.000000	
		BaP	10	μM	51	1×10^6	Survivors	0.000051	
		BaP	20	μM	120	1×10^6	Survivors	0.000120	
		BaP	30	μM	155	1×10^6	Survivors	0.000155	
		Control	0	μM	0	1×10^6	Survivors	0.000000	
		FA	10	μM	27	1×10^6	Survivors	0.000027	
		FA	20	μM	50	1×10^6	Survivors	0.000050	
		FA	40	μM	62	1×10^6	Survivors	0.000062	
		Control	0	μM	0	1×10^6	Survivors	0.000000	
		BaA	20	μM	12	1×10^6	Survivors	0.000012	
		BaA	50	μM	29	1×10^6	Survivors	0.000029	
		BaA	100	μM	34	1×10^6	Survivors	0.000034	
		BaA	150	μM	64	1×10^6	Survivors	0.000064	
		Control	0	μM	0	1×10^6	Survivors	0.000000	
		CH	20	μM	17	1×10^6	Survivors	0.000017	
		CH	50	μM	26	1×10^6	Survivors	0.000026	
		CH	100	μM	30	1×10^6	Survivors	0.000030	
		Control	0	μM	0	1×10^6	Survivors	0.000000	
		Tphen	50	μM	10	1×10^6	Survivors	0.000010	
		Tphen	100	μM	20	1×10^6	Survivors	0.000020	
		Tphen	200	μM	35	1×10^6	Survivors	0.000035	
		Control	0	μM	3	1×10^6	Survivors	0.000003	
		CPcdP	23	μM	11	1×10^6	Survivors	0.000011	
		CPcdP	47	μM	24	1×10^6	Survivors	0.000024	
		CPcdP	88	μM	27	1×10^6	Survivors	0.000027	
24670	Durant et al., 1999	BaP	1,000	ng/mL	170	1×10^6	Survivors	0.00017	
		BaP	1,000	ng/mL	170	1×10^6	Survivors	0.00017	
		BaP	1,000	ng/mL	200	1×10^6	Survivors	0.00020	
		BaP	1,000	ng/mL	200	1×10^6	Survivors	0.00020	
		BaP	1,000	ng/mL	160	1×10^6	Survivors	0.00016	

Table C-11. In vitro mammalian mutagenicity: dose-response data

Record number	Reference	PAH	Dose	Dose units	Mutants	In number	Units	% Response	Comments
		BaP	1,000	ng/mL	170	1×10^6	Survivors	0.00017	
		BaP	1,000	ng/mL	190	1×10^6	Survivors	0.00019	
		BaP	1,000	ng/mL	200	1×10^6	Survivors	0.00020	
		BaP	1,000	ng/mL	210	1×10^6	Survivors	0.00021	
		Averaged BaP	1,000	ng/mL	186	1×10^6	Survivors	0.00019	
		Averaged controls	0	ng/mL	20	1×10^6	Survivors	0.00002	
		Control	0	ng/mL	18	1×10^6	Survivors	0.000018	
		BaPery	0.1	ng/mL	21	1×10^6	Survivors	0.000021	
		BaPery	0.3	ng/mL	23	1×10^6	Survivors	0.000023	
		BaPery	1	ng/mL	28	1×10^6	Survivors	0.000028	
		BaPery	3	ng/mL	50	1×10^6	Survivors	0.000050	
		BaPery	10	ng/mL	82	1×10^6	Survivors	0.000082	
		BaPery	100	ng/mL	200	1×10^6	Survivors	0.00020	
		Control	0	ng/mL	18	1×10^6	Survivors	0.000018	
		BbPery	1	ng/mL	19	1×10^6	Survivors	0.000019	
		BbPery	3	ng/mL	22	1×10^6	Survivors	0.000022	
		BbPery	10	ng/mL	32	1×10^6	Survivors	0.000032	
		BbPery	100	ng/mL	54	1×10^6	Survivors	0.000054	
		Control	0	ng/mL	21	1×10^6	Survivors	0.000021	
		DBaef	1	ng/mL	29	1×10^6	Survivors	0.000029	
		DBaef	10	ng/mL	72	1×10^6	Survivors	0.000072	
		DBaef	100	ng/mL	190	1×10^6	Survivors	0.00019	
		DBaef	1,000	ng/mL	np	1×10^6	Survivors		Not plated due to excessive toxicity
		Control	0	ng/mL	21	1×10^6	Survivors	0.000021	
		DBaF	1	ng/mL	21	1×10^6	Survivors	0.000021	
		DBaF	10	ng/mL	37	1×10^6	Survivors	0.000037	
		DBaF	100	ng/mL	81	1×10^6	Survivors	0.000081	
		DBaF	1,000	ng/mL	190	1×10^6	Survivors	0.00019	
		Control	0	ng/mL	19	1×10^6	Survivors	0.000019	
		DBaHP	0.1	ng/mL	24	1×10^6	Survivors	0.000024	

Table C-11. In vitro mammalian mutagenicity: dose-response data

Record number	Reference	PAH	Dose	Dose units	Mutants	In number	Units	% Response	Comments
		DBahP	1	ng/mL	24	1×10^6	Survivors	0.000024	
		DBahP	10	ng/mL	46	1×10^6	Survivors	0.000046	
		DBahP	100	ng/mL	80	1×10^6	Survivors	0.000080	
		Control	0	ng/mL	20	1×10^6	Survivors	0.000020	
		DBaiP	0.3	ng/mL	20	1×10^6	Survivors	0.000020	
		DBaiP	1	ng/mL	35	1×10^6	Survivors	0.000035	
		DBaiP	10	ng/mL	88	1×10^6	Survivors	0.000088	
		DBaiP	100	ng/mL	150	1×10^6	Survivors	0.00015	
		Control	0	ng/mL	21	1×10^6	Survivors	0.000021	
		DBelP	10	ng/mL	28	1×10^6	Survivors	0.000028	
		DBelP	100	ng/mL	34	1×10^6	Survivors	0.000034	
		DBelP	1,000	ng/mL	55	1×10^6	Survivors	0.000055	
		Control	0	ng/mL	21	1×10^6	Survivors	0.000021	
		N23aP	0.1	ng/mL	23	1×10^6	Survivors	0.000023	
		N23aP	1	ng/mL	44	1×10^6	Survivors	0.000044	
		N23aP	10	ng/mL	84	1×10^6	Survivors	0.000084	
		N23aP	100	ng/mL	94	1×10^6	Survivors	0.000094	
		N23aP	1,000	ng/mL	73	1×10^6	Survivors	0.000073	
		Control	0	ng/mL	19	1×10^6	Survivors	0.000019	
		N23eP	1	ng/mL	20	1×10^6	Survivors	0.000020	
		N23eP	10	ng/mL	41	1×10^6	Survivors	0.000041	
		N23eP	100	ng/mL	74	1×10^6	Survivors	0.000074	
		N23eP	1,000	ng/mL	98	1×10^6	Survivors	0.00010	
14250	Hass et al., 1982	Control	0	$\mu\text{g/mL}$	4	1×10^6	CFC	0.0000040	
		BaP	0.30	$\mu\text{g/mL}$	267	1×10^6	CFC	0.00027	
		BaP	1.00	$\mu\text{g/mL}$	293	1×10^6	CFC	0.00029	
		DBaiP	0.03	$\mu\text{g/mL}$	124	1×10^6	CFC	0.00012	
		DBaiP	0.10	$\mu\text{g/mL}$	289	1×10^6	CFC	0.00029	
		DBaiP	0.30	$\mu\text{g/mL}$	1211	1×10^6	CFC	0.00121	
		DBahP	0.03	$\mu\text{g/mL}$	110	1×10^6	CFC	0.00011	
		DBahP	0.10	$\mu\text{g/mL}$	264	1×10^6	CFC	0.00026	
		DBahP	0.30	$\mu\text{g/mL}$	668	1×10^6	CFC	0.00067	

Table C-11. In vitro mammalian mutagenicity: dose-response data

Record number	Reference	PAH	Dose	Dose units	Mutants	In number	Units	% Response	Comments
18740	Huberman and Sachs, 1976	Control	0	µg/mL	6	1 × 10 ⁵	Survivors	0.000060	
		BaP	1	µg/mL	425	1 × 10 ⁵	Survivors	0.00425	
		DBacA	1	µg/mL	22	1 × 10 ⁵	Survivors	0.00022	
		DBahA	1	µg/mL	17	1 × 10 ⁵	Survivors	0.00017	
18990	Jotz and Mitchell, 1981	Control	0	µg/mL	80	1 × 10 ⁶	Survivors	0.000080	
		BaP	4.5	µg/mL	224	1 × 10 ⁶	Survivors	0.00022	With metabolic activation
		Control	0	µg/mL	116	1 × 10 ⁶	Survivors	0.00012	
		Pyr	10.6	µg/mL	150	1 × 10 ⁶	Survivors	0.00015	With metabolic activation
24720	Kligerman et al., 1986	Control	0	nmol/mL	92	1 × 10 ⁶	Survivors	0.00009	Average of two experiments
		BaP	2.0	nmol/mL	258	1 × 10 ⁶	Survivors	0.00026	
		BaP	3.0	nmol/mL	417	1 × 10 ⁶	Survivors	0.00042	
		BaP	4.0	nmol/mL	557	1 × 10 ⁶	Survivors	0.00056	
		Control	0	nmol/mL	90	1 × 10 ⁶	Survivors	0.00009	
		BIAC	0.5	nmol/mL	93	1 × 10 ⁶	Survivors	0.00009	
		BIAC	2.5	nmol/mL	197	1 × 10 ⁶	Survivors	0.00020	
		BIAC	5.0	nmol/mL	374	1 × 10 ⁶	Survivors	0.00037	
19180	Krahn and Heidelberger, 1977	Control	0	nmol/mL	1.7	1 × 10 ⁵	Survivors	0.000017	
		BaP	15.9	nmol/mL	14	1 × 10 ⁵	Survivors	0.000136	3-MC S9; 40% survival
		Control	0	nmol/mL	1.5	1 × 10 ⁵	Survivors	0.000015	
		BaA	46.5	nmol/mL	6.5	1 × 10 ⁵	Survivors	0.000065	3-MC S9; 40% survival
24680	Lafleur et al., 1993	Control	0	µg/mL	1.2	1 × 10 ⁶	Survivors	0.0000012	
		BaP	0.02	µg/mL	4.8	1 × 10 ⁶	Survivors	0.0000048	
		BaP	0.06	µg/mL	24	1 × 10 ⁶	Survivors	0.000024	
		BaP	0.2	µg/mL	25	1 × 10 ⁶	Survivors	0.000025	
		BaP	1	µg/mL	39	1 × 10 ⁶	Survivors	0.000039	
		BaP	5	µg/mL	56	1 × 10 ⁶	Survivors	0.000056	
		Control	0	µg/mL	1.8	1 × 10 ⁶	Survivors	0.0000018	
		ACEA	1	µg/mL	6.0	1 × 10 ⁶	Survivors	0.0000060	

Table C-11. In vitro mammalian mutagenicity: dose-response data

Record number	Reference	PAH	Dose	Dose units	Mutants	In number	Units	% Response	Comments
		ACEA	3	µg/mL	15	1 × 10 ⁶	Survivors	0.000015	
		ACEA	8	µg/mL	21	1 × 10 ⁶	Survivors	0.000021	
		Control	0	µg/mL	2.5	1 × 10 ⁶	Survivors	0.0000025	
		CPcdP	0.03	µg/mL	4.2	1 × 10 ⁶	Survivors	0.0000042	
		CPcdP	0.06	µg/mL	4.9	1 × 10 ⁶	Survivors	0.0000049	
		CPcdP	0.2	µg/mL	5.9	1 × 10 ⁶	Survivors	0.0000059	
		CPcdP	0.6	µg/mL	10	1 × 10 ⁶	Survivors	0.000010	
		CPcdP	2	µg/mL	17	1 × 10 ⁶	Survivors	0.000017	
		Control	0	µg/mL	2.8	1 × 10 ⁶	Survivors	0.0000028	
		CPhiACEA	0.1	µg/mL	12	1 × 10 ⁶	Survivors	0.000012	
		CPhiACEA	0.3	µg/mL	25	1 × 10 ⁶	Survivors	0.000025	
		CPhiACEA	0.8	µg/mL	31	1 × 10 ⁶	Survivors	0.000031	
7550	Li and Lin, 1996	Control	0	ng/mL	2	1 × 10 ⁵	Survivors	0.000020	
		BaP	10	ng/mL	5	1 × 10 ⁵	Survivors	0.000050	
		BaA	10	ng/mL	5.6	1 × 10 ⁵	Survivors	0.000056	
11450	Nesnow et al., 1984	Control	0	µg/mL	16	1 × 10 ⁶	Survivors	0.000016	
		BaP	0.5	µg/mL	10	1 × 10 ⁶	Survivors	0.000010	
		BaP	1.0	µg/mL	46	1 × 10 ⁶	Survivors	0.000046	
		BaP	2.5	µg/mL	72	1 × 10 ⁶	Survivors	0.000072	
		BaP	5.0	µg/mL	206	1 × 10 ⁶	Survivors	0.000206	
		BaP	10.0	µg/mL	215	1 × 10 ⁶	Survivors	0.000215	
		BaP	20.0	µg/mL	293	1 × 10 ⁶	Survivors	0.000293	
		BeAC	1.0	µg/mL	17	1 × 10 ⁶	Survivors	0.000017	
		BeAC	2.5	µg/mL	53	1 × 10 ⁶	Survivors	0.000053	
		BeAC	5.0	µg/mL	435	1 × 10 ⁶	Survivors	0.000435	
		BeAC	10.0	µg/mL	235	1 × 10 ⁶	Survivors	0.000235	
		BeAC	20.0	µg/mL	349	1 × 10 ⁶	Survivors	0.000349	
		BjAC	1.0	µg/mL	24	1 × 10 ⁶	Survivors	0.000024	
		BjAC	2.5	µg/mL	94	1 × 10 ⁶	Survivors	0.000094	
		BjAC	5.0	µg/mL	268	1 × 10 ⁶	Survivors	0.000268	
		BjAC	10.0	µg/mL	225	1 × 10 ⁶	Survivors	0.000225	
		BjAC	20.0	µg/mL	215	1 × 10 ⁶	Survivors	0.000215	

Table C-11. In vitro mammalian mutagenicity: dose-response data

Record number	Reference	PAH	Dose	Dose units	Mutants	In number	Units	% Response	Comments
		BIAC	1.0	µg/mL	31	1 × 10 ⁶	Survivors	0.000031	
		BIAC	2.5	µg/mL	454	1 × 10 ⁶	Survivors	0.000454	
		BIAC	5.0	µg/mL	320	1 × 10 ⁶	Survivors	0.000320	
		BIAC	10.0	µg/mL	704	1 × 10 ⁶	Survivors	0.000704	
		BIAC	20.0	µg/mL	769	1 × 10 ⁶	Survivors	0.000769	
15630	Raveh and Huberman, 1983	Control	0	µg/mL	3	1 × 10 ⁵	Survivors	0.000030	
		BaP	0.3	µg/mL	25	1 × 10 ⁵	Survivors	0.00025	
		BaP	1	µg/mL	103	1 × 10 ⁵	Survivors	0.0010	
		CPcdP	0.3	µg/mL	9	1 × 10 ⁵	Survivors	0.000090	
		CPcdP	1	µg/mL	20	1 × 10 ⁵	Survivors	0.00020	
15640	Raveh et al., 1982	BaP	0	µg/mL	7	1 × 10 ⁶	CFC	0.0000070	
		BaP	0.3	µg/mL	20	1 × 10 ⁶	CFC	0.000020	
		BaP	1	µg/mL	74	1 × 10 ⁶	CFC	0.000074	
		BaP	3	µg/mL	74	1 × 10 ⁶	CFC	0.000074	
		CPcdP	0	µg/mL	1	1 × 10 ⁶	CFC	0.0000010	
		CPcdP	0.3	µg/mL	5	1 × 10 ⁶	CFC	0.0000047	
		CPcdP	1	µg/mL	10	1 × 10 ⁶	CFC	0.000010	
		CPcdP	3	µg/mL	28	1 × 10 ⁶	CFC	0.000028	
21410	Slaga et al., 1978	Control	0	µM	0.7	1 × 10 ⁴	Survivors	0.000070	
		BaA	4.4	µM	0.9	1 × 10 ⁴	Survivors	0.000090	
		BaA	44.0	µM	2.1	1 × 10 ⁴	Survivors	0.00021	
		BaP	0.4	µM	11.0	1 × 10 ⁴	Survivors	0.0011	
		BaP	1.3	µM	25.0	1 × 10 ⁴	Survivors	0.0025	
		BaP	4.0	µM	99.0	1 × 10 ⁴	Survivors	0.0099	
16190	Vaca et al., 1992	BaP	0	µM	3	1 × 10 ⁵	Survivors	0.000032	
		BaP	2	µM	10	1 × 10 ⁵	Survivors	0.000102	
		BaP	4	µM	23	1 × 10 ⁵	Survivors	0.000229	
		BaP	10	µM	31	1 × 10 ⁵	Survivors	0.000306	
		FA	0	µM	10	1 × 10 ⁵	Survivors	0.000105	
		FA	5	µM	20	1 × 10 ⁵	Survivors	0.000203	
		FA	7.5	µM	27	1 × 10 ⁵	Survivors	0.000274	

Table C-11. In vitro mammalian mutagenicity: dose-response data

Record number	Reference	PAH	Dose	Dose units	Mutants	In number	Units	% Response	Comments
			10	μM	32	1 × 10 ⁵	Survivors	0.000318	
21900	Wangenheim and Bolcsfoldi, 1988	Control	0	mol/L	61	1 × 10 ⁶	Survivors	0.000061	
		Control	0	mol/L	62	1 × 10 ⁶	Survivors	0.000062	Used average of controls
		Average	0	mol/L	62	1 × 10 ⁶	Survivors	0.000062	
		BaP	0.000001	mol/L	65	1 × 10 ⁶	Survivors	0.000065	
		BaP	0.000005	mol/L	243	1 × 10 ⁶	Survivors	0.000243	
		BaP	0.000010	mol/L	858	1 × 10 ⁶	Survivors	0.00086	
		Control	0	mol/L	68	1 × 10 ⁶	Survivors	0.00007	
		FE	0.0000195	mol/L	92	1 × 10 ⁶	Survivors	0.00009	
		FE	0.0000389	mol/L	91	1 × 10 ⁶	Survivors	0.00009	
		FE	0.0000681	mol/L	114	1 × 10 ⁶	Survivors	0.00011	
		FE	0.000122	mol/L	154	1 × 10 ⁶	Survivors	0.00015	
		FE	0.000170	mol/L	147	1 × 10 ⁶	Survivors	0.00015	
		Control	0	mol/L	125	1 × 10 ⁶	Survivors	0.00013	
		Control	0	mol/L	106	1 × 10 ⁶	Survivors	0.00011	
		Average	0	mol/L	116	1 × 10 ⁶	Survivors	0.00012	
		Pyr	0.0000101	mol/L	162	1 × 10 ⁶	Survivors	0.00016	
		Pyr	0.0000151	mol/L	228	1 × 10 ⁶	Survivors	0.00023	
		Pyr	0.0000202	mol/L	345	1 × 10 ⁶	Survivors	0.00035	
		Pyr	0.0000252	mol/L	418	1 × 10 ⁶	Survivors	0.00042	
		Pyr	0.0000302	mol/L	650	1 × 10 ⁶	Survivors	0.00065	

1

Table C-12. In vitro malignant/morphological cell transformation: data use

Record number	Reference	Page	Table number	Figure number	PAHs	Data to be extracted	Basis for RPF	Comment	Notes
17610	Casto, 1979	54	I and IV		BaP, DBaH _A	TF in number foci per 10 ⁵ surviving cells and dose (µg/mL)	Ratio of slopes	Data on enhancement of viral transformation not used; no straightforward way to model dose-response	Model as incidence data using multistage
17970	DiPaolo et al., 1969	871	3		BaP, DBaH _A , BaA, BeP, DBaC _A	Total transformants, total number of colonies, and dose (µg/mL)	Point estimate		Do not use percent transformants; appears to be error for DBaH _A
18020	Dunkel et al., 1981					Use data as reported in 23720 Pienta 1977; report under that record			
18080	Emura et al., 1980	153, 154	I and II		BaP, BbF, BaA, IP	T, number of transformed colonies/1,000 survivals in 10 dishes and dose (µg/mL)	Ratio of slopes		Model as incidence data using multistage
14130	Greb et al., 1980	147	1		BaP, CH, BaA, BbF, DBaH _A , BeP	Relative transformation rate (potency) in percent/mmol	Ratio of slopes		Relative transformation potency at LC ₅₀ ; slope already calculated
14640	Krolewski et al., 1986	1,648	1		BaP, CPcdP	Transformation frequency per viable cell × 10 ⁻³ ; single dose (5 µM)	Point estimate		Use only BaP and CPcdP alone (not with IVA/AIA)
14700	Laaksonen et al., 1983	62	4		BaP, BaA	Transformation frequency (number of foci/10 ⁵ surviving cells) and dose (µM)	Ratio of slopes		Inverse dose-response relationship possible due to cytotoxicity; use peak
14850	Lubet et al., 1983	992	1		BaP, BeP	DwT-III/td (dishes with Type III foci/total dishes) and dose (µg/mL)	Ratio of slopes		Control data in caption (no transformants); model as incidence data
24710	Mohapatra et al., 1987	327	1		BaP, BeAC, BjAC, BIAC	Number of dishes scored and percent of dishes with Type II or Type III foci and dose (µg/mL)	Ratio of slope to BaP point estimate	Use BaP incidence as BMR	Convert percent into number of dishes and model as incidence data
24700	Nesnow et al., 1990	224	1		BaP, BIAC	Anchorage independent colonies/50,000 cells and dose (µg/mL)	Ratio of slopes		Continuous data, no SD for controls; use peak
7980	Nesnow et al., 1997	1,975	I		BaP, DBaP	Type II and III foci/dish (mean and SD) and dose (µM)	Ratio of slopes		Model as continuous data
7990	Nesnow et al., 1994	2,227	I		BaP, DBaH _A	Type II and III Foci/dish and dose; use 1 µg/mL dose for DBaH _A and mean foci/dish (in parentheses); single dose for BaP	Point estimate		

Table C-12. In vitro malignant/morphological cell transformation: data use

Record number	Reference	Page	Table number	Figure number	PAHs	Data to be extracted	Basis for RPF	Comment	Notes
8000	Nesnow et al., 1993a	28	I		DBkmnoAPH	Peak of Type II and III foci/dish; use 5 µg/mL dose for DBkmnoAPH and 3 µg/mL dose for BaP; average number foci/dish across the two experiments	Point estimate		Peak transformation for each compound; DBkmnoAPH reported in paper as CP(3,4)B[a]P
23720	Pienta et al., 1977	648	IV		BaP, BaA, DBahA	Transformed colonies/surviving colonies and dose (µg/mL, in row across)	Ratio of slopes		Model as incidence data using multistage

1

Table C-13. In vitro malignant/morphological cell transformation: dose-response data

Record number	Reference	PAH	Dose	Dose units	Transformation measure				n	units	% Response	Notes
					Mean	SD	SE	Units				
17610	Casto, 1979	Control	0	µg/mL	0			Foci	100,000	Surviving cells	0	
		BaP	0.62	µg/mL	8			Foci	100,000	Surviving cells	0.00008	
		BaP	1.25	µg/mL	10			Foci	100,000	Surviving cells	0.0001	
		DBahA	1.2	µg/mL	0.5			Foci	100,000	Surviving cells	0.000005	
		DBahA	2.5	µg/mL	1			Foci	100,000	Surviving cells	0.00001	
17970	DiPaolo et al., 1969	Control	0	µg/mL	0			Transformants	354	Number of surviving	0	
		BaP	10	µg/mL	8			Transformants	138	Number of surviving	0.058	
		DBahA	10	µg/mL	11			Transformants	354	Number of surviving	0.031	
		BaA	10	µg/mL	2			Transformants	190	Number of surviving	0.011	
		BeP	10	µg/mL	1			Transformants	172	Number of surviving	0.0058	
		DBacA	10	µg/mL	2			Transformants	181	Number of surviving	0.011	
18080	Emura et al., 1980	Control	0	µg/mL	0			Transformed colonies	1,000	Survivals	0	
	Expt 1	BaP	0.01	µg/mL	0			Transformed colonies	1,000	Survivals	0	
		BaP	0.05	µg/mL	1.1			Transformed colonies	1,000	Survivals	0.0011	
		BaP	0.1	µg/mL	2.9			Transformed colonies	1,000	Survivals	0.0029	
		BaP	0.25	µg/mL	5.3			Transformed colonies	1,000	Survivals	0.0053	
		BaP	0.5	µg/mL	6.8			Transformed colonies	1,000	Survivals	0.0068	
		BbF	0.025	µg/mL	0			Transformed colonies	1,000	Survivals	0	
		BbF	0.1	µg/mL	0.4			Transformed colonies	1,000	Survivals	0.00040	
		BbF	0.25	µg/mL	0.3			Transformed colonies	1,000	Survivals	0.00030	

Table C-13. In vitro malignant/morphological cell transformation: dose-response data

Record number	Reference	PAH	Dose	Dose units	Transformation measure				n	units	% Response	Notes
					Mean	SD	SE	Units				
		BbF	0.5	µg/mL	0.6			Transformed colonies	1,000	Survivals	0.00060	
		BbF	1	µg/mL	1.2			Transformed colonies	1,000	Survivals	0.0012	
		BaA	0.025	µg/mL	0			Transformed colonies	1,000	Survivals	0	
		BaA	0.1	µg/mL	0.3			Transformed colonies	1,000	Survivals	0.00030	
		BaA	0.25	µg/mL	0.3			Transformed colonies	1,000	Survivals	0.00030	
		BaA	0.5	µg/mL	0.6			Transformed colonies	1,000	Survivals	0.00060	
		BaA	1	µg/mL	1			Transformed colonies	1,000	Survivals	0.0010	
	Expt 2	Control	0	µg/mL	0			Transformed colonies	1,000	Survivals	0	
		BaP	0.01	µg/mL	0.4			Transformed colonies	1,000	Survivals	0.00040	
		BaP	0.05	µg/mL	1			Transformed colonies	1,000	Survivals	0.0010	
		BaP	0.1	µg/mL	2.9			Transformed colonies	1,000	Survivals	0.0029	
		BaP	0.25	µg/mL	4.6			Transformed colonies	1,000	Survivals	0.0046	
		BaP	0.5	µg/mL	7.8			Transformed colonies	1,000	Survivals	0.0078	
		IP	0.025	µg/mL	0			Transformed colonies	1,000	Survivals	0	
		IP	0.1	µg/mL	0.3			Transformed colonies	1,000	Survivals	0.00030	
		IP	0.25	µg/mL	0.3			Transformed colonies	1,000	Survivals	0.00030	
		IP	0.5	µg/mL	0.7			Transformed colonies	1,000	Survivals	0.00070	
		IP	1	µg/mL	1			Transformed colonies	1,000	Survivals	0.0010	

Table C-13. In vitro malignant/morphological cell transformation: dose-response data

Record number	Reference	PAH	Dose	Dose units	Transformation measure				n	units	% Response	Notes
					Mean	SD	SE	Units				
14130	Greb et al., 1980	BaP	NA		277			%/mmol				
		CH	NA		37			%/mmol				
		BaA	NA		13.9			%/mmol				
		BbF	NA		11.5			%/mmol				
		DBahA	NA		0.3			%/mmol				
		BeP	NA		3.1			%/mmol				
14640	Krolewski et al., 1986	Control	0	µM	0			Transformation frequency	1,000	Viable cells	0	
		BaP	5	µM	5.5	0.7		Transformation frequency	1,000	Viable cells	0.0055	
		CPcdP	5	µM	1.7	0.3		Transformation frequency	1,000	Viable cells	0.0017	
14700	Laaksonen et al., 1983	Control	0	µM	0			Foci	1 × 10 ⁵	Surviving cells	0	
		BaP	5	µM	0.8			Foci	1 × 10 ⁵	Surviving cells	0.0000080	Inverse dose-response relationship possible due to cytotoxicity; use peak
		BaP	10	µM	0.9			Foci	1 × 10 ⁵	Surviving cells	0.0000090	
		BaP	20	µM	0.3			Foci	1 × 10 ⁵	Surviving cells	0.0000030	
		BaP	40	µM	0.4			Foci	1 × 10 ⁵	Surviving cells	0.0000040	
		Control	0		0			Foci	1 × 10 ⁵	Surviving cells	0	
		BaA	11	µM	1.8			Foci	1 × 10 ⁵	Surviving cells	0.000018	Inverse dose-response relationship possible due to cytotoxicity; use peak
		BaA	22	µM	1.5			Foci	1 × 10 ⁵	Surviving cells	0.000015	
		BaA	44	µM	1.1			Foci	1 × 10 ⁵	Surviving cells	0.000011	
		BaA	88	µM	0.8			Foci	1 × 10 ⁵	Surviving cells	0.0000080	
14850	Lubet et al., 1983	Control	0	µg/mL	0			Dishes with Type III foci		Total dishes	0	
		BaP	1	µg/mL	1			Dishes with Type III foci	15	Total dishes	0.067	
		BaP	3	µg/mL	4			Dishes with Type III foci	15	Total dishes	0.267	
		BaP	10	µg/mL	5			Dishes with Type III foci	15	Total dishes	0.333	

Table C-13. In vitro malignant/morphological cell transformation: dose-response data

Record number	Reference	PAH	Dose	Dose units	Transformation measure				n	units	% Response	Notes
					Mean	SD	SE	Units				
		BeP	10	µg/mL	0			Dishes with Type III foci	15	Total dishes	0	
		BeP	30	µg/mL	1			Dishes with Type III foci	15	Total dishes	0.067	
		BeP	100	µg/mL	7			Dishes with Type III foci	15	Total dishes	0.467	
24710	Mohapatra et al., 1987	Control	0	µg/mL	0			Dishes with Type II or III foci	48	Dishes scored	0	
		BaP	1	µg/mL	44			Dishes with Type II or III foci	48	Dishes scored	0.92	
		BjAC	0.01	µg/mL	2			Dishes with Type II or III foci	48	Dishes scored	0.04	
		BjAC	0.05	µg/mL	5			Dishes with Type II or III foci	48	Dishes scored	0.1	
		BjAC	0.5	µg/mL	34			Dishes with Type II or III foci	48	Dishes scored	0.71	
		BjAC	1	µg/mL	45			Dishes with Type II or III foci	48	Dishes scored	0.94	
		BjAC	2	µg/mL	48			Dishes with Type II or III foci	48	Dishes scored	1	
		Control	0	µg/mL	0			Dishes with Type II or III foci	60	Dishes scored	0	
		BaP	1	µg/mL	50			Dishes with Type II or III foci	60	Dishes scored	0.83	
		BIAC	0.5	µg/mL	8			Dishes with Type II or III foci	60	Dishes scored	0.13	
		BIAC	1	µg/mL	14			Dishes with Type II or III foci	60	Dishes scored	0.26	
		BIAC	2.5	µg/mL	31			Dishes with Type II or III foci	60	Dishes scored	0.52	
		BIAC	5	µg/mL	42			Dishes with Type II or III foci	60	Dishes scored	0.7	
		BIAC	10	µg/mL	51			Dishes with Type II or III foci	60	Dishes scored	0.85	
		Control	0	µg/mL	0			Dishes with Type II or III foci	36	Dishes scored	0	

Table C-13. In vitro malignant/morphological cell transformation: dose-response data

Record number	Reference	PAH	Dose	Dose units	Transformation measure				n	units	% Response	Notes
					Mean	SD	SE	Units				
		BaP	1	µg/mL	31			Dishes with Type II or III foci	36	Dishes scored	0.86	
		BeAC	0.5	µg/mL	4			Dishes with Type II or III foci	36	Dishes scored	0.11	
		BeAC	1	µg/mL	6			Dishes with Type II or III foci	36	Dishes scored	0.17	
		BeAC	2.5	µg/mL	13			Dishes with Type II or III foci	36	Dishes scored	0.36	
		BeAC	5	µg/mL	15			Dishes with Type II or III foci	36	Dishes scored	0.42	
		BeAC	10	µg/mL	21			Dishes with Type II or III foci	36	Dishes scored	0.58	
24700	Nesnow et al., 1990	Acetone	0	µg/mL	25			Anchorage independent colonies/ 50,000 cells				
		BaP	0.1	µg/mL	43	14.7		Anchorage independent colonies/ 50,000 cells				
		BaP	0.5	µg/mL	42	20.7		Anchorage independent colonies/ 50,000 cells				
		BaP	2.5	µg/mL	39	19.5		Anchorage independent colonies/ 50,000 cells				
		BaP	10	µg/mL	72	23.1		Anchorage independent colonies/ 50,000 cells				
		Acetone	0	µg/mL	30			Anchorage independent colonies/ 50,000 cells				

Table C-13. In vitro malignant/morphological cell transformation: dose-response data

Record number	Reference	PAH	Dose	Dose units	Transformation measure			Units	n	units	% Response	Notes
					Mean	SD	SE					
		BIAC	0.1	µg/mL	74	5.2		Anchorage independent colonies/50,000 cells				
		BIAC	0.5	µg/mL	68	14.4		Anchorage independent colonies/50,000 cells				
		BIAC	2.5	µg/mL	123	15.6		Anchorage independent colonies/50,000 cells				
		BIAC	10	µg/mL	150	16.8		Anchorage independent colonies/50,000 cells				
7980	Nesnow et al., 1997	Control	0	µM	0	0		Type II and III foci/dish				
		BaP	0.4	µM	0.44	0.24		Type II and III foci/dish				
		BaP	1.2	µM	1.25	0.15		Type II and III foci/dish				
		BaP	4	µM	2.54	0.56		Type II and III foci/dish				
		DBaP	0.0033	µM	0.14	0.35		Type II and III foci/dish				
		DBaP	0.1	µM	1	0.24		Type II and III foci/dish				
		DBaP	0.33	µM	1.74	0.78		Type II and III foci/dish				
7990	Nesnow et al., 1994	Control	0	µg/mL	0.06	0.10		Type II and III foci/dish				
		BaP	1	µg/mL	1	0.43		Type II and III foci/dish				
		DBaH	0.25	µg/mL	0.23	0.21		Type II and III foci/dish				
		DBaH	0.5	µg/mL	0.25	0.33		Type II and III foci/dish				

Table C-13. In vitro malignant/morphological cell transformation: dose-response data

Record number	Reference	PAH	Dose	Dose units	Transformation measure			n	units	% Response	Notes	
					Mean	SD	SE					Units
		DBahA	1	µg/mL	0.43	0.11		Type II and III foci/dish				
		DBahA	2.5	µg/mL	0.29	0.085		Type II and III foci/dish				
8000	Nesnow et al., 1993a	Control	0	µg/mL	0			Type II and III foci/dish				
		BaP	0.3	µg/mL	0.48			Type II and III foci/dish				
		BaP	1	µg/mL	0.665			Type II and III foci/dish				
		BaP	3	µg/mL	1.4			Type II and III foci/dish				
		Control	0	µg/mL	0			Type II and III foci/dish				
		DBkmno APH	0.5	µg/mL	0.23			Type II and III foci/dish				
		DBkmno APH	1	µg/mL	0.52			Type II and III foci/dish				
		DBkmno APH	2.5	µg/mL	0.605			Type II and III foci/dish				
		DBkmno APH	5	µg/mL	1.085			Type II and III foci/dish				
23720	Pienta et al., 1977	Control	0	µg/mL	0			Transformed colonies	504	Surviving colonies	0	BaP and BaA data also reported in Record 18020 Dunkel 1981
		BaP	1	µg/mL	1			Transformed colonies	393	Surviving colonies	0.0025	
		BaP	5	µg/mL	2			Transformed colonies	406	Surviving colonies	0.0049	
		BaP	10	µg/mL	3			Transformed colonies	434	Surviving colonies	0.0069	
		BaP	20	µg/mL	5			Transformed colonies	410	Surviving colonies	0.0122	
		BaP	40	µg/mL	4			Transformed colonies	427	Surviving colonies	0.0094	
		Control	0	µg/mL	0			Transformed colonies	229	Surviving colonies	0	

Table C-13. In vitro malignant/morphological cell transformation: dose-response data

Record number	Reference	PAH	Dose	Dose units	Transformation measure				n	units	% Response	Notes
					Mean	SD	SE	Units				
		BaA	0.1	µg/mL	1			Transformed colonies	225	Surviving colonies	0.0044	
		BaA	0.5	µg/mL	2			Transformed colonies	252	Surviving colonies	0.0079	
		BaA	1	µg/mL	2			Transformed colonies	193	Surviving colonies	0.0104	
		BaA	5	µg/mL	1			Transformed colonies	312	Surviving colonies	0.0032	
		BaA	10	µg/mL	7			Transformed colonies	250	Surviving colonies	0.028	
		Control	0	µg/mL	0			Transformed colonies	229	Surviving colonies	0	
		DBahA	0.1	µg/mL	0			Transformed colonies	219	Surviving colonies	0	
		DBahA	0.5	µg/mL	4			Transformed colonies	233	Surviving colonies	0.0172	
		DBahA	1	µg/mL	4			Transformed colonies	217	Surviving colonies	0.0184	
		DBahA	5	µg/mL	5			Transformed colonies	270	Surviving colonies	0.0185	
		DBahA	10	µg/mL	0			Transformed colonies	232	Surviving colonies	0	

Table C-14. In vitro DNA adducts: data use

Record number	Reference	Page	Table number	Figure number	PAHs	Data to be extracted	Basis for RPF	Comment	Notes
16890	Allen and Coombs, 1980	245	1		BaP, BaA	μmol compound/mol DNA P ₁	Point estimate	Adducts in nuclear and mitochondrial DNA	Calculate separate RPFs for nuclear and mitochondrial DNA
6300	Binkova et al., 2000	62		3	BaP, DBaP	Adducts at each dose level	Ratio of slopes	Slope of adduct versus dose curve	May need to drop high-dose data for adequate fit
9510	Bryla and Weyand, 1992	39	1		BaP, BaA, DBaC	Adducts at each dose level	Ratio of slopes	Slope of adduct versus dose curve under light conditions (maximum response for all compounds)	
22800	Grover and Sims, 1968	160	1		BaP, DBaH, DBaC, BaA, Pyr, PH	Reaction with DNA	Point estimate		
10660	Johnsen et al., 1998	80		2	BjAC, BIAC, BaP	Total adduct levels in human lymphocytes and HL-60 cells	Point estimate	Total adducts formed in human lymphocytes or HL-60 cells	Calculate RPFs separately by cell type
10670	Johnsen et al., 1997	196	II		BjAC, BIAC, BaP	DNA adduct levels in PCB-treated rat lung cells	Point estimate	Adducts in PCB-treated rat lung Clara and Type 2 cells	Calculate RPFs separately by cell type
7870	Melendez-Colon et al., 2000	13		2	BaP, DBaP	Stable DNA adducts at each dose level	Ratio of slopes	Slope of adduct versus dose curve at two doses	
21200	Segerback and Vodicka, 1993	2,465		3	Pyr, BghiP, FA, DBaH, BbF, BaP, BaA, CH	Total adduct levels	Point estimate	Total adduct level in optimized nuclease P1 adduct enrichment procedure	

Table C-15. In vitro DNA adducts: dose-response data

Record number	Reference	PAH	Dose	Dose units	DNA adducts			n	Units	Notes
					Mean	SD	Adduct units			
16890	Allen and Coombs, 1980	BaP	0.235	µg/mL	7.5	1.9	µmol/mol DNA P			Nuclear DNA
		BaA	0.644	µg/mL	0.44	0.11	µmol/mol DNA P			Nuclear DNA
		BaP	0.235	µg/mL	413	164	µmol/mol DNA P			Mitochondrial DNA
		BaA	0.644	µg/mL	104	40.2	µmol/mol DNA P			Mitochondrial DNA
6300	Binkova et al., 2000	BaP	0.010	µM	1.8	1.16	Adducts	1 × 10 ⁸	Nucleotides	
			0.10	µM	18	7.18	Adducts	1 × 10 ⁸	Nucleotides	
			0.40	µM	95	39.4	Adducts	1 × 10 ⁸	Nucleotides	
			1.0	µM	258	115	Adducts	1 × 10 ⁸	Nucleotides	
			4.0	µM	205	81.9	Adducts	1 × 10 ⁸	Nucleotides	
			10	µM	69	21.9	Adducts	1 × 10 ⁸	Nucleotides	
			40	µM	37	10.8	Adducts	1 × 10 ⁸	Nucleotides	
		DBaP	0.010	µM	179	55.3	Adducts	1 × 10 ⁸	Nucleotides	
			0.020	µM	534	52.6	Adducts	1 × 10 ⁸	Nucleotides	
			0.040	µM	1,304	375	Adducts	1 × 10 ⁸	Nucleotides	
			0.080	µM	1,696	644	Adducts	1 × 10 ⁸	Nucleotides	
			0.10	µM	2,317	774	Adducts	1 × 10 ⁸	Nucleotides	
			0.40	µM	1,971	729	Adducts	1 × 10 ⁸	Nucleotides	
			1.0	µM	632	170	Adducts	1 × 10 ⁸	Nucleotides	
9510	Bryla and Weyand, 1992	BaP	0.12	nmol	0.17		Adducts	1 × 10 ⁷	Nucleotides	Light conditions; max for BaP and others
		BaP	12	nmol	1.37		Adducts	1 × 10 ⁷	Nucleotides	
		BaP	120	nmol	2.21		Adducts	1 × 10 ⁷	Nucleotides	
		BaP	600	nmol	5.45		Adducts	1 × 10 ⁷	Nucleotides	
		BaA	0.12	nmol	0.15		Adducts	1 × 10 ⁷	Nucleotides	
		BaA	12	nmol	0.09		Adducts	1 × 10 ⁷	Nucleotides	
		BaA	120	nmol	0.8		Adducts	1 × 10 ⁷	Nucleotides	
		BaA	600	nmol	0.95		Adducts	1 × 10 ⁷	Nucleotides	

Table C-15. In vitro DNA adducts: dose-response data

Record number	Reference	PAH	Dose	Dose units	DNA adducts			n	Units	Notes
					Mean	SD	Adduct units			
		DBacA	0.12	nmol	0		Adducts	1×10^7	Nucleotides	
		DBacA	12	nmol	0.06		Adducts	1×10^7	Nucleotides	
		DBacA	120	nmol	0.57		Adducts	1×10^7	Nucleotides	
		DBacA	600	nmol	1.76		Adducts	1×10^7	Nucleotides	
22800	Grover and Sims, 1968	BaP	5	µg	1.41		µmol/g-atom of DNA P			
		DBahA	5	µg	0.44		µmol/g-atom of DNA P			
		DBacA	5	µg	0.56		µmol/g-atom of DNA P			
		BaA	5	µg	0.7		µmol/g-atom of DNA P			
		Pyr	5	µg	0.31		µmol/g-atom of DNA P			
		PH	5	µg	0.05		µmol/g-atom of DNA P			
10670	Johnsen et al., 1997	BaP	30	µg/mL	0.05		fmol adducts/µg DNA			Clara cells
		BjAC	30	µg/mL	0.15		fmol adducts/µg DNA			Clara cells
		BIAC	30	µg/mL	0.24		fmol adducts/µg DNA			Clara cells
		BaP	30	µg/mL	0.02		fmol adducts/µg DNA			Type 2 cells
		BjAC	30	µg/mL	0.06		fmol adducts/µg DNA			Type 2 cells
		BIAC	30	µg/mL	0.03		fmol adducts/µg DNA			Type 2 cells
10660	Johnsen et al., 1998	BaP	30	µg/mL	0.333	0.093	fmol adducts/µg DNA	3		Human lymphocytes
		BjAC	30	µg/mL	0.110	0.026	fmol adducts/µg DNA	3		Human lymphocytes
		BIAC	30	µg/mL	1.089	0.595	fmol adducts/µg DNA	3		Human lymphocytes
		BaP	30	µg/mL	0.239	0.172	fmol adducts/µg DNA	3		HL-60 cells

Table C-15. In vitro DNA adducts: dose-response data

Record number	Reference	PAH	Dose	Dose units	DNA adducts			n	Units	Notes
					Mean	SD	Adduct units			
		BjAC	30	µg/mL	0.149	0.146	fmol adducts/µg DNA	3		HL-60 cells
		BIAC	30	µg/mL	0.942	0.344	fmol adducts/µg DNA	3		HL-60 cells
7870	Melendez-Colon et al., 2000	BaP	1	µm	18	8.07	Stable adducts	1 × 10 ⁶	Nucleotides	
		BaP	2	µm	34	6.46	Stable adducts	1 × 10 ⁶	Nucleotides	
		DBaP	1	µm	254	4.30	Stable adducts	1 × 10 ⁶	Nucleotides	
		DBaP	2	µm	348	17.20	Stable adducts	1 × 10 ⁶	Nucleotides	
21200	Segeberback and Vodicka, 1993	BaP	100	mM	15		µmol adducts per mol dNp			
		Pyr	100	mM	0.14		µmol adducts per mol dNp			
		BghiP	100	mM	0.50		µmol adducts per mol dNp			
		FA	100	mM	1.5		µmol adducts per mol dNp			
		DBahA	100	mM	2.8		µmol adducts per mol dNp			
		BbF	100	mM	3.7		µmol adducts per mol dNp			
		BaA	100	mM	30		µmol adducts per mol dNp			
		CH	100	mM	50		µmol adducts per mol dNp			

1
2

Table C-16. In vitro DNA damage: data use

Record number	Reference	Page	Table number	Figure number	PAHs	Data to be extracted	Basis for RPF	Comment	Notes
16840	Agrelo and Amos, 1981	531	2		BaP, Pyr	Hydroxyurea inhibited [³ H]-thymidine incorporation into cells (dpm) and dose (µg/mL); use 10 µg/mL dose for BaP and 100 µg/mL dose for pyrene	Point estimate		
23790	Ichinotsubo et al., 1977	56	Table II		BaP, DBaiP, DBahA	Use column designated JC5519 +S9 for BaP, DBaiP, and DBahA; dose as µg/well and response as diameter of zone of inhibition (mm); the control is wild type strain AB1157	Point estimate	<i>E. coli</i> Rec BC, S9 identification unknown	
10660	Johnsen et al., 1998	82		4	BaP, BjaC, BIAC	DNA damage (NAAC, 10 ⁻³ h ⁻¹), SD and dose (µg/mL) for both human lymphocytes and HL-60 cells; use 24 h + 1 h AraC/HU data (crosshatched bars)	Ratio of slopes (human lymphocytes); point estimates (HL-60 cells)		Model as continuous data
19740	Martin et al., 1978	2,624	1		BaP, BeP, BaA, DBaC, DBahA	Maximum dpm/µg DNA above background and dose (M); dose is in column marked "M"	Point estimate	Background already subtracted	
19830	Mersch-Sundermann et al., 1992	3-6	2		BaP, AA, BaA, BbF, BghiF, BjF, BbFE, BghiP, BeP, CH, DBaC, DBahA, DBaP, DBahP, DBaiP, FA, IP, PH, Tphen	SOS induction potential for assay (+S9) for each compound (already incorporates dose)	Ratio of SOS induction potentials	SOSIP reported in text as slope of steepest portion of the induction factor dose-response curve	No modeling necessary; slopes reported in text
20810	Robinson and Mitchell, 1981	520	1		BaP, Pyr	Maximum [³ H]-TDR incorporation and dose (test concentration in µg/mL in parentheses after maximum) for rows with metabolic activation (+); use compound-specific background [³ H]-TDR incorporation in same row	Point estimate		
20940	Rossmann et al., 1991	354	2		BaP, AC, DBaC, DBahA, PH	Max enhancement of prophage induction over background and dose (amount at max, in µg/well) for those rows with S9 (+ rows).	Point estimate	Background already addressed	
21730	Tong et al., 1981b	480	I		BaP, BaA	DNA repair grains/nucleus, SD, and dose (M); four doses BaA, three doses BaP and DMSO control	Ratio of slopes		Model as continuous data

Table C-17. In vitro DNA damage: dose-response data

Record number	Reference	PAH	Dose	Dose units	Endpoint	DNA damage			n	Notes
						Mean	SD	Units		
16840	Agrelo and Amos, 1981	Control	0	µg/mL	Unscheduled DNA synthesis	177		dpm		HU inhibited
		BaP	0.001	µg/mL	Unscheduled DNA synthesis	195		dpm		HU inhibited
		BaP	0.01	µg/mL	Unscheduled DNA synthesis	126		dpm		HU inhibited
		BaP	0.1	µg/mL	Unscheduled DNA synthesis	262		dpm		HU inhibited
		BaP	1	µg/mL	Unscheduled DNA synthesis	818		dpm		HU inhibited
		BaP	10	µg/mL	Unscheduled DNA synthesis	2,270		dpm		HU inhibited
		BaP	100	µg/mL	Unscheduled DNA synthesis	819		dpm		HU inhibited
		BaP	1,000	µg/mL	Unscheduled DNA synthesis	373		dpm		HU inhibited
		Control	0	µg/mL	Unscheduled DNA synthesis	1,168		dpm		HU inhibited
		Pyr	0.032	µg/mL	Unscheduled DNA synthesis	1,293		dpm		HU inhibited
		Pyr	0.16	µg/mL	Unscheduled DNA synthesis	1,192		dpm		HU inhibited
		Pyr	0.8	µg/mL	Unscheduled DNA synthesis	1,367		dpm		HU inhibited
		Pyr	4	µg/mL	Unscheduled DNA synthesis	1,510		dpm		HU inhibited
		Pyr	20	µg/mL	Unscheduled DNA synthesis	1,694		dpm		HU inhibited
		Pyr	100	µg/mL	Unscheduled DNA synthesis	1,716		dpm		HU inhibited
23790	Ichinotsubo et al., 1977	Control	0		DNA damage	0		Diameter of zone of inhibition mm		
		BaP	70	µg/well	DNA damage	6		Diameter of zone of inhibition mm		
		Control	0		DNA damage	0		Diameter of zone of inhibition mm		
		DBaiP	600	µg/well	DNA damage	10		Diameter of zone of inhibition mm		
		Control	0		DNA damage	0		Diameter of zone of inhibition mm		

Table C-17. In vitro DNA damage: dose-response data

Record number	Reference	PAH	Dose	Dose units	Endpoint	DNA damage			n	Notes
						Mean	SD	Units		
		DBahA	25	µg/well	DNA damage	10		Diameter of zone of inhibition mm		
10660	Johnsen et al., 1998	DMSO	0	µg/mL	DNA damage	4.4	1.3	NAAC, 10 ⁻³ h ⁻¹	3	Human lymphocytes with AraC/HU
		BaP	3	µg/mL	DNA damage	12	3.2	NAAC, 10 ⁻³ h ⁻⁶	3	Human lymphocytes with AraC/HU; no continuous linear model fit
			30	µg/mL	DNA damage	15	2.7	NAAC, 10 ⁻³ h ⁻⁷	3	Human lymphocytes with AraC/HU
		BjAC	3	µg/mL	DNA damage	6.0	2.1	NAAC, 10 ⁻³ h ⁻²	3	Human lymphocytes with AraC/HU
			30	µg/mL	DNA damage	9.4	3.4	NAAC, 10 ⁻³ h ⁻³	3	Human lymphocytes with AraC/HU
		BIAC	3	µg/mL	DNA damage	8.2	3.2	NAAC, 10 ⁻³ h ⁻⁴	3	Human lymphocytes with AraC/HU; no continuous linear model fit
			30	µg/mL	DNA damage	9.3	2.1	NAAC, 10 ⁻³ h ⁻⁵	3	Human lymphocytes with AraC/HU
		DMSO	0	µg/mL	DNA damage	7.8	3.1	NAAC, 10 ⁻³ h ⁻⁵	3	HL-60 cells with AraC/HU
		BaP	30	µg/mL	DNA damage	13.2	9.5	NAAC, 10 ⁻³ h ⁻⁵	3	HL-60 cells with AraC/HU
		BjAC	30	µg/mL	DNA damage	9.6	3.0	NAAC, 10 ⁻³ h ⁻⁵	3	HL-60 cells with AraC/HU
		BIAC	30	µg/mL	DNA damage	11.6	5.5	NAAC, 10 ⁻³ h ⁻⁵	3	HL-60 cells with AraC/HU
19740	Martin et al., 1978	BaP	1 × 10 ⁻⁵	M	Unscheduled DNA synthesis	210		Maximum dpm/µg DNA		Increase above background
		BeP	1 × 10 ⁻⁶	M	Unscheduled DNA synthesis	256		Maximum dpm/µg DNA		Increase above background
		BaA	1 × 10 ⁻⁷	M	Unscheduled DNA synthesis	59		Maximum dpm/µg DNA		Increase above background
		DBacA	1 × 10 ⁻⁵	M	Unscheduled DNA synthesis	97		Maximum dpm/µg DNA		Increase above background
		DBahA	1 × 10 ⁻⁵	M	Unscheduled DNA synthesis	96		Maximum dpm/µg DNA		Increase above background

Table C-17. In vitro DNA damage: dose-response data

Record number	Reference	PAH	Dose	Dose units	Endpoint	DNA damage			n	Notes
						Mean	SD	Units		
19830	Mersch-Sundermann et al., 1992	BaP	NA		SOS induction potential	0.605	NA			Steepest slope of induction factor dose-response curve; + S9
		AA	NA		SOS induction potential	0.142	NA			Steepest slope of induction factor dose-response curve; + S9
		BaA	NA		SOS induction potential	0.1	NA			Steepest slope of induction factor dose-response curve; + S9
		BbF	NA		SOS induction potential	0.045	NA			Steepest slope of induction factor dose-response curve; + S9
		BghiF	NA		SOS induction potential	0.34	NA			Steepest slope of induction factor dose-response curve; + S9
		BjF	NA		SOS induction potential	0.254	NA			Steepest slope of induction factor dose-response curve; + S9
		BbFE	NA		SOS induction potential	0.024	NA			Steepest slope of induction factor dose-response curve; + S9
		BghiP	NA		SOS induction potential	0.033	NA			Steepest slope of induction factor dose-response curve; + S9
		BeP	NA		SOS induction potential	0.032	NA			Steepest slope of induction factor dose-response curve; + S9
		CH	NA		SOS induction potential	0.221	NA			Steepest slope of induction factor dose-response curve; + S9
		DBacA	NA		SOS induction potential	0.104	NA			Steepest slope of induction factor dose-response curve; + S9
		DBahA	NA		SOS induction potential	0.039	NA			Steepest slope of induction factor dose-response curve; + S9
		DBalP	NA		SOS induction potential	2.1	NA			Steepest slope of induction factor dose-response curve; + S9
		DBahP	NA		SOS induction potential	0.117	NA			Steepest slope of induction factor dose-response curve; + S9
		DBaiP	NA		SOS induction potential	0.174	NA			Steepest slope of induction factor dose-response curve; + S9
		FA	NA		SOS induction potential	0.412	NA			Steepest slope of induction factor dose-response curve; + S9

Table C-17. In vitro DNA damage: dose-response data

Record number	Reference	PAH	Dose	Dose units	Endpoint	DNA damage			n	Notes
						Mean	SD	Units		
		IP	NA		SOS induction potential	0.036	NA			Steepest slope of induction factor dose-response curve; + S9
		PH	NA		SOS induction potential	0.053	NA			Steepest slope of induction factor dose-response curve; + S9
		Tphen	NA		SOS induction potential	0.26	NA			Steepest slope of induction factor dose-response curve; + S9
20810	Robinson and Mitchell, 1981	Control	0	µg/mL	Unscheduled DNA synthesis	53	4	[³ H]-TdR incorporation		Maximum [³ H]-TdR incorporation
		BaP	10	µg/mL	Unscheduled DNA synthesis	142	7	[³ H]-TdR incorporation		Maximum [³ H]-TdR incorporation
		Control	0	µg/mL	Unscheduled DNA synthesis	52	2	[³ H]-TdR incorporation		Maximum [³ H]-TdR incorporation
		Pyr	7.2	µg/mL	Unscheduled DNA synthesis	115	9	[³ H]-TdR incorporation		Maximum [³ H]-TdR incorporation
20940	Rossmann et al., 1991	BaP	12.5	µg/mL	DNA damage	10.4		Lambda pro-phage induction		Maximum enhancement over background
		AC	12.5	µg/mL	DNA damage	4.8		Lambda pro-phage induction		Maximum enhancement over background
		DBacA	1.44	µg/mL	DNA damage	8		Lambda pro-phage induction		Maximum enhancement over background
		DBahA	2	µg/mL	DNA damage	4		Lambda pro-phage induction		Maximum enhancement over background
		PH	25	µg/mL	DNA damage	4.5		Lambda pro-phage induction		Maximum enhancement over background

Table C-17. In vitro DNA damage: dose-response data

Record number	Reference	PAH	Dose	Dose units	Endpoint	DNA damage			n	Notes
						Mean	SD	Units		
21730	Tong et al., 1981b	Control	0	M	Unscheduled DNA synthesis	0.1	0.1	Grains/nucleus		
		BaP	1×10^{-4}	M	Unscheduled DNA synthesis	45.1	3.7	Grains/nucleus		
		BaP	5×10^{-4}	M	Unscheduled DNA synthesis	47.7	3.7	Grains/nucleus		
		BaP	1×10^{-3}	M	Unscheduled DNA synthesis	65.6	17.8	Grains/nucleus		
		BaA	5×10^{-5}	M	Unscheduled DNA synthesis	0.6		Grains/nucleus		
		BaA	1×10^{-4}	M	Unscheduled DNA synthesis	14.8	2.6	Grains/nucleus		
		BaA	5×10^{-4}	M	Unscheduled DNA synthesis	17.2	6	Grains/nucleus		
		BaA	1×10^{-3}	M	Unscheduled DNA synthesis	Toxic		Grains/nucleus		

1

Table C-18. In vitro clastogenicity: data use

Record number	Reference	Page	Table number	PAHs	Data to be used	Basis for RPF	Comment
14620	Kochhar, 1982	846	Not numbered	BaP, BaA	Percentage of cells with aberrations and dose ($\mu\text{g/mL}$)	Ratio of slopes	Model as incidence data
14640	Krolewski et al., 1986	1,648	II	BaP, CPcdP	Mean number sister chromatid exchange/ chromosome, SD, and dose (μM)	Ratio of slopes	Use first column of data; not data with AIA or IVA; model as continuous data
19690	Mane et al., 1990	81	III	BaP, BaA	Sister chromatid exchange frequencies/ for V79 cell + rat MEC and dose	Point estimates	Use sister chromatid exchange data for V79 + rat MEC only
21710	Tong et al., 1981a	469	1	BaP, BaA	Sister chromatid exchange/cell, SD, and dose	Point estimates	Continuous data, no n provided in study

1

Table C-19. In vitro clastogenicity: dose-response data

Record number	Reference	PAH	Dose	Dose units	n	Clastogenicity			Notes
						Mean	SD	Units	
14620	Kochhar, 1982	Control	0	µg/mL	100	0.06		Fraction cells with aberrations	
		BaP	0.6	µg/mL	100	0.23		Fraction cells with aberrations	
		BaP	1.25	µg/mL	100	0.32		Fraction cells with aberrations	
		BaP	2.5	µg/mL	100	0.45		Fraction cells with aberrations	
		BaP	5	µg/mL	100	0.56		Fraction cells with aberrations	
		BaA	0.6	µg/mL	100	0.17		Fraction cells with aberrations	
		BaA	1.25	µg/mL	100	0.23		Fraction cells with aberrations	
		BaA	2.5	µg/mL	100	0.3		Fraction cells with aberrations	
		BaA	5	µg/mL	100	0.38		Fraction cells with aberrations	
14640	Krolewski et al., 1986	Control	0	µM	30	0.147	0.059	Sister chromatid exchange	
		BaP	1	µM	30	0.874	0.275	Sister chromatid exchange	
		BaP	5	µM	30	0.932	0.266	Sister chromatid exchange	
		CPcdP	1	µM	30	0.348	0.119	Sister chromatid exchange	
		CPcdP	5	µM	30	0.432	0.15	Sister chromatid exchange	
19690	Mane et al., 1990	Control	0	µg/mL		0.3	1	Sister chromatid exchange frequency	For V79 cell + rat MEC
		BaP	1	µg/mL		3	1	Sister chromatid exchange frequency	For V79 cell + rat MEC
		BaA	1	µg/mL		0.7	0.5	Sister chromatid exchange frequency	For V79 cell + rat MEC
21710	Tong et al., 1981a	Control	0	M		11.15	3.81	Sister chromatid exchange/cell	
		BaP	1 × 10 ⁻⁶	M		16.15	3.83	Sister chromatid exchange/cell	
		BaP	1 × 10 ⁻⁵	M		59.75	16.96	Sister chromatid exchange/cell	
		BaP	1 × 10 ⁻⁴	M		103.3	22.75	Sister chromatid exchange/cell	
		Control	0	M		15.75	5.18	Sister chromatid exchange/cell	
		BaA	1 × 10 ⁻⁵	M		21.2	9.59	Sister chromatid exchange/cell	
		BaA	1 × 10 ⁻⁴	M		29.15	9.93	Sister chromatid exchange/cell	
		BaA	1 × 10 ⁻³	M		26.2	6.96	Sister chromatid exchange/cell	

Table C-20. In vivo DNA adducts: data use

Record number	Reference	Page	Table number	Figure number	PAHs	Data to be extracted	Basis for RPF	Comment	Notes
6210	Arif et al., 1997	36		4	DBaP and BaP	Mean adduct levels for heart, pancreas, bladder, liver	Point estimate	Mean adduct levels summed across mammary epithelial, lung, heart, pancreas, bladder, liver	
17630	Cavalieri et al., 1981a	491	3		CPcdP, ACEP (reported in paper as CPAP), BaP	Done	Point estimate	DNA-bound PAH in mouse skin after 4-hr or 24-hr treatment	Calculate separate RPFs for 4-hr and 24-hr treatment
18810	Hughes and Phillips, 1990	1,614		3	DBaP, DBaeP, DBahP, DBaiP, BaP	AUC for skin and lung through 84 d	Point estimate	Sum of AUCs for skin and lung 0–84 d	
11190	Mass et al., 1993	188	1		BjAC, BaP	Done	Ratio of Slopes	AUC (adduct-time curve) versus dose for lung adducts 24–72 hr	
8010	Nesnow et al., 1993b	39		1 and 2	BbF, BaP	AUC for lung, liver, and PBL through 56 d	Point estimate	Sum of AUCs for lung, liver, and lymphocytes 0–56 d	
24590/20920	Nesnow et al., 1998b; Ross et al., 1995	402	2		BaP, BbF, DBahA, CPcdP, DBaP	Done	Ratio of Slopes	Slope of TIDAL/dose (slope reported in Record 24590 based on data from Record 20920); DBaP data reported in separate study without BaP concurrent	
22810	Phillips et al., 1979	205	I		DBahA, DBacA, BaP	Done	Point estimate	Peak binding in mouse skin; BaA dropped; not clear if reported level is peak	
24790	Kligerman et al., 2002	846	1		BaA, BaP, BbF, CH	Done	Point estimate	Adducts in mouse or rat PBLs at single time point after either intraperitoneal or gavage administration	Calculate separate RPFs for intraperitoneal and gavage, rat and mouse
24801	Weyand et al., 2004	12, 14		4 and 6	BcFE, BaP	Mean adduct levels for lung and forestomach	Point estimate	Adducts in mouse lung and forestomach at single time point after either intraperitoneal or dietary administration	Calculate separate RPFs for lung and forestomach after oral exposure and for lung after intraperitoneal exposure

Table C-21. In vivo DNA adducts: dose-response data

Record number	Reference	PAH	Species	Dose	Dose units	Organ	Time	DNA adducts				Slope of AUC versus dose	Comments
								Mean	SD	SE	Adduct units		
6210	Arif et al., 1997	Control	Rat	0	µmol/mammary gland	Liver		0			Adducts/10 ⁹ nucleotides		
		BaP	Rat	0.25	µmol/mammary gland	Mammary gland		300	45		Adducts/10 ⁹ nucleotides		
		BaP	Rat	0.25	µmol/mammary gland	Lung		11	1.3		Adducts/10 ⁹ nucleotides		
		BaP	Rat	0.25	µmol/mammary gland	Heart		9.5			Adducts/10 ⁹ nucleotides		
		BaP	Rat	0.25	µmol/mammary gland	Pancreas		0			Adducts/10 ⁹ nucleotides		
		BaP	Rat	0.25	µmol/mammary gland	Bladder		0			Adducts/10 ⁹ nucleotides		
		BaP	Rat	0.25	µmol/mammary gland	Liver		4.5			Adducts/10 ⁹ nucleotides		
						Sum		324.74					
		DBaP	Rat	0.25	µmol/mammary gland	Mammary gland		1,878	378		Adducts/10 ⁹ nucleotides		
		DBaP	Rat	0.25	µmol/mammary gland	Lung		85	24		Adducts/10 ⁹ nucleotides		
		DBaP	Rat	0.25	µmol/mammary gland	Heart		64			Adducts/10 ⁹ nucleotides		
		DBaP	Rat	0.25	µmol/mammary gland	Pancreas		32			Adducts/10 ⁹ nucleotides		
		DBaP	Rat	0.25	µmol/mammary gland	Bladder		69			Adducts/10 ⁹ nucleotides		
		DBaP	Rat	0.25	µmol/mammary gland	Liver		116			Adducts/10 ⁹ nucleotides		
						Sum		2,244.63					
17630	Cavalieri et al., 1981a	BaP		0.2	µmol/mouse	Skin	4 hr	16.3		1	µmol adduct/mol DNA		
		CPcdP		0.2	µmol/mouse	Skin	4 hr	2.3		0.2	µmol adduct/mol DNA		
		ACEP		0.2	µmol/mouse	Skin	4 hr	2.2		0.1	µmol adduct/mol DNA		
		BaP		0.2	µmol/mouse	Skin	24 hr	6.7		1.6	µmol adduct/mol DNA		

Table C-21. In vivo DNA adducts: dose-response data

Record number	Reference	PAH	Species	Dose	Dose units	Organ	Time	DNA adducts				Slope of AUC versus dose	Comments
								Mean	SD	SE	Adduct units		
		CPcdP		0.2	μmol/mouse	Skin	24 hr	8.8		1	μmol adduct/mol DNA		
		ACEP		0.2	μmol/mouse	Skin	24 hr	0.30		0.1	μmol adduct/mol DNA		
18810	Hughes and Phillips, 1990	BaP		1	μmol	Skin	1 d	7.8			fmol adducts/μg DNA		Only peak extracted; interrupted scale precluded digitizing
		BaP		1	μmol	Lung	2 d	1.2			fmol adducts/μg DNA		
		BaP		1	μmol	Sum skin and lung		9.0			fmol adducts/μg DNA		
		DBaP		1	μmol	Skin	2 d	0.50			fmol adducts/μg DNA		
		DBaP		1	μmol	Lung	7 d	Cannot determine			fmol adducts/μg DNA		
		DBaP		1	μmol	Sum skin and lung		Cannot determine			fmol adducts/μg DNA		
		DBaH		1	μmol	Skin	2 d	3.1			fmol adducts/μg DNA		
		DBaH		1	μmol	Lung	2 d	0.14			fmol adducts/μg DNA		
		DBaH		1	μmol	Sum skin and lung		3.2			fmol adducts/μg DNA		
		DBaI		1	μmol	Skin	2 d	0.75			fmol adducts/μg DNA		
		DBaI		1	μmol	Lung	2 d	0.10			fmol adducts/μg DNA		
		DBaI		1	μmol	Sum skin and lung		0.85			fmol adducts/μg DNA		
		DBaL		1	μmol	Skin	1 d	62			fmol adducts/μg DNA		
		DBaL		1	μmol	Lung	2 d	2.3			fmol adducts/μg DNA		
		DBaL		1	μmol	Sum skin and lung		65			fmol adducts/μg DNA		

Table C-21. In vivo DNA adducts: dose-response data

Record number	Reference	PAH	Species	Dose	Dose units	Organ	Time	DNA adducts				Slope of AUC versus dose	Comments
								Mean	SD	SE	Adduct units		
11190	Mass et al., 1993	BaP		20	mg/kg bw	Lung	24 hr	116	53		amol adducts/μg DNA		AUC calculated using trapezoid rule
		BaP		20	mg/kg bw	Lung	48 hr	122	25		amol adducts/μg DNA		
		BaP		20	mg/kg bw	Lung	72 hr	181	101		amol adducts/μg DNA		
		BaP		50	mg/kg bw	Lung	24 hr	120	20		amol adducts/μg DNA		
		BaP		50	mg/kg bw	Lung	48 hr	201	170		amol adducts/μg DNA		
		BaP		50	mg/kg bw	Lung	72 hr	432	274		amol adducts/μg DNA		
		BaP		100	mg/kg bw	Lung	24 hr	427	140		amol adducts/μg DNA		
		BaP		100	mg/kg bw	Lung	48 hr	407	197		amol adducts/μg DNA		
		BaP		100	mg/kg bw	Lung	72 hr	2,004	314		amol adducts/μg DNA		
		BaP		20	mg/kg bw	Lung	AUC	7,884				469.73	
		BaP		50	mg/kg bw	Lung	AUC	12,888					
		BaP		100	mg/kg bw	Lung	AUC	44,064					
		BjAC		20	mg/kg bw	Lung	24 hr	63	34		amol adducts/μg DNA		AUC calculated using trapezoid rule
		BjAC		20	mg/kg bw	Lung	48 hr	97	101		amol adducts/μg DNA		
		BjAC		20	mg/kg bw	Lung	72 hr	255	392		amol adducts/μg DNA		
		BjAC		50	mg/kg bw	Lung	24 hr	116	121		amol adducts/μg DNA		
		BjAC		50	mg/kg bw	Lung	48 hr	402	237		amol adducts/μg DNA		
		BjAC		50	mg/kg bw	Lung	72 hr	1,954	1,921		amol adducts/μg DNA		
		BjAC		100	mg/kg bw	Lung	24 hr	180	133		amol adducts/μg DNA		

Table C-21. In vivo DNA adducts: dose-response data

Record number	Reference	PAH	Species	Dose	Dose units	Organ	Time	DNA adducts				Slope of AUC versus dose	Comments
								Mean	SD	SE	Adduct units		
		BjAC		100	mg/kg bw	Lung	48 hr	532	559		amol adducts/μg DNA		
		BjAC		100	mg/kg bw	Lung	72 hr	2,439	2,242		amol adducts/μg DNA		
		BjAC		20	mg/kg bw	Lung	AUC	6,900				464.25	
		BjAC		50	mg/kg bw	Lung	AUC	35,880					
		BjAC		100	mg/kg bw	Lung	AUC	46,356					
8010	Nesnow et al., 1993b	BaP		100	mg/kg	Lung	d 1	453					AUC calculated using trapezoid rule
		BaP		100	mg/kg	Lung	d 3	1,001					
		BaP		100	mg/kg	Lung	d 7	574					
		BaP		100	mg/kg	Lung	d 14	386					
		BaP		100	mg/kg	Lung	d 28	381					
		BaP		100	mg/kg	Lung	d 56	143					
		BaP		100	mg/kg	Lung	AUC	20,892					
		BaP		100	mg/kg	Liver	d 1	398					
		BaP		100	mg/kg	Liver	d 3	1,317					
		BaP		100	mg/kg	Liver	d 7	931					
		BaP		100	mg/kg	Liver	d 14	537					
		BaP		100	mg/kg	Liver	d 28	394					
		BaP		100	mg/kg	Liver	d 56	116					
		BaP		100	mg/kg	Liver	AUC	25,207					
		BaP		100	mg/kg	PBL	d 1	158					
		BaP		100	mg/kg	PBL	d 3	273					
		BaP		100	mg/kg	PBL	d 7	162					
		BaP		100	mg/kg	PBL	d 14	187					
		BaP		100	mg/kg	PBL	d 28	72					
		BaP		100	mg/kg	PBL	d 56	41					
		BaP		100	mg/kg	PBL	AUC	5,985					
		BaP		100	mg/kg	Sum of AUCs		52,084					
		BbF		100	mg/kg	Lung	d 1	21					AUC calculated using trapezoid rule

Table C-21. In vivo DNA adducts: dose-response data

Record number	Reference	PAH	Species	Dose	Dose units	Organ	Time	DNA adducts				Slope of AUC versus dose	Comments
								Mean	SD	SE	Adduct units		
		BbF		100	mg/kg	Lung	d 3	184					
		BbF		100	mg/kg	Lung	d 5	233					
		BbF		100	mg/kg	Lung	d 7	211					
		BbF		100	mg/kg	Lung	d 14	229					
		BbF		100	mg/kg	Lung	d 28	145					
		BbF		100	mg/kg	Lung	d 56	106					
		BbF		100	mg/kg	Lung	AUC	8,763					
		BbF		100	mg/kg	Liver	d 1	12					
		BbF		100	mg/kg	Liver	d 3	35					
		BbF		100	mg/kg	Liver	d 5	51					
		BbF		100	mg/kg	Liver	d 7	61					
		BbF		100	mg/kg	Liver	d 14	21					
		BbF		100	mg/kg	Liver	d 28	15					
		BbF		100	mg/kg	Liver	d 56	12					
		BbF		100	mg/kg	Liver	AUC	1,173					
		BbF		100	mg/kg	PBL	d 1	12					
		BbF		100	mg/kg	PBL	d 3	29					
		BbF		100	mg/kg	PBL	d 5	59					
		BbF		100	mg/kg	PBL	d 7	57					
		BbF		100	mg/kg	PBL	d 14	40					
		BbF		100	mg/kg	PBL	d 28	15					
		BbF		100	mg/kg	PBL	d 56	13					
		BbF		100	mg/kg	PBL	AUC	1,378					
		BbF		100	mg/kg	Sum of AUCs		11,314					
24590/20920	Nesnow et al., 1998b; Ross, 1995	BaP		NA		Lung	>21 d			3.9		113	Slope of dose versus TIDAL value (in fmol-d/ μ g DNA)
		BbF		NA		Lung	>21 d			5		37.5	Slope of dose versus TIDAL value (in fmol-d/ μ g DNA)

Table C-21. In vivo DNA adducts: dose-response data

Record number	Reference	PAH	Species	Dose	Dose units	Organ	Time	DNA adducts				Slope of AUC versus dose	Comments
								Mean	SD	SE	Adduct units		
		CPcdP		NA		Lung	>21 d			3.69		148	Slope of dose versus TIDAL value (in fmol-d/ μ g DNA)
		DBahA		NA		Lung	>21 d			19.1		219	Slope of dose versus TIDAL value (in fmol-d/ μ g DNA)
		DBaP		NA		Lung	>21 d			267		1,390	Slope of dose versus TIDAL value (in fmol-d/ μ g DNA)
22810	Phillips et al., 1979	BaP		1	μ mol/mouse	Skin	19 hr	27			pmol adducts/mg DNA		peak
		DBacA		1	μ mol/mouse	Skin	24 hr	10			pmol adducts/mg DNA		peak
		DBahA		1	μ mol/mouse	Skin	72 hr	15			pmol adducts/mg DNA		peak
24790	Kligerman et al., 2002	BaP	Mice	100	mg/kg	PBL	d 7	4,186	273		amol adducts/ μ g DNA		Intraperitoneal
		BaA	Mice	100	mg/kg	PBL	d 7	93	8		amol adducts/ μ g DNA		Intraperitoneal
		BbF	Mice	100	mg/kg	PBL	d 7	516	7		amol adducts/ μ g DNA		Intraperitoneal
		CH	Mice	100	mg/kg	PBL	d 7	81	11		amol adducts/ μ g DNA		Intraperitoneal
		Control	Mice	0	mg/kg	PBL	d 7	0			amol adducts/ μ g DNA		Intraperitoneal
		BaP	Mice	100	mg/kg	PBL	d 7	143	17		amol adducts/ μ g DNA		Gavage
		BaA	Mice	100	mg/kg	PBL	d 7	32	2		amol adducts/ μ g DNA		Gavage
		BbF	Mice	100	mg/kg	PBL	d 7	39	4		amol adducts/ μ g DNA		Gavage
		CH	Mice	100	mg/kg	PBL	d 7	37	1		amol adducts/ μ g DNA		Gavage
		Control	Mice	0	mg/kg	PBL	d 7	0			amol adducts/ μ g DNA		Gavage

Table C-21. In vivo DNA adducts: dose-response data

Record number	Reference	PAH	Species	Dose	Dose units	Organ	Time	DNA adducts				Slope of AUC versus dose	Comments
								Mean	SD	SE	Adduct units		
		BaP	Rat	100	mg/kg	PBL	d 7	755	56		amol adducts/μg DNA	Intraperitoneal	
		BaA	Rat	100	mg/kg	PBL	d 7	38	3		amol adducts/μg DNA	Intraperitoneal	
		BbF	Rat	100	mg/kg	PBL	d 7	63	1		amol adducts/μg DNA	Intraperitoneal	
		CH	Rat	100	mg/kg	PBL	d 7	24	2		amol adducts/μg DNA	Intraperitoneal	
		Control	Rat	0	mg/kg	PBL	d 7	0			amol adducts/μg DNA	Intraperitoneal	
		BaP	Rat	100	mg/kg	PBL	d 7	177	30		amol adducts/μg DNA	Gavage	
		BaA	Rat	100	mg/kg	PBL	d 7	20	2		amol adducts/μg DNA	Gavage	
		BbF	Rat	100	mg/kg	PBL	d 7	17	1		amol adducts/μg DNA	Gavage	
		CH	Rat	100	mg/kg	PBL	d 7	10	4		amol adducts/μg DNA	Gavage	
		Control	Rat	0	mg/kg	PBL	d 7	0			amol adducts/μg DNA	Gavage	
24801	Weyand et al., 2004	BaP	Mice	230	mg/kg food	Lung	d 14	0.084		0.009	pmol adducts/mg DNA	Diet	
		BcFE	Mice	13.6	mg/kg food	Lung	d 14	0.014		0.002	pmol adducts/mg DNA	Diet	
		BcFE	Mice	197	mg/kg food	Lung	d 14	0.18		0.023	pmol adducts/mg DNA	Diet	
		BaP	Mice	230	mg/kg food	Forestomach	d 14	0.033		0.005	pmol adducts/mg DNA	Diet	
		BcFE	Mice	197	mg/kg food	Forestomach	d 14	0.0092		0.001	pmol adducts/mg DNA	Diet	
		BaP	Mice	230	mg/kg food	Sum of lung and forestomach	d 14	0.117			pmol adducts/mg DNA	Diet	
		BcFE	Mice	13.6	mg/kg food	Sum of lung and forestomach	d 14	0.014			pmol adducts/mg DNA	Diet	

Table C-21. In vivo DNA adducts: dose-response data

Record number	Reference	PAH	Species	Dose	Dose units	Organ	Time	DNA adducts				Slope of AUC versus dose	Comments
								Mean	SD	SE	Adduct units		
		BcFE	Mice	197	mg/kg food	Sum of lung and forestomach	d 14	0.19			pmol adducts/mg DNA		Diet
		BaP	Mice	100	mg/kg bw	Lung	24 h	0.78		0.13	pmol adducts/mg DNA		Intraperitoneal
		BcFE	Mice	100	mg/kg bw	Lung	24 h	0.33		0.030	pmol adducts/mg DNA		Intraperitoneal

Table C-22. In vivo clastogenicity: data use

Record number	Reference	Page	Table number	Figure number	PAHs	Data to be extracted	Basis for RPF	Comment
24740	Allen et al., 1999		I and III		BaP, DBaP	Total micronucleated polychromatic erythrocytes (MN-PCEs) and dose (mg/kg); extract data for bone marrow and peripheral blood for both A/J mice (Table 1) and p53 ^{+/+} (wild type) mice (Table III)	Point estimate	Incidence data; single dose BaP
14270	He and Baker, 1991	166	1		BaP, CH	MN cells/1,000 binucleated and dose (µg/mouse)	Ratio of slopes	Incidence data
17190	Bayer, 1978	426	3		BaP, PH	Sister chromatid exchange/cells and dose (mg/kg)	Point estimate	Continuous data; only one dose PH significant; BaP given as 3,4-BaP
20950	Roszinsky-Kocher et al., 1979	66	1		BaP, DBaP, A, CH, PH, BeP, BbF, BaA	Sister chromatid exchanges/metaphase and dose (mg/kg)	Point estimate	
24720	Kligerman et al., 1986	129	3		BaP, BlAC	Sister chromatid exchanges/metaphase and dose (mg/kg)	Point estimate	Continuous data, no SD for control; use lowest dose approaching peak
24790	Kligerman et al., 2002	846	1		BaP, BaA, BbF, CH	Sister chromatid exchanges/metaphase, intraperitoneal, for BaP, BaA, BbF, and CH; sister chromatid exchanges, gavage, for BaP and BaA (use 17.91 value for BaP); also use MN bn/1,000 bn, gavage, for BaP and BbF; dose in mg/kg	Point estimates	Separate RPFs for sister chromatid exchanges and micronuclei, oral and intraperitoneal

Table C-23. In vivo clastogenicity: dose-response data

Record number	Reference	PAH	Route of administration	Clastogenicity								<i>p</i> < 0.05	Notes
				Dose	Dose units	Mean	SD	Units	n	% Response	Units		
24740	Allen et al., 1999	Tri-caprylin	Intra-peritoneal	0	mg/kg	2.6		MN-PCEs	1,000	0.0026	PCEs		A/J mice, bone marrow
		BaP	Intra-peritoneal	200	mg/kg	11.2		MN-PCEs	1,000	0.0112	PCEs	x	
		DBalP	Intra-peritoneal	0.3	mg/kg	2		MN-PCEs	1,000	0.0020	PCEs		
		DBalP	Intra-peritoneal	1.5	mg/kg	3.9		MN-PCEs	1,000	0.0039	PCEs	x	
		DBalP	Intra-peritoneal	3	mg/kg	3.4		MN-PCEs	1,000	0.0034	PCEs		
		DBalP	Intra-peritoneal	6	mg/kg	3.8		MN-PCEs	1,000	0.0038	PCEs		
		Tri-caprylin	Intra-peritoneal	0	mg/kg	2.8		MN-PCEs	1,000	0.0028	PCEs		A/J mice, peripheral blood
		BaP	Intra-peritoneal	200	mg/kg	9.5		MN-PCEs	1,000	0.0095	PCEs	x	
		DBalP	Intra-peritoneal	0.3	mg/kg	2.8		MN-PCEs	1,000	0.0028	PCEs		
		DBalP	Intra-peritoneal	1.5	mg/kg	2.9		MN-PCEs	1,000	0.0029	PCEs		
		DBalP	Intra-peritoneal	3	mg/kg	4		MN-PCEs	1,000	0.0040	PCEs		
		DBalP	Intra-peritoneal	6	mg/kg	4.3		MN-PCEs	1,000	0.0043	PCEs	x	
		Tri-caprylin	Intra-peritoneal	0	mg/kg	3.2		MN-PCEs	1,000	0.0032	PCEs		p53 +/- wt mice, bone marrow
		BaP	Intra-peritoneal	200	mg/kg	5.1		MN-PCEs	1,000	0.0051	PCEs	x	
		DBalP	Intra-peritoneal	9	mg/kg	4.3		MN-PCEs	1,000	0.0043	PCEs		
		DBalP	Intra-peritoneal	12	mg/kg	7.4		MN-PCEs	1,000	0.0074	PCEs	x	
		DBalP	Intra-peritoneal	18	mg/kg	6.1		MN-PCEs	1,000	0.0061	PCEs	x	
		Tri-caprylin	Intra-peritoneal	0	mg/kg	3.5		MN-PCEs	1,000	0.0035	PCEs		p53 +/- wt mice, peripheral blood

Table C-23. In vivo clastogenicity: dose-response data

Record number	Reference	PAH	Route of administration	Clastogenicity								p < 0.05	Notes
				Dose	Dose units	Mean	SD	Units	n	% Response	Units		
		BaP	Intra-peritoneal	200	mg/kg	5.7		MN-PCEs	1,000	0.0057	PCEs	x	
		DBaP	Intra-peritoneal	9	mg/kg	3.1		MN-PCEs	1,000	0.0031	PCEs		
		DBaP	Intra-peritoneal	12	mg/kg	3.1		MN-PCEs	1,000	0.0031	PCEs		
		DBaP	Intra-peritoneal	18	mg/kg	4.6		MN-PCEs	1,000	0.0046	PCEs		
14270	He and Baker, 1991	Control	Dermal	0	µg/mouse	13.3	2.8	MN cells	1,000	0.013	Binucleated		
		BaP	Dermal	0.5	µg/mouse	50.5	11.5	MN cells	1,000	0.051	Binucleated	x	
		BaP	Dermal	5	µg/mouse	66.8	4.1	MN cells	1,000	0.067	Binucleated	x	
		BaP	Dermal	50	µg/mouse	76	2.8	MN cells	1,000	0.076	Binucleated	x	
		BaP	Dermal	100	µg/mouse	64.3	5.4	MN cells	1,000	0.064	Binucleated	x	
		BaP	Dermal	500	µg/mouse	55.8	13	MN cells	1,000	0.056	Binucleated	x	
		Control	Dermal	0	µg/mouse	12.8	2.2	MN cells	1,000	0.013	Binucleated		
		CH	Dermal	50	µg/mouse	43.3	2.2	MN cells	1,000	0.043	Binucleated	x	
		CH	Dermal	100	µg/mouse	56	4.9	MN cells	1,000	0.056	Binucleated	x	
		CH	Dermal	500	µg/mouse	62	8.6	MN cells	1,000	0.062	Binucleated	x	
		CH	Dermal	1,000	µg/mouse	47.3	3.8	MN cells	1,000	0.047	Binucleated	x	
17190	Bayer, 1978	Pooled controls	Intra-peritoneal	0	mg/kg	3.2	0.07	Sister chromatid exchange/cells					
		BaP	Intra-peritoneal	2.5	mg/kg	3.4	0.8	Sister chromatid exchange/cells					
		BaP	Intra-peritoneal	25	mg/kg	3.5	0.2	Sister chromatid exchange/cells					
		BaP	Intra-peritoneal	40	mg/kg	3.9	0.2	Sister chromatid exchange/cells				x	

Table C-23. In vivo clastogenicity: dose-response data

Record number	Reference	PAH	Route of administration	Clastogenicity							p < 0.05	Notes	
				Dose	Dose units	Mean	SD	Units	n	% Response			Units
		BaP	Intra-peritoneal	50	mg/kg	6.4	0.2	Sister chromatid exchange/cells				x	
		BaP	Intra-peritoneal	75	mg/kg	6.4	0.3	Sister chromatid exchange/cells				x	
		BaP	Intra-peritoneal	100	mg/kg	7.4	0.2	Sister chromatid exchange/cells				x	
		PH	Intra-peritoneal	25	mg/kg	3.5	0.2	Sister chromatid exchange/cells					Only one dose significant
		PH	Intra-peritoneal	50	mg/kg	3.4	0.2	Sister chromatid exchange/cells					
		PH	Intra-peritoneal	75	mg/kg	3.5	0.2	Sister chromatid exchange/cells					
		PH	Intra-peritoneal	100	mg/kg	4.1	0.2	Sister chromatid exchange/cells				x	
20950	Roszinsky-Kocher et al., 1979	Control	Intra-peritoneal	0	mg/kg	3.9	0.9	Sister chromatid exchanges/meta-phase					
		BaP	Intra-peritoneal	900	mg/kg	10.6	1.6	Sister chromatid exchanges/meta-phase				x	

Table C-23. In vivo clastogenicity: dose-response data

Record number	Reference	PAH	Route of administration	Clastogenicity							p < 0.05	Notes	
				Dose	Dose units	Mean	SD	Units	n	% Response			Units
		DBahA	Intra-peritoneal	900	mg/kg	4.9	0.7	Sister chromatid exchanges				x	
		CH	Intra-peritoneal	900	mg/kg	5.1	1	Sister chromatid exchanges				x	
		PH	Intra-peritoneal	900	mg/kg	5.5	0.7	Sister chromatid exchanges				x	
		BeP	Intra-peritoneal	900	mg/kg	5.5	0.7	Sister chromatid exchanges				x	
		BbF	Intra-peritoneal	900	mg/kg	5.6	0.5	Sister chromatid exchanges				x	
		BaA	Intra-peritoneal	900	mg/kg	6.1	0.4	Sister chromatid exchanges				x	
24720	Kligerman et al., 1986	Control	Gavage	0	mg/kg	11.9		Sister chromatid exchanges/ meta-phase					
		BaP	Gavage	63	mg/kg	19.4	0.0	Sister chromatid exchanges/ meta-phase					
		BaP	Gavage	252	mg/kg	21.5	1.4	Sister chromatid exchanges/ meta-phase					
		BaP	Gavage	504	mg/kg	21.7	1.4	Sister chromatid exchanges/ meta-phase					
		Control	Gavage	0	mg/kg	11.0		Sister chromatid exchanges/ meta-phase					

Table C-23. In vivo clastogenicity: dose-response data

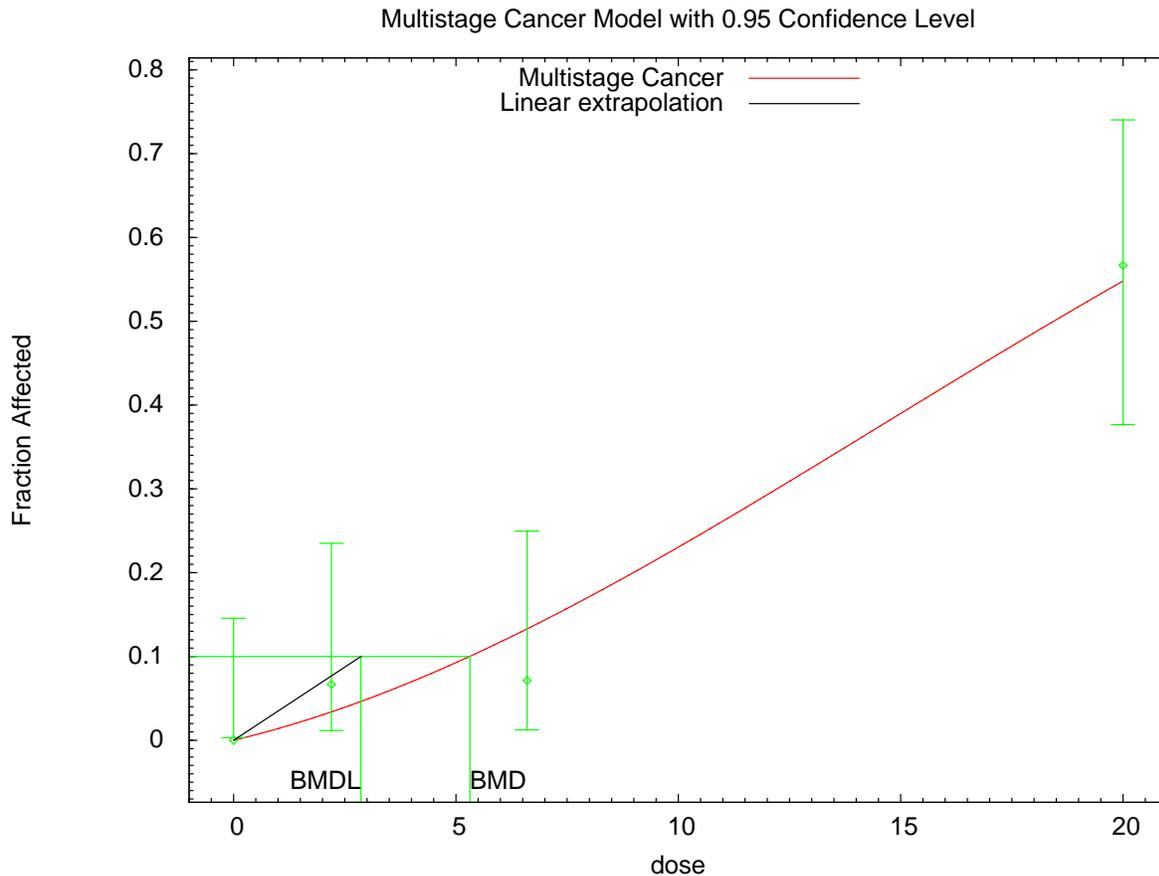
Record number	Reference	PAH	Route of administration	Clastogenicity							p < 0.05	Notes	
				Dose	Dose units	Mean	SD	Units	n	% Response			Units
		BIAC	Gavage	32	mg/kg	16.5	3.6	Sister chromatid exchanges/ meta-phase					
		BIAC	Gavage	63	mg/kg	20.5	1.6	Sister chromatid exchanges/ meta-phase					
		BIAC	Gavage	126	mg/kg	27.8	2.6	Sister chromatid exchanges/ meta-phase					
24790	Kligerman et al., 2002	Control	Intra-peritoneal	0	mg/kg	8.79	1.26	Sister chromatid exchanges					
		BaP	Intra-peritoneal	100	mg/kg	21.21	2.93	Sister chromatid exchanges				x	
		BaA	Intra-peritoneal	100	mg/kg	14.8	3.16	Sister chromatid exchanges				x	
		BbF	Intra-peritoneal	100	mg/kg	22.25	1.45	Sister chromatid exchanges				x	
		CH	Intra-peritoneal	100	mg/kg	11.96	1.8	Sister chromatid exchanges				x	
		Control	Gavage	0	mg/kg	11.12	1.5	Sister chromatid exchanges					
		BaP	Gavage	100	mg/kg	17.91	1.49	Sister chromatid exchanges				x	
		BaA	Gavage	100	mg/kg	13.38	1.53	Sister chromatid exchanges				x	
		Control	Gavage	0	mg/kg	6.6	0.9	MN bn	1,000	0.007	Binucleated		

Table C-23. In vivo clastogenicity: dose-response data

Record number	Reference	PAH	Route of administration	Clastogenicity								<i>p</i> < 0.05	Notes
				Dose	Dose units	Mean	SD	Units	n	% Response	Units		
		BaP	Gavage	100	mg/kg	9.1	1.8	MN bn	1,000	0.009	Binucleated	x	
		BbF	Gavage	100	mg/kg	8.3	0.9	MN bn	1,000	0.008	Binucleated	x	

1 **APPENDIX D. BENCHMARK DOSE MODELING OUTPUTS**

2
3 **D.1. DERMAL BIOASSAYS**



8
9 Cav 1983 bap dermal.out.txt

10
11 =====
12 Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
13 Input Data File:
14 C:\USEPA\IRIS\PAH\dermal\complete\Cavalieri1983\BaP\msc_CavalieriBaP_MS_2.(d)
15 Gnuplot Plotting File:
16 C:\USEPA\IRIS\PAH\dermal\complete\Cavalieri1983\BaP\msc_CavalieriBaP_MS_2.plt
17 Tue Dec 22 14:50:32 2009
18 =====

19
20 BMDS Model Run

21 ~~~~~

22
23 The form of the probability function is:

24
25
$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta1} * \text{dose}^1 - \text{beta2} * \text{dose}^2)]$$

26

1
 2 The parameter betas are restricted to be positive
 3
 4
 5 Dependent variable = incidence
 6 Independent variable = dose
 7
 8 Total number of observations = 4
 9 Total number of records with missing values = 0
 10 Total number of parameters in model = 3
 11 Total number of specified parameters = 0
 12 Degree of polynomial = 2
 13
 14
 15 Maximum number of iterations = 250
 16 Relative Function Convergence has been set to: 2.22045e-016
 17 Parameter Convergence has been set to: 1.49012e-008
 18
 19 **** We are sorry but Relative Function and Parameter Convergence ****
 20 **** are currently unavailable in this model. Please keep checking ****
 21 **** the web sight for model updates which will eventually ****
 22 **** incorporate these convergence criterion. Default values used. ****

23
 24
 25
 26 Default Initial Parameter Values
 27 Background = 0.0155298
 28 Beta(1) = 0
 29 Beta(2) = 0.00204447
 30

31
 32 Asymptotic Correlation Matrix of Parameter Estimates

33
 34 (*** The model parameter(s) -Background
 35 have been estimated at a boundary point, or have been
 36 specified by the user,
 37 and do not appear in the correlation matrix)
 38

	Beta(1)	Beta(2)
Beta(1)	1	-0.96
Beta(2)	-0.96	1

39
 40
 41
 42
 43
 44
 45
 46
 47 Parameter Estimates

Confidence Interval Variable	Estimate	Std. Err.	95.0% Wald
			Lower Conf. Limit
Upper Conf. Limit Background	0	*	*
* Beta(1)	0.0126577	*	*
* Beta(2)	0.00134916	*	*

58 *
 59 *
 60 * - Indicates that this value is not calculated.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48

Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-35.0798	4			
Fitted model	-36.0272	2	1.89478	2	
0.3878 Reduced model	-55.062	1	39.9644	3	<.0001
AIC:	76.0543				

Goodness of Fit

Dose	Est._Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.0000	0.000	0.000	29	0.000
2.2000	0.0338	1.014	2.000	30	0.996
6.6000	0.1326	3.714	2.000	28	-0.955
20.0000	0.5474	16.423	17.000	30	0.212

Chi^2 = 1.95 d.f. = 2 P-value = 0.3772

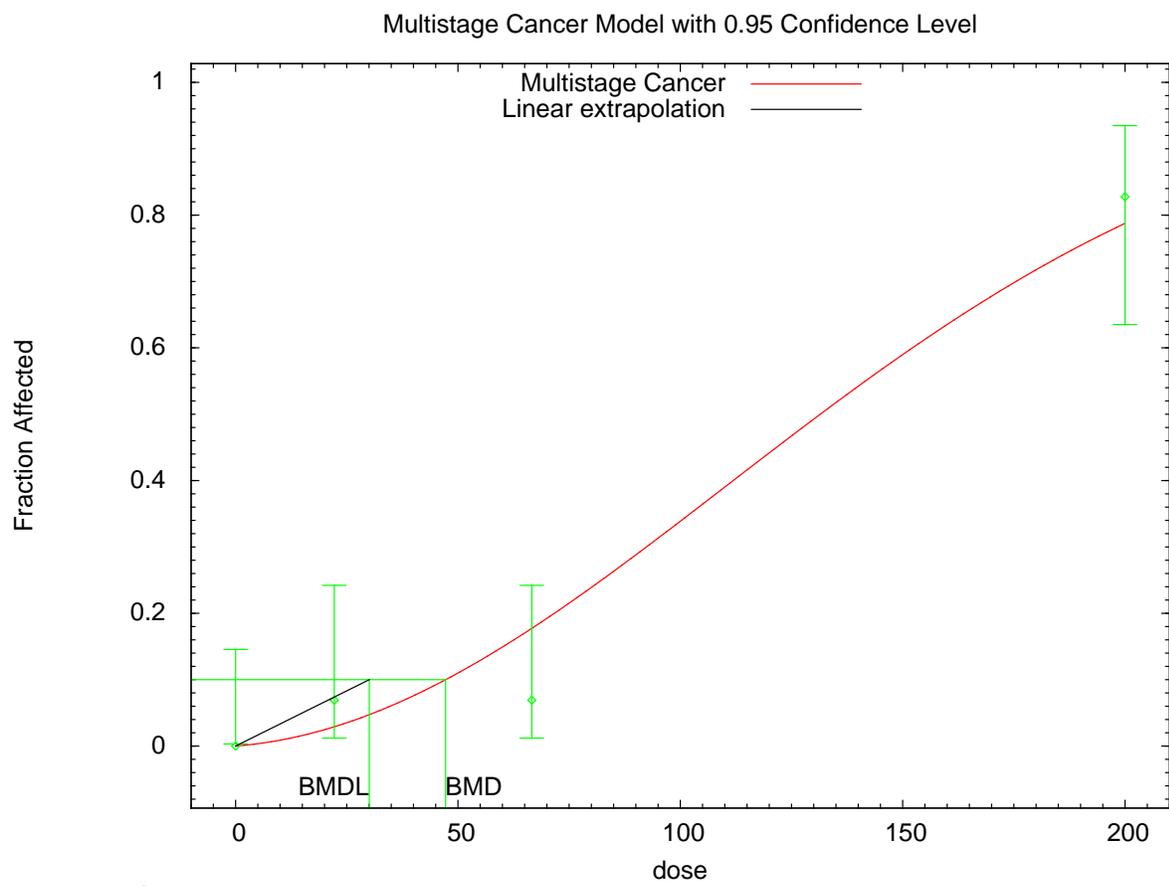
Benchmark Dose Computation

Specified effect = 0.1
 Risk Type = Extra risk
 Confidence level = 0.95
 BMD = 5.31398
 BMDL = 2.86439
 BMDU = 8.84432

Taken together, (2.86439, 8.84432) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 0.0349115

1
2



11:16 12/28 2009

CAVALIERI1983CPcdP.OUT.txt

```
=====  
      Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)  
      Input Data File:  
C:\USEPA\IRIS\PAH\dermal\complete\Cavalieri1983\CPcdP\msc_CavalieriCPcdP_MS_2  
.(d)  
      Gnuplot Plotting File:  
C:\USEPA\IRIS\PAH\dermal\complete\Cavalieri1983\CPcdP\msc_CavalieriCPcdP_MS_2  
.plt  
                                     Tue Dec 22 14:50:32 2009  
=====
```

BMDS Model Run

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta1} * \text{dose}^1 - \text{beta2} * \text{dose}^2)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

1
 2 Total number of observations = 4
 3 Total number of records with missing values = 0
 4 Total number of parameters in model = 3
 5 Total number of specified parameters = 0
 6 Degree of polynomial = 2
 7
 8
 9 Maximum number of iterations = 250
 10 Relative Function Convergence has been set to: 2.22045e-016
 11 Parameter Convergence has been set to: 1.49012e-008
 12
 13 **** We are sorry but Relative Function and Parameter Convergence ****
 14 **** are currently unavailable in this model. Please keep checking ****
 15 **** the web sight for model updates which will eventually ****
 16 **** incorporate these convergence criterion. Default values used. ****

20 Default Initial Parameter Values

21 Background = 0
 22 Beta(1) = 0
 23 Beta(2) = 4.42193e-005

26 Asymptotic Correlation Matrix of Parameter Estimates

27
 28 (*** The model parameter(s) -Background
 29 have been estimated at a boundary point, or have been
 30 specified by the user,
 31 and do not appear in the correlation matrix)

	Beta(1)	Beta(2)
Beta(1)	1	-0.93
Beta(2)	-0.93	1

41 Parameter Estimates

Confidence Interval	Variable	Estimate	Std. Err.	95.0% Wald
				Lower Conf. Limit
Upper Conf. Limit	Background	0	*	*
*	Beta(1)	0.000525847	*	*
*	Beta(2)	3.60995e-005	*	*
*				

54 * - Indicates that this value is not calculated.

58 Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
-------	-----------------	-----------	----------	-----------	---------

1 Full model -27.8865 4
 2 Fitted model -30.0799 2 4.38685 2
 3 0.1115
 4 Reduced model -64.1091 1 72.4452 3 <.0001
 5
 6 AIC: 64.1598
 7
 8
 9

Goodness of Fit

Dose	Est._Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.0000	0.000	0.000	29	0.000
22.2000	0.0290	0.842	2.000	29	1.281
66.6000	0.1773	5.141	2.000	29	-1.527
200.0000	0.7876	22.840	24.000	29	0.527

17
 18 Chi^2 = 4.25 d.f. = 2 P-value = 0.1194
 19

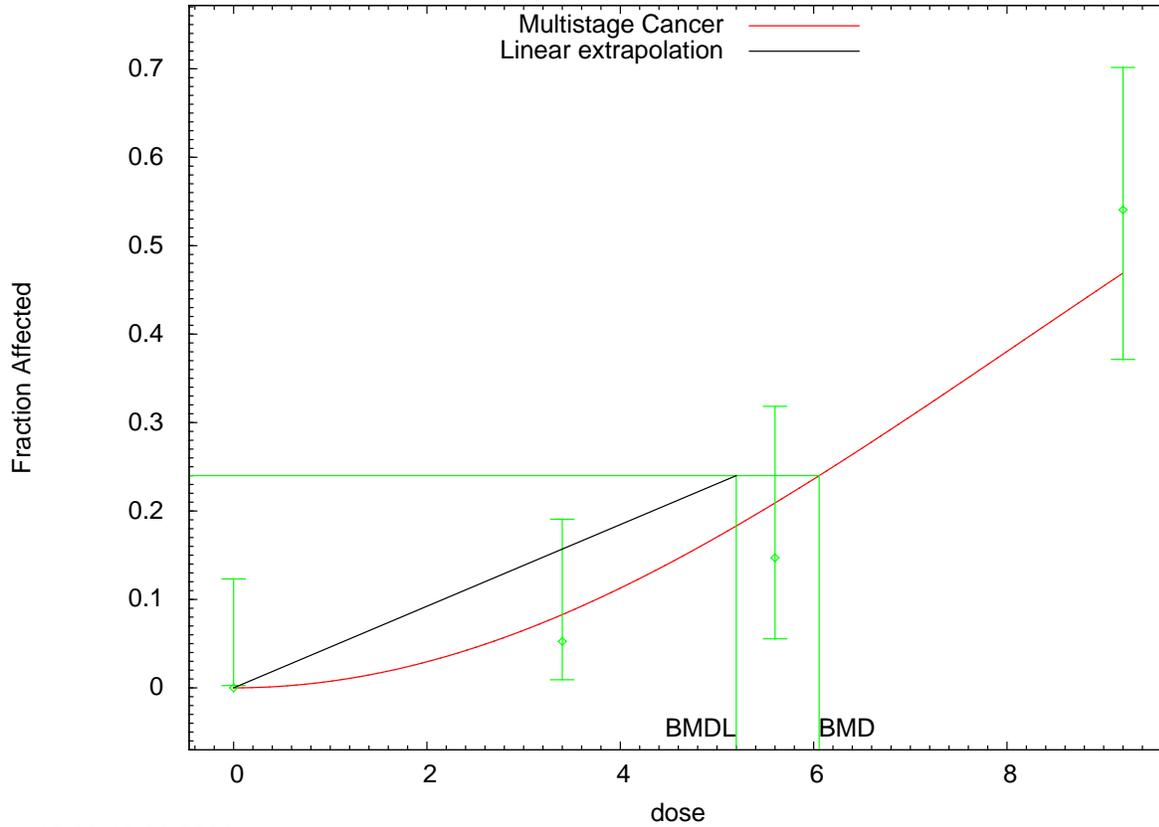
Benchmark Dose Computation

20
 21
 22
 23 Specified effect = 0.1
 24
 25 Risk Type = Extra risk
 26
 27 Confidence level = 0.95
 28
 29 BMD = 47.2296
 30
 31 BMDL = 30.0553
 32
 33 BMDU = 62.746
 34

35 Taken together, (30.0553, 62.746) is a 90 % two-sided confidence
 36 interval for the BMD
 37

38 Multistage Cancer Slope Factor = 0.00332721
 39
 40
 41
 42

Multistage Cancer Model with 0.95 Confidence Level



12:39 12/28 2009

HABS1980BBF.OUT.txt

```

=====
      Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
      Input Data File:
      C:\USEPA\IRIS\PAH\dermal\complete\Habs1980\BbF\msc_HabsBbF_MS_2_10.(d)
      Gnuplot Plotting File:
      C:\USEPA\IRIS\PAH\dermal\complete\Habs1980\BbF\msc_HabsBbF_MS_2_10.plt
      Thu Dec 24 10:03:13 2009
=====
  
```

BMDS Model Run

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta1} * \text{dose}^{1-\text{beta2}} * \text{dose}^2)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

Total number of observations = 4

Total number of records with missing values = 0

1 Total number of parameters in model = 3
 2 Total number of specified parameters = 0
 3 Degree of polynomial = 2
 4
 5
 6 Maximum number of iterations = 250
 7 Relative Function Convergence has been set to: 2.22045e-016
 8 Parameter Convergence has been set to: 1.49012e-008
 9
 10 **** We are sorry but Relative Function and Parameter Convergence ****
 11 **** are currently unavailable in this model. Please keep checking ****
 12 **** the web sight for model updates which will eventually ****
 13 **** incorporate these convergence criterion. Default values used. ****

17 Default Initial Parameter Values

18 Background = 0
 19 Beta(1) = 0
 20 Beta(2) = 0.00945627

23 Asymptotic Correlation Matrix of Parameter Estimates

24 (*** The model parameter(s) -Background -Beta(1)
 25 have been estimated at a boundary point, or have been
 26 specified by the user,
 27 and do not appear in the correlation matrix)
 28

29
 30 Beta(2)
 31
 32 Beta(2) 1

36 Parameter Estimates

Confidence Interval		95.0% Wald		
Variable	Estimate	Std. Err.	Lower	Conf. Limit
Upper Conf. Limit				
Background	0	*	*	
Beta(1)	0	*	*	
Beta(2)	0.00748156	*	*	

49 * - Indicates that this value is not calculated.

53 Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-47.5575	4			
Fitted model	-48.6255	1	2.13602	3	
0.5447					
Reduced model	-69.4912	1	43.8674	3	<.0001

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38

AIC: 99.251

Goodness of Fit

Dose	Est._Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.0000	0.000	0.000	35	0.000
3.4000	0.0829	3.148	2.000	38	-0.676
5.6000	0.2091	7.110	5.000	34	-0.890
9.2000	0.4691	17.358	20.000	37	0.870

Chi^2 = 2.01 d.f. = 3 P-value = 0.5711

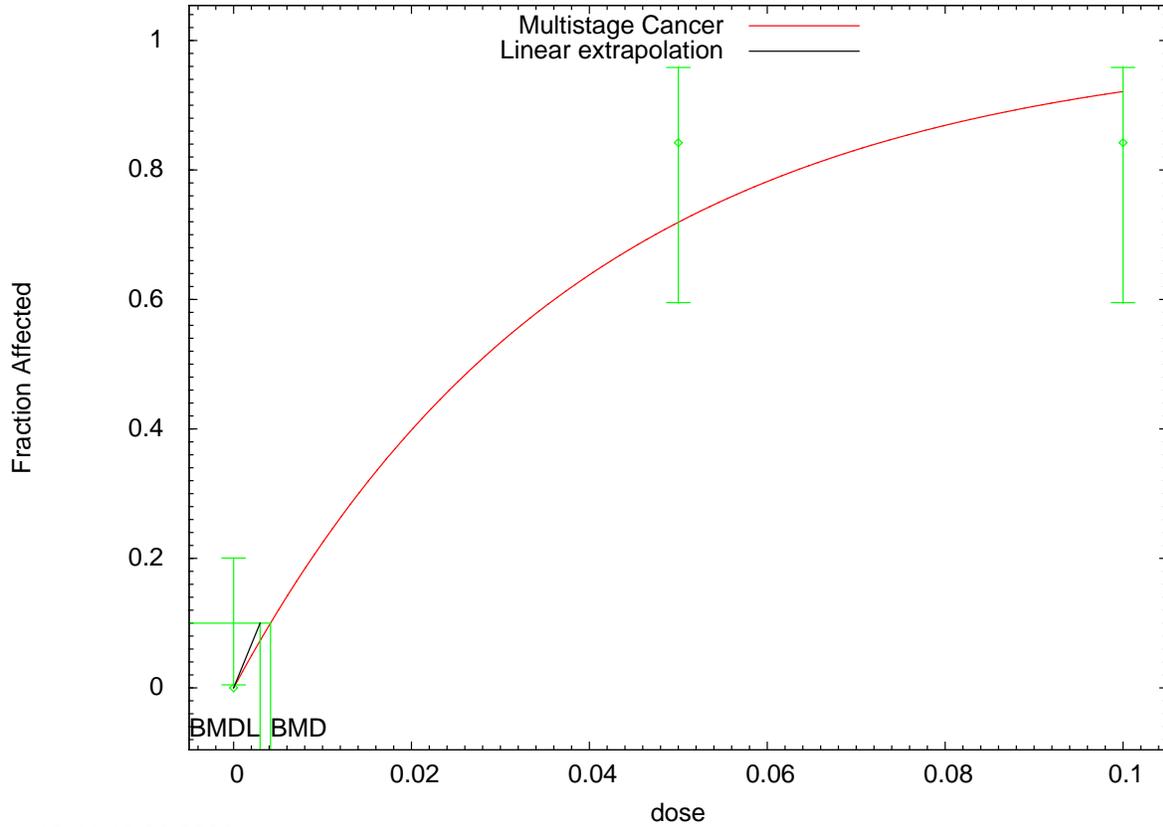
Benchmark Dose Computation

Specified effect = 0.24
Risk Type = Extra risk
Confidence level = 0.95
BMD = 6.05655
BMDL = 5.19938
BMDU = 7.17099

Taken together, (5.19938, 7.17099) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 0.0461594

Multistage Cancer Model with 0.95 Confidence Level



12:44 12/28 2009

HOFFMANWYNDER966DBAIP.OUT.txt

=====

Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)

Input Data File:

C:\USEPA\IRIS\PAH\dermal\complete\HoffWynd1966\DBaiP\msc_HoffWynDBaiP_MS_1.(d
)

Gnuplot Plotting File:

C:\USEPA\IRIS\PAH\dermal\complete\HoffWynd1966\DBaiP\msc_HoffWynDBaiP_MS_1.pl
t

Tue Dec 22 14:50:33 2009

=====

BMDS Model Run

~~~~~

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1 - \text{background}) * [1 - \text{EXP}(-\text{beta}1 * \text{dose}^1)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

Total number of observations = 3

1 Total number of records with missing values = 0  
 2 Total number of parameters in model = 2  
 3 Total number of specified parameters = 0  
 4 Degree of polynomial = 1  
 5  
 6  
 7 Maximum number of iterations = 250  
 8 Relative Function Convergence has been set to: 2.22045e-016  
 9 Parameter Convergence has been set to: 1.49012e-008  
 10  
 11 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 12 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 13 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 14 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

17  
18 Default Initial Parameter Values

19 Background = 0.264818  
 20 Beta(1) = 18.4583  
 21  
 22

23 Asymptotic Correlation Matrix of Parameter Estimates

24  
 25 ( \*\*\* The model parameter(s) -Background  
 26 have been estimated at a boundary point, or have been  
 27 specified by the user,  
 28 and do not appear in the correlation matrix )  
 29

30 Beta(1)  
 31  
 32 Beta(1) 1  
 33  
 34  
 35

36 Parameter Estimates

| Confidence Interval |          | 95.0% Wald |       |             |
|---------------------|----------|------------|-------|-------------|
| Variable            | Estimate | Std. Err.  | Lower | Conf. Limit |
| Upper Conf. Limit   |          |            |       |             |
| Background          | 0        | *          | *     |             |
| Beta(1)             | 25.3832  | *          | *     |             |

47 \* - Indicates that this value is not calculated.

51 Analysis of Deviance Table

| Model         | Log(likelihood) | # Param's | Deviance | Test d.f. | P-value |
|---------------|-----------------|-----------|----------|-----------|---------|
| Full model    | -16.5742        | 3         |          |           |         |
| Fitted model  | -18.019         | 1         | 2.88957  | 2         |         |
| Reduced model | -39.8916        | 1         | 46.6349  | 2         | <.0001  |
| AIC:          | 38.0379         |           |          |           |         |

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34

Goodness of Fit

| Dose   | Est._Prob. | Expected | Observed | Size | Scaled Residual |
|--------|------------|----------|----------|------|-----------------|
| 0.0000 | 0.0000     | 0.000    | 0.000    | 20   | 0.000           |
| 0.0500 | 0.7189     | 13.660   | 16.000   | 19   | 1.194           |
| 0.1000 | 0.9210     | 17.499   | 16.000   | 19   | -1.275          |

Chi^2 = 3.05      d.f. = 2      P-value = 0.2174

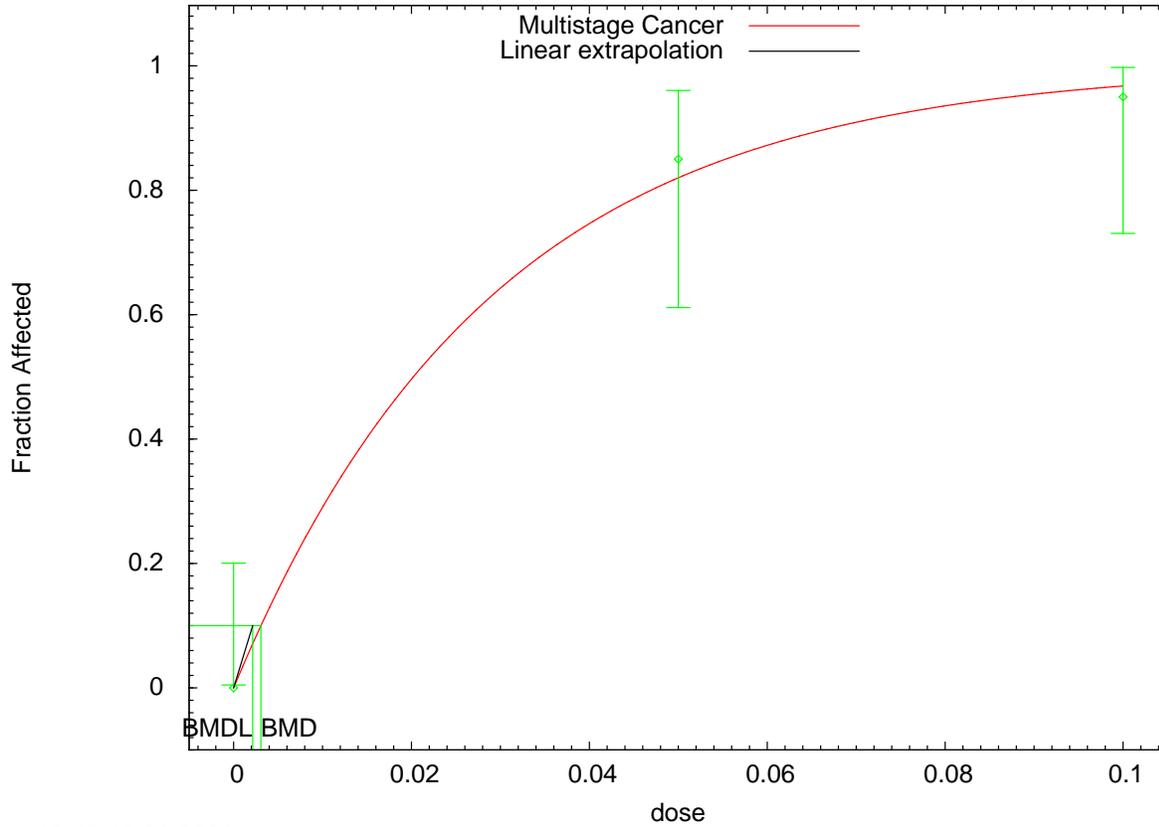
Benchmark Dose Computation

Specified effect =            0.1  
Risk Type            =        Extra risk  
Confidence level =            0.95  
                  BMD =        0.00415079  
                  BMDL =        0.00298234  
                  BMDU =        0.00587793

Taken together, (0.00298234, 0.00587793) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor =            33.5308

Multistage Cancer Model with 0.95 Confidence Level



12:45 12/28 2009

HOFFMANWYNDER1966BAP.OUT.txt

```

=====
Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
Input Data File:
C:\USEPA\IRIS\PAH\dermal\complete\HoffWynd1966\BaP\msc_HoffWynBaP_MS_1.(d)
Gnuplot Plotting File:
C:\USEPA\IRIS\PAH\dermal\complete\HoffWynd1966\BaP\msc_HoffWynBaP_MS_1.plt
Tue Dec 22 14:50:32 2009
=====

```

BMDS Model Run

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1 - \text{background}) * [1 - \text{EXP}(-\text{beta}1 * \text{dose}^1)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence  
Independent variable = dose

Total number of observations = 3  
Total number of records with missing values = 0  
Total number of parameters in model = 2

1 Total number of specified parameters = 0  
 2 Degree of polynomial = 1  
 3  
 4  
 5 Maximum number of iterations = 250  
 6 Relative Function Convergence has been set to: 2.22045e-016  
 7 Parameter Convergence has been set to: 1.49012e-008  
 8  
 9 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 10 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 11 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 12 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

15 Default Initial Parameter Values

17 Background = 0.124609  
 18 Beta(1) = 29.9573

21 Asymptotic Correlation Matrix of Parameter Estimates

22  
 23 ( \*\*\* The model parameter(s) -Background  
 24 have been estimated at a boundarypoint, or have been  
 25 specified by the user,  
 26 and do not appear in the correlation matrix )

27  
 28 Beta(1)  
 29  
 30 Beta(1) 1

34 Parameter Estimates

| Confidence Interval |          | 95.0% Wald |       |             |
|---------------------|----------|------------|-------|-------------|
| Variable            | Estimate | Std. Err.  | Lower | Conf. Limit |
| Background          | 0        | *          | *     |             |
| Beta(1)             | 34.3074  | *          | *     |             |

45 \* - Indicates that this value is not calculated.

49 Analysis of Deviance Table

| Model         | Log(likelihood) | # Param's | Deviance | Test d.f. | P-value |
|---------------|-----------------|-----------|----------|-----------|---------|
| Full model    | -12.4245        | 3         |          |           |         |
| Fitted model  | -12.5735        | 1         | 0.297928 | 2         |         |
| Reduced model | -40.3807        | 1         | 55.9124  | 2         | <.0001  |
| AIC:          | 27.1469         |           |          |           |         |

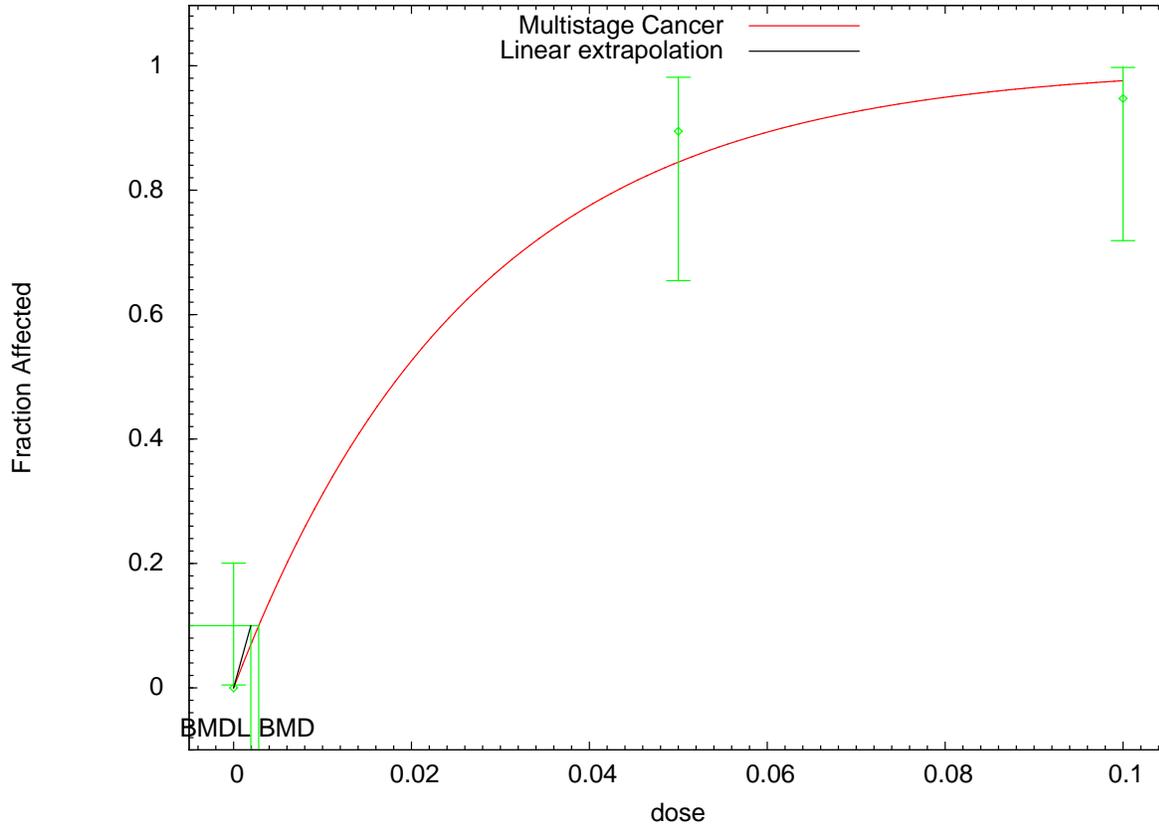
60 Goodness of Fit

```

1
2      Dose      Est._Prob.    Expected    Observed    Size      Scaled
3      -----
4      0.0000    0.0000      0.000      0.000      20       0.000
5      0.0500    0.8201     16.402     17.000     20       0.348
6      0.1000    0.9676     19.353     19.000     20      -0.446
7
8  Chi^2 = 0.32      d.f. = 2      P-value = 0.8522
9
10
11      Benchmark Dose Computation
12
13  Specified effect =          0.1
14
15  Risk Type      =      Extra risk
16
17  Confidence level =          0.95
18
19          BMD =      0.00307107
20
21          BMDL =      0.00215021
22
23          BMDU =      0.00440601
24
25  Taken together, (0.00215021, 0.00440601) is a 90      % two-sided confidence
26  interval for the BMD
27
28  Multistage Cancer Slope Factor =          46.5071
29
30
31

```

Multistage Cancer Model with 0.95 Confidence Level



12:47 12/28 2009

HOFFMANWYNDER1966DBAEF.OUT.txt

=====

Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)

Input Data File:

C:\USEPA\IRIS\PAH\dermal\complete\HoffWynd1966\DBaeF\msc\_HoffWynDBaeF\_MS\_1.(d  
)

Gnuplot Plotting File:

C:\USEPA\IRIS\PAH\dermal\complete\HoffWynd1966\DBaeF\msc\_HoffWynDBaeF\_MS\_1.pl  
t

Tue Dec 22 14:50:34 2009

=====

BMDS Model Run

~~~~~

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta}1 * \text{dose}^1)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

Total number of observations = 3

1 Total number of records with missing values = 0
 2 Total number of parameters in model = 2
 3 Total number of specified parameters = 0
 4 Degree of polynomial = 1
 5
 6
 7 Maximum number of iterations = 250
 8 Relative Function Convergence has been set to: 2.22045e-016
 9 Parameter Convergence has been set to: 1.49012e-008
 10
 11 **** We are sorry but Relative Function and Parameter Convergence ****
 12 **** are currently unavailable in this model. Please keep checking ****
 13 **** the web sight for model updates which will eventually ****
 14 **** incorporate these convergence criterion. Default values used. ****

17 Default Initial Parameter Values

18 Background = 0.22871
 19 Beta(1) = 29.4444

22 Asymptotic Correlation Matrix of Parameter Estimates

23 (*** The model parameter(s) -Background
 24 have been estimated at a boundary point, or have been
 25 specified by the user,
 26 and do not appear in the correlation matrix)
 27
 28

29
 30 Beta(1)
 31
 32 Beta(1) 1

35 Parameter Estimates

Confidence Interval		95.0% Wald		
Variable	Estimate	Std. Err.	Lower	Conf. Limit
Background	0	*	*	
Beta(1)	37.3037	*	*	

37 * - Indicates that this value is not calculated.

48 Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-10.3111	3			
Fitted model	-10.7582	1	0.894194	2	
Reduced model	-38.9521	1	57.2822	2	<.0001
AIC:	23.5163				

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34

Goodness of Fit

Dose	Est._Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.0000	0.000	0.000	20	0.000
0.0500	0.8451	16.058	17.000	19	0.598
0.1000	0.9760	18.544	18.000	19	-0.816

Chi^2 = 1.02 d.f. = 2 P-value = 0.5995

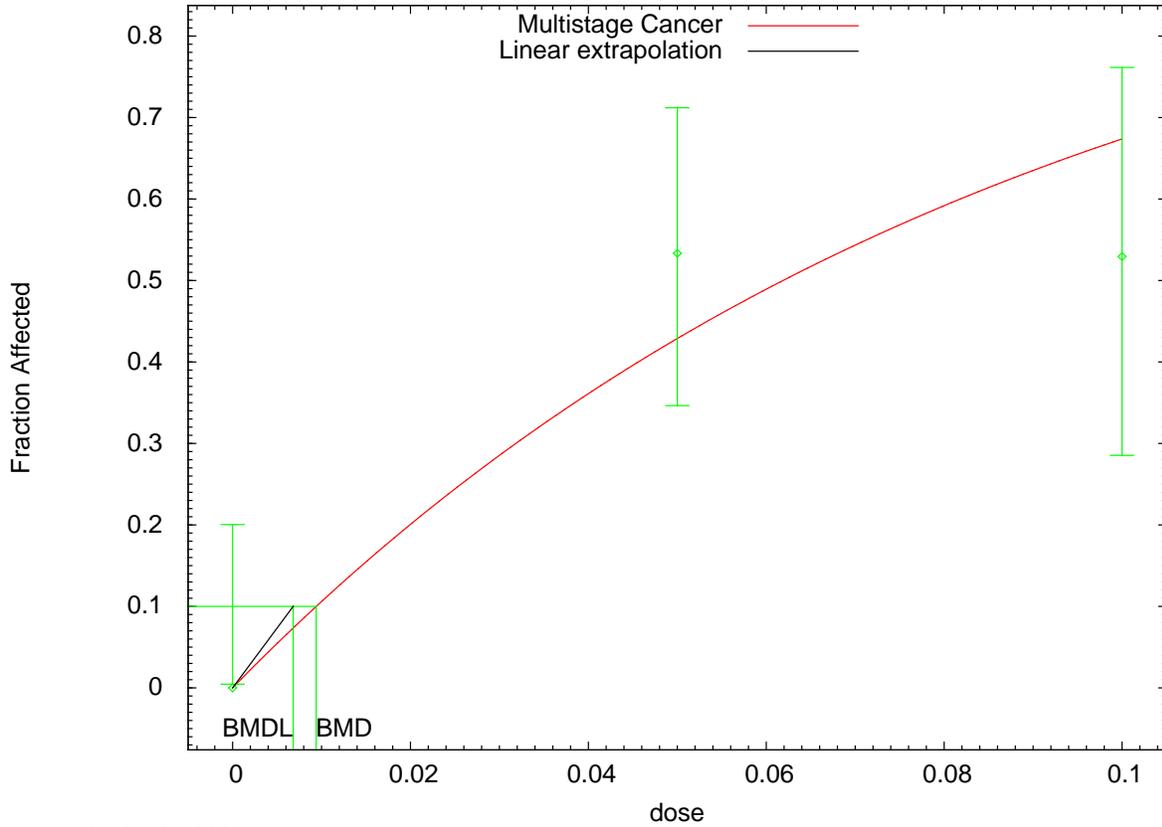
Benchmark Dose Computation

Specified effect = 0.1
Risk Type = Extra risk
Confidence level = 0.95
 BMD = 0.0028244
 BMDL = 0.00193834
 BMDU = 0.00411821

Taken together, (0.00193834, 0.00411821) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 51.5905

Multistage Cancer Model with 0.95 Confidence Level



12:48 12/28 2009

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30

HOFFMANWYNDER1996DBAEP.OUT.txt

=====

Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)

Input Data File:

C:\USEPA\IRIS\PAH\dermal\complete\HoffWynd1966\DBaep\msc_HoffWynDBaep_MS_1.(d
)

Gnuplot Plotting File:

C:\USEPA\IRIS\PAH\dermal\complete\HoffWynd1966\DBaep\msc_HoffWynDBaep_MS_1.pl
t

Tue Dec 22 14:50:32 2009

=====

BMS Model Run

~~~~~

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1 - \text{background}) * [1 - \text{EXP}(-\text{betal} * \text{dose}^1)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

Total number of observations = 3

1 Total number of records with missing values = 0  
 2 Total number of parameters in model = 2  
 3 Total number of specified parameters = 0  
 4 Degree of polynomial = 1  
 5  
 6  
 7 Maximum number of iterations = 250  
 8 Relative Function Convergence has been set to: 2.22045e-016  
 9 Parameter Convergence has been set to: 1.49012e-008  
 10  
 11 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 12 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 13 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 14 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

17  
18 Default Initial Parameter Values

19 Background = 0.120514  
 20 Beta(1) = 7.53772  
 21  
 22

23 Asymptotic Correlation Matrix of Parameter Estimates

24  
 25 ( \*\*\* The model parameter(s) -Background  
 26 have been estimated at a boundary point, or have been  
 27 specified by the user,  
 28 and do not appear in the correlation matrix )  
 29

30 Beta(1)  
 31  
 32 Beta(1) 1  
 33  
 34  
 35

36 Parameter Estimates

| Confidence Interval |          | 95.0% Wald |       |             |
|---------------------|----------|------------|-------|-------------|
| Variable            | Estimate | Std. Err.  | Lower | Conf. Limit |
| Upper Conf. Limit   |          |            |       |             |
| Background          | 0        | *          | *     |             |
| Beta(1)             | 11.2084  | *          | *     |             |

47 \* - Indicates that this value is not calculated.

51 Analysis of Deviance Table

| Model         | Log(likelihood) | # Param's | Deviance | Test d.f. | P-value |
|---------------|-----------------|-----------|----------|-----------|---------|
| Full model    | -32.4818        | 3         |          |           |         |
| Fitted model  | -33.903         | 1         | 2.84251  | 2         |         |
| Reduced model | -44.2604        | 1         | 23.5572  | 2         | <.0001  |
| AIC:          | 69.8061         |           |          |           |         |

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33

Goodness of Fit

| Dose   | Est._Prob. | Expected | Observed | Size | Scaled Residual |
|--------|------------|----------|----------|------|-----------------|
| 0.0000 | 0.0000     | 0.000    | 0.000    | 20   | 0.000           |
| 0.0500 | 0.4290     | 12.871   | 16.000   | 30   | 1.154           |
| 0.1000 | 0.6740     | 11.458   | 9.000    | 17   | -1.272          |

Chi^2 = 2.95      d.f. = 2      P-value = 0.2288

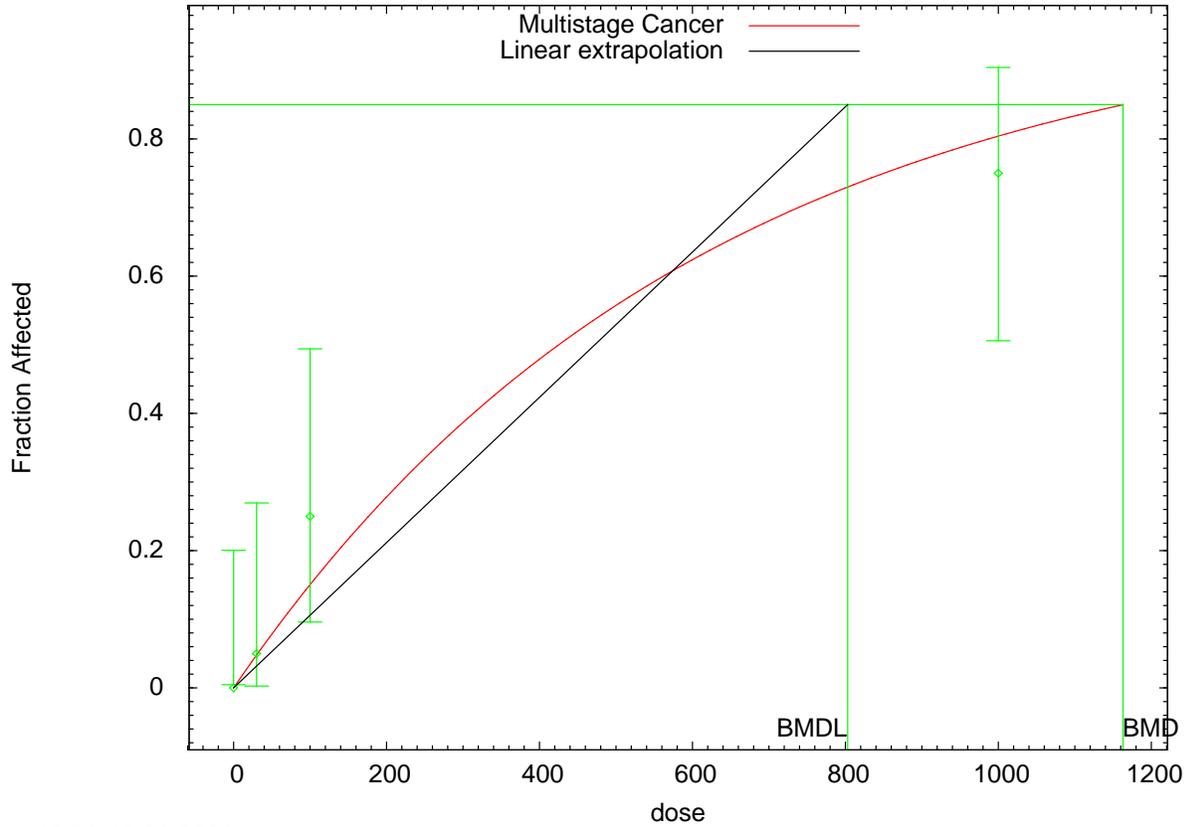
Benchmark Dose Computation

Specified effect = 0.1  
Risk Type = Extra risk  
Confidence level = 0.95  
BMD = 0.00940018  
BMDL = 0.00681373  
BMDU = 0.0134192

Taken together, (0.00681373, 0.0134192) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 14.6763

Multistage Cancer Model with 0.95 Confidence Level



12:50 12/28 2009

LAVOIE1982BkF.OUT.txt

```

=====
      Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
      Input Data File:
      C:\USEPA\IRIS\PAH\dermal\initiation\LaVoie1982\BkF\msc_LaVoieBkF_MS_2_85.(d)
      Gnuplot Plotting File:
      C:\USEPA\IRIS\PAH\dermal\initiation\LaVoie1982\BkF\msc_LaVoieBkF_MS_2_85.plt
      Thu Dec 24 10:09:52 2009
=====

```

BMD5 Model Run

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta1} * \text{dose}^{1-\text{beta2}} * \text{dose}^2)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

Total number of observations = 4

Total number of records with missing values = 0

1 Total number of parameters in model = 3  
 2 Total number of specified parameters = 0  
 3 Degree of polynomial = 2  
 4  
 5  
 6 Maximum number of iterations = 250  
 7 Relative Function Convergence has been set to: 2.22045e-016  
 8 Parameter Convergence has been set to: 1.49012e-008  
 9  
 10 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 11 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 12 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 13 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

17 Default Initial Parameter Values

18 Background = 0.0504814  
 19 Beta(1) = 0.00134342  
 20 Beta(2) = 0

23 Asymptotic Correlation Matrix of Parameter Estimates

24  
 25 ( \*\*\* The model parameter(s) -Background -Beta(2)  
 26 have been estimated at a boundary point, or have been  
 27 specified by the user,  
 28 and do not appear in the correlation matrix )

30 Beta(1)

32 Beta(1) 1

36 Parameter Estimates

38 95.0% Wald

| 39 Confidence Interval |            |           |       |             |
|------------------------|------------|-----------|-------|-------------|
| 40 Variable            | Estimate   | Std. Err. | Lower | Conf. Limit |
| 41 Upper Conf. Limit   |            |           |       |             |
| 42 Background          | 0          | *         | *     |             |
| 43 *                   |            |           |       |             |
| 44 Beta(1)             | 0.00163117 | *         | *     |             |
| 45 *                   |            |           |       |             |
| 46 Beta(2)             | 0          | *         | *     |             |
| 47 *                   |            |           |       |             |

49 \* - Indicates that this value is not calculated.

53 Analysis of Deviance Table

| 55 Model         | Log(likelihood) | # Param's | Deviance | Test d.f. | P-value |
|------------------|-----------------|-----------|----------|-----------|---------|
| 56 Full model    | -26.4637        | 4         |          |           |         |
| 57 Fitted model  | -27.3094        | 1         | 1.69146  | 3         |         |
| 58 0.6388        |                 |           |          |           |         |
| 59 Reduced model | -46.0525        | 1         | 39.1775  | 3         | <.0001  |

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37

AIC: 56.6189

Goodness of Fit

| Dose      | Est._Prob. | Expected | Observed | Size | Scaled Residual |
|-----------|------------|----------|----------|------|-----------------|
| 0.0000    | 0.0000     | 0.000    | 0.000    | 20   | 0.000           |
| 30.0000   | 0.0478     | 0.955    | 1.000    | 20   | 0.047           |
| 100.0000  | 0.1505     | 3.010    | 5.000    | 20   | 1.244           |
| 1000.0000 | 0.8043     | 16.086   | 15.000   | 20   | -0.612          |

Chi^2 = 1.93      d.f. = 3      P-value = 0.5881

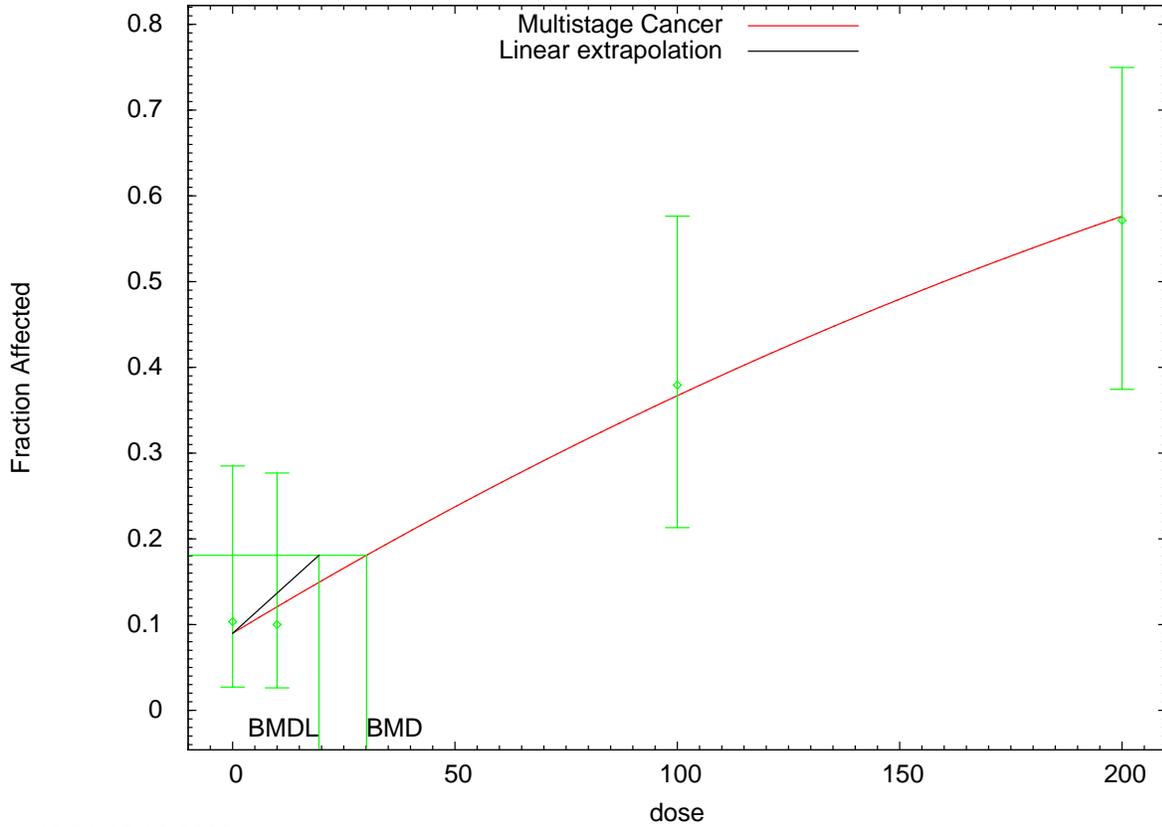
Benchmark Dose Computation

Specified effect = 0.85  
Risk Type = Extra risk  
Confidence level = 0.95  
BMD = 1163.04  
BMDL = 802.998  
BMDU = 1836.46

Taken together, (802.998, 1836.46) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 0.00105853

Multistage Cancer Model with 0.95 Confidence Level



12:51 12/28 2009

RAVEH1982CPCDP.OUT.txt

```

=====
Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
Input Data File:
C:\USEPA\IRIS\PAH\dermal\initiation\Raveh1982\CPcdP\msc_RavehCPcdP_MS_2.(d)
Gnuplot Plotting File:
C:\USEPA\IRIS\PAH\dermal\initiation\Raveh1982\CPcdP\msc_RavehCPcdP_MS_2.plt
Tue Dec 22 14:50:35 2009
=====

```

BMDS Model Run

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta1} * \text{dose}^1 - \text{beta2} * \text{dose}^2)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

Total number of observations = 4

Total number of records with missing values = 0

1 Total number of parameters in model = 3  
 2 Total number of specified parameters = 0  
 3 Degree of polynomial = 2  
 4  
 5  
 6 Maximum number of iterations = 250  
 7 Relative Function Convergence has been set to: 2.22045e-016  
 8 Parameter Convergence has been set to: 1.49012e-008  
 9  
 10 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 11 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 12 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 13 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

17 Default Initial Parameter Values

18 Background = 0.086614  
 19 Beta(1) = 0.00379482  
 20 Beta(2) = 0

23 Asymptotic Correlation Matrix of Parameter Estimates

|            | Background | Beta(1) | Beta(2) |
|------------|------------|---------|---------|
| Background | 1          | -0.51   | 0.37    |
| Beta(1)    | -0.51      | 1       | -0.96   |
| Beta(2)    | 0.37       | -0.96   | 1       |

35 Parameter Estimates

| Confidence Interval | Variable   | Estimate     | Std. Err. | 95.0% Wald        |
|---------------------|------------|--------------|-----------|-------------------|
|                     |            |              |           | Lower Conf. Limit |
| Upper Conf. Limit   | Background | 0.0898027    | *         | *                 |
| *                   | Beta(1)    | 0.0034393    | *         | *                 |
| *                   | Beta(2)    | 1.91358e-006 | *         | *                 |

48 \* - Indicates that this value is not calculated.

52 Analysis of Deviance Table

| Model                   | Log(likelihood) | # Param's | Deviance | Test d.f. | P-value |
|-------------------------|-----------------|-----------|----------|-----------|---------|
| Full model              | -57.7672        | 4         |          |           |         |
| Fitted model            | -57.8738        | 3         | 0.213129 | 1         |         |
| 0.6443<br>Reduced model | -69.2679        | 1         | 23.0015  | 3         | <.0001  |
| AIC:                    | 121.748         |           |          |           |         |

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36

Goodness of Fit

| Dose     | Est._Prob. | Expected | Observed | Size | Scaled Residual |
|----------|------------|----------|----------|------|-----------------|
| 0.0000   | 0.0898     | 2.604    | 3.000    | 29   | 0.257           |
| 10.0000  | 0.1207     | 3.622    | 3.000    | 30   | -0.349          |
| 100.0000 | 0.3669     | 10.641   | 11.000   | 29   | 0.138           |
| 200.0000 | 0.5762     | 16.134   | 16.000   | 28   | -0.051          |

Chi^2 = 0.21      d.f. = 1      P-value = 0.6472

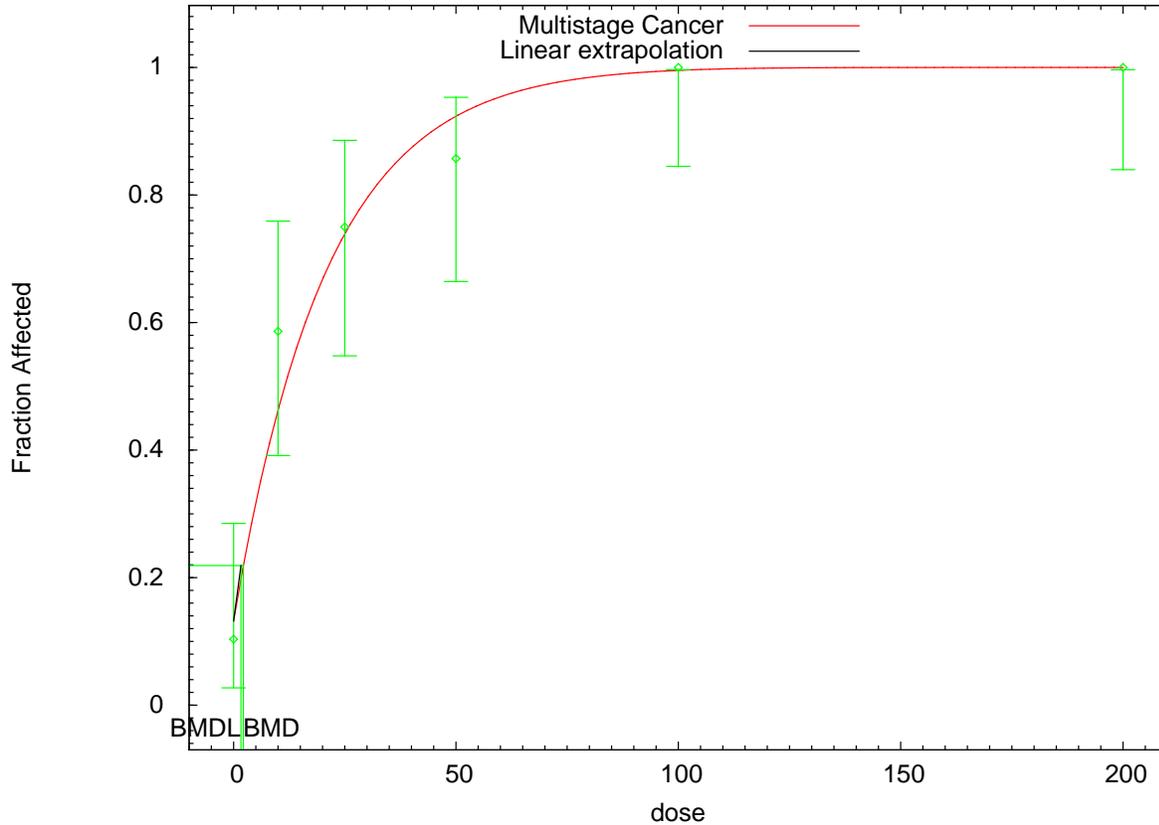
Benchmark Dose Computation

Specified effect =            0.1  
Risk Type            =        Extra risk  
Confidence level =            0.95  
                  BMD =        30.1292  
                  BMDL =        19.4197  
                  BMDU =        83.2495

Taken together, (19.4197, 83.2495) is a 90      % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor =    0.00514942

Multistage Cancer Model with 0.95 Confidence Level



12:52 12/28 2009

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30

RAVEH\_1982BaP.OUT.txt

```

=====
      Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
      Input Data File:
      C:\USEPA\IRIS\PAH\dermal\initiation\Raveh1982\BaP\msc_RavehBaP_MS_4.(d)
      Gnuplot Plotting File:
      C:\USEPA\IRIS\PAH\dermal\initiation\Raveh1982\BaP\msc_RavehBaP_MS_4.plt
      Tue Dec 22 14:50:34 2009
=====

```

BMDS Model Run

~~~~~

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1 - \text{background}) * [1 - \text{EXP}(-\beta_1 * \text{dose}^1 - \beta_2 * \text{dose}^2 - \beta_3 * \text{dose}^3 - \beta_4 * \text{dose}^4)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

Total number of observations = 6

Total number of records with missing values = 0

1 Total number of parameters in model = 5
 2 Total number of specified parameters = 0
 3 Degree of polynomial = 4
 4
 5
 6 Maximum number of iterations = 250
 7 Relative Function Convergence has been set to: 2.22045e-016
 8 Parameter Convergence has been set to: 1.49012e-008
 9
 10 **** We are sorry but Relative Function and Parameter Convergence ****
 11 **** are currently unavailable in this model. Please keep checking ****
 12 **** the web sight for model updates which will eventually ****
 13 **** incorporate these convergence criterion. Default values used. ****

17 Default Initial Parameter Values

18 Background = 0
 19 Beta(1) = 6.01899e+017
 20 Beta(2) = 0
 21 Beta(3) = 0
 22 Beta(4) = 0

25 Asymptotic Correlation Matrix of Parameter Estimates

26
 27 (*** The model parameter(s) -Beta(2) -Beta(3)
 28 have been estimated at a boundary point, or have been
 29 specified by the user,
 30 and do not appear in the correlation matrix)

	Background	Beta(1)	Beta(4)
Background	1	-0.66	0.27
Beta(1)	-0.66	1	-0.52
Beta(4)	0.27	-0.52	1

42 Parameter Estimates

Confidence Interval		95.0% Wald		
Variable	Estimate	Std. Err.	Lower	Conf. Limit
Upper Conf. Limit				
Background	0.132052	*	*	
Beta(1)	0.0479561	*	*	
Beta(2)	0	*	*	
Beta(3)	0	*	*	
Beta(4)	4.58928e-009	*	*	

59 * - Indicates that this value is not calculated.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49

Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-56.5419	6			
Fitted model	-58.376	3	3.66814	3	
Reduced model	-101.065	1	89.0461	5	<.0001
AIC:	122.752				

Goodness of Fit

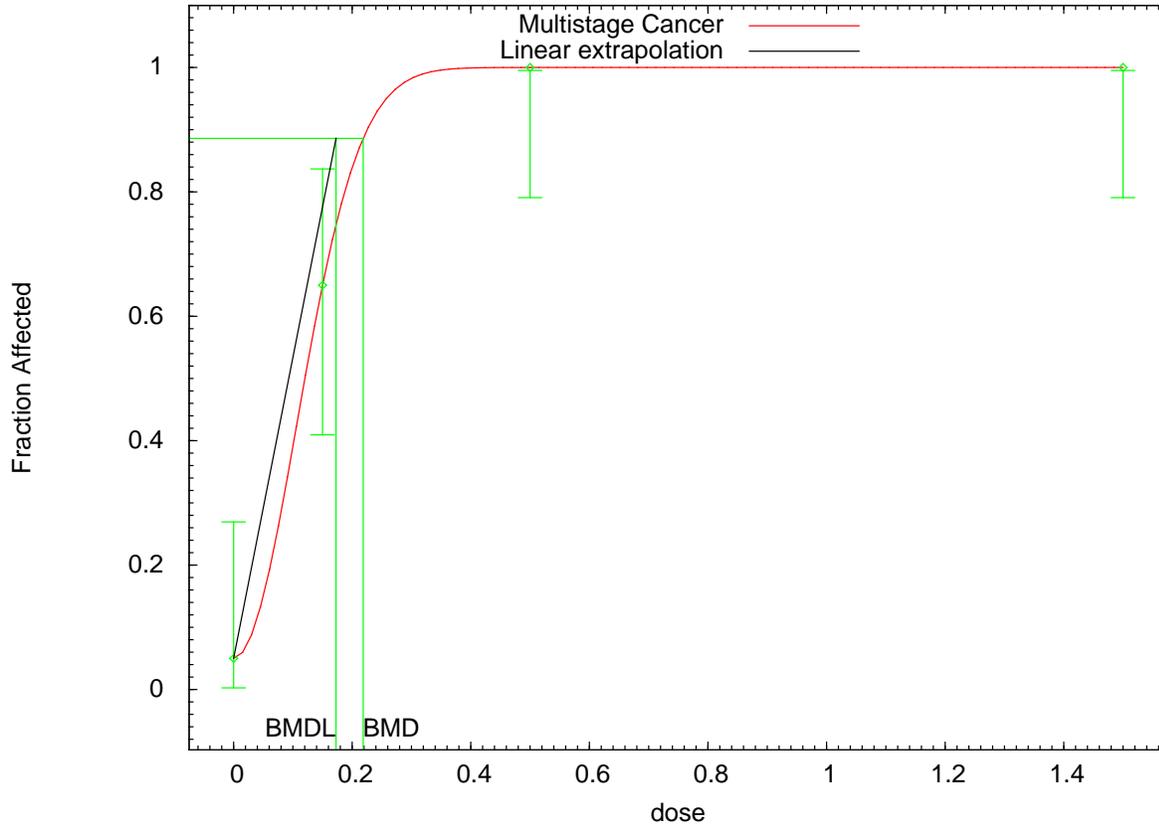
Dose	Est._Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.1321	3.829	3.000	29	-0.455
10.0000	0.4627	13.419	17.000	29	1.334
25.0000	0.7388	20.685	21.000	28	0.135
50.0000	0.9233	25.853	24.000	28	-1.316
100.0000	0.9955	26.878	27.000	27	0.351
200.0000	1.0000	26.000	26.000	26	0.001

Chi^2 = 3.86 d.f. = 3 P-value = 0.2771

Benchmark Dose Computation

Specified effect = 0.1
Risk Type = Extra risk
Confidence level = 0.95
BMD = 2.19702
BMDL = 1.66278
BMDU = 3.30927
Taken together, (1.66278, 3.30927) is a 90 % two-sided confidence interval for the BMD
Multistage Cancer Slope Factor = 0.0601403

Multistage Cancer Model with 0.95 Confidence Level



12:53 12/28 2009

RICE_CPDEFEC.OUT.txt

=====

Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)

Input Data File:

C:\USEPA\IRIS\PAH\dermal\initiation\Rice\CPdefC\msc_RiceCPdefC_MS_2_88.(d)

Gnuplot Plotting File:

C:\USEPA\IRIS\PAH\dermal\initiation\Rice\CPdefC\msc_RiceCPdefC_MS_2_88.plt

Tue Dec 22 16:05:10 2009

=====

BMDS Model Run

~~~~~

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta1} * \text{dose}^1 - \text{beta2} * \text{dose}^2)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

Total number of observations = 4

Total number of records with missing values = 0

Total number of parameters in model = 3

1 Total number of specified parameters = 0  
 2 Degree of polynomial = 2  
 3  
 4  
 5 Maximum number of iterations = 250  
 6 Relative Function Convergence has been set to: 2.22045e-016  
 7 Parameter Convergence has been set to: 1.49012e-008  
 8  
 9 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 10 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 11 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 12 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

13  
 14  
 15  
 16 Default Initial Parameter Values

17 Background = 1  
 18 Beta(1) = 6.76726e+019  
 19 Beta(2) = 0  
 20

21  
 22 Asymptotic Correlation Matrix of Parameter Estimates

23  
 24 ( \*\*\* The model parameter(s) -Beta(1)  
 25 have been estimated at a boundary point, or have been  
 26 specified by the user,  
 27 and do not appear in the correlation matrix )  
 28

|            | Background | Beta(2) |
|------------|------------|---------|
| Background | 1          | -0.52   |
| Beta(2)    | -0.52      | 1       |

29  
 30  
 31  
 32  
 33  
 34  
 35  
 36  
 37 Parameter Estimates

| Confidence Interval | Variable   | Estimate  | Std. Err. | 95.0% Wald        |
|---------------------|------------|-----------|-----------|-------------------|
|                     |            |           |           | Lower Conf. Limit |
| Upper Conf. Limit   | Background | 0.0499931 | *         | *                 |
|                     | Beta(1)    | 0         | *         | *                 |
|                     | Beta(2)    | 44.3919   | *         | *                 |

38  
 39  
 40  
 41  
 42  
 43  
 44  
 45  
 46  
 47  
 48  
 49  
 50 \* - Indicates that this value is not calculated.  
 51  
 52

53  
 54 Analysis of Deviance Table

| Model                   | Log(likelihood) | # Param's | Deviance    | Test d.f. | P-value |
|-------------------------|-----------------|-----------|-------------|-----------|---------|
| Full model              | -16.9192        | 4         |             |           |         |
| Fitted model            | -16.9195        | 2         | 0.000547543 | 2         |         |
| 0.9997<br>Reduced model | -49.6481        | 1         | 65.4577     | 3         | <.0001  |

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39

AIC: 37.839

Goodness of Fit

| Dose   | Est._Prob. | Expected | Observed | Size | Scaled Residual |
|--------|------------|----------|----------|------|-----------------|
| 0.0000 | 0.0500     | 1.000    | 1.000    | 20   | 0.000           |
| 0.1500 | 0.6501     | 13.002   | 13.000   | 20   | -0.001          |
| 0.5000 | 1.0000     | 19.000   | 19.000   | 19   | 0.017           |
| 1.5000 | 1.0000     | 19.000   | 19.000   | 19   | 0.000           |

Chi^2 = 0.00      d.f. = 2      P-value = 0.9999

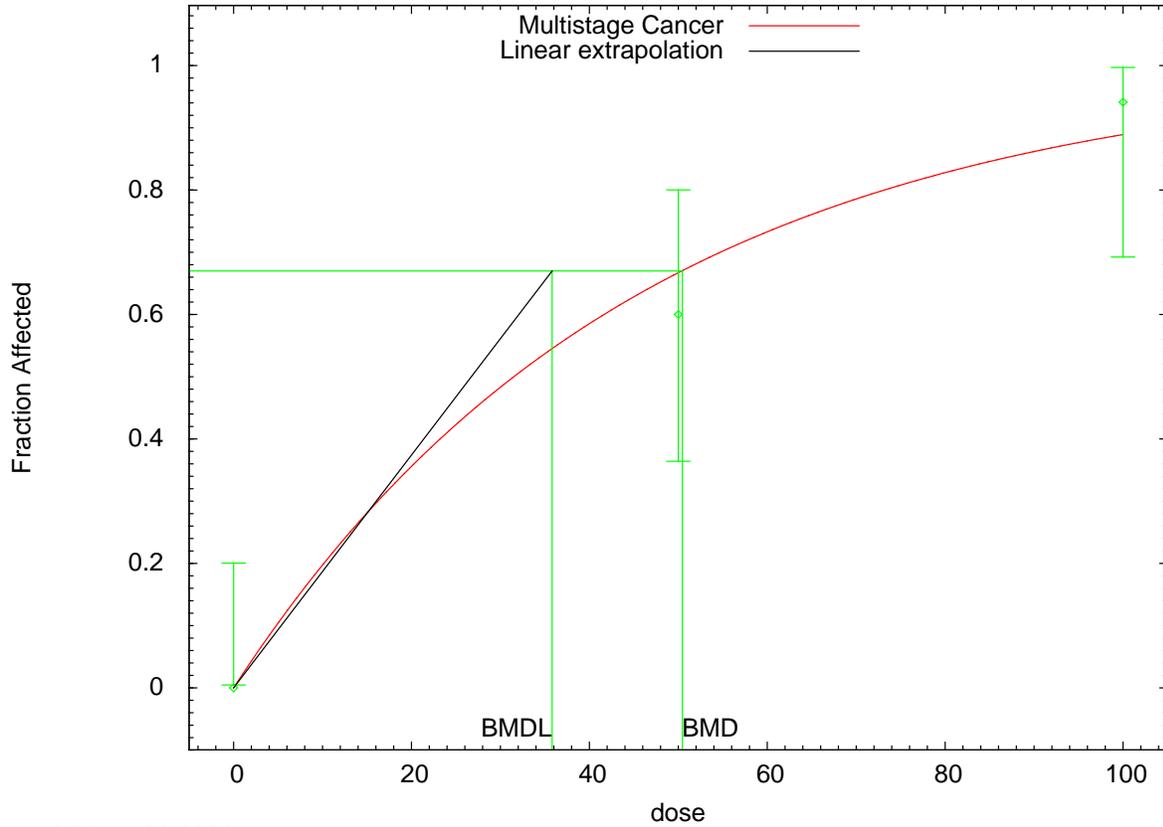
Benchmark Dose Computation

Specified effect = 0.88  
Risk Type = Extra risk  
Confidence level = 0.95  
BMD = 0.218546  
BMDL = 0.172781  
BMDU = 0.384831

Taken together, (0.172781, 0.384831) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 5.09315

Multistage Cancer Model with 0.95 Confidence Level



12:56 12/28 2009

NESNOW\_1984\_DERMAL\_BLAC\_MALE.txt

```

=====
      Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
      Input Data File:
      C:\USEPA\IRIS\PAH\dermal\initiation\Nesnow1984\BIACmale\msc_NesnowBAICmale3HD
      D_MS_1.(d)
      Gnuplot Plotting File:
      C:\USEPA\IRIS\PAH\dermal\initiation\Nesnow1984\BIACmale\msc_NesnowBAICmale3HD
      D_MS_1.plt
  
```

Tue Dec 22 16:05:10 2009

=====  
 BMDS Model Run  
 ~~~~~

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta}1 * \text{dose}^1)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence
 Independent variable = dose

1 Total number of observations = 3
 2 Total number of records with missing values = 0
 3 Total number of parameters in model = 2
 4 Total number of specified parameters = 0
 5 Degree of polynomial = 1
 6
 7
 8 Maximum number of iterations = 250
 9 Relative Function Convergence has been set to: 2.22045e-016
 10 Parameter Convergence has been set to: 1.49012e-008
 11
 12 **** We are sorry but Relative Function and Parameter Convergence ****
 13 **** are currently unavailable in this model. Please keep checking ****
 14 **** the web sight for model updates which will eventually ****
 15 **** incorporate these convergence criterion. Default values used. ****

19 Default Initial Parameter Values

20 Background = 0
 21 Beta(1) = 0.0283321
 22
 23

24 Asymptotic Correlation Matrix of Parameter Estimates

25 (*** The model parameter(s) -Background
 26 have been estimated at a boundary point, or have been
 27 specified by the user,
 28 and do not appear in the correlation matrix)
 29

30
 31 Beta(1)
 32
 33 Beta(1) 1
 34
 35

37 Parameter Estimates

		95.0% Wald		
Confidence Interval	Variable	Estimate	Std. Err.	Lower Conf. Limit
Upper Conf. Limit	Background	0	*	*
	Beta(1)	0.0219722	*	*

48 * - Indicates that this value is not calculated.

52 Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-17.2634	3			
Fitted model	-17.7362	1	0.945584	2	
0.6233 Reduced model	-39.5006	1	44.4744	2	<.0001
AIC:	37.4725				

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36

Goodness of Fit

Dose	Est._Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.0000	0.000	0.000	20	0.000
50.0000	0.6667	13.333	12.000	20	-0.632
100.0000	0.8889	15.111	16.000	17	0.686

Chi^2 = 0.87 d.f. = 2 P-value = 0.6471

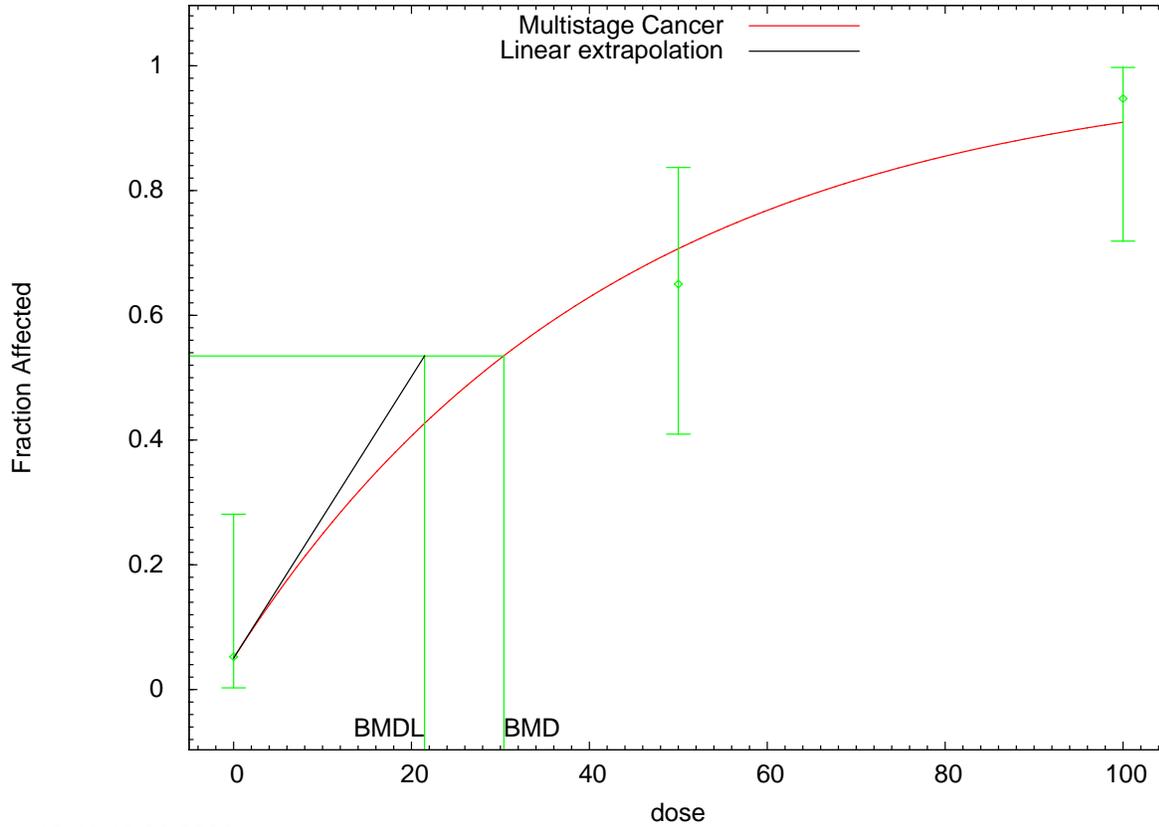
Benchmark Dose Computation

Specified effect = 0.67
Risk Type = Extra risk
Confidence level = 0.95
 BMD = 50.4574
 BMDL = 35.8134
 BMDU = 72.6771

Taken together, (35.8134, 72.6771) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 0.0187081

Multistage Cancer Model with 0.95 Confidence Level



13:46 12/28 2009

NESNOW_1984_DERMAL_BLAC_FEMALE.txt

=====

Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)

Input Data File:

C:\USEPA\IRIS\PAH\dermal\initiation\Nesnow1984\BIACfemale\msc_NesnowBlaCfemal
e3HDD_MS_4.(d)

Gnuplot Plotting File:

C:\USEPA\IRIS\PAH\dermal\initiation\Nesnow1984\BIACfemale\msc_NesnowBlaCfemal
e3HDD_MS_4.plt

Mon Dec 28 13:46:08 2009

=====

BMDS Model Run

~~~~~

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1 - \text{background}) * [1 - \text{EXP}(-\text{beta}1 * \text{dose}^1)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

Total number of observations = 3

1 Total number of records with missing values = 0  
 2 Total number of parameters in model = 2  
 3 Total number of specified parameters = 0  
 4 Degree of polynomial = 1  
 5  
 6  
 7 Maximum number of iterations = 250  
 8 Relative Function Convergence has been set to: 2.22045e-016  
 9 Parameter Convergence has been set to: 1.49012e-008  
 10  
 11 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 12 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 13 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 14 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

17 Default Initial Parameter Values

18 Background = 0  
 19 Beta(1) = 0.0289037

22 Asymptotic Correlation Matrix of Parameter Estimates

|            | Background | Beta(1) |
|------------|------------|---------|
| Background | 1          | -0.49   |
| Beta(1)    | -0.49      | 1       |

33 Parameter Estimates

| Confidence Interval |           | 95.0% Wald |       |             |
|---------------------|-----------|------------|-------|-------------|
| Variable            | Estimate  | Std. Err.  | Lower | Conf. Limit |
| Background          | 0.0505105 | *          | *     |             |
| Beta(1)             | 0.0234713 | *          | *     |             |

44 \* - Indicates that this value is not calculated.

48 Analysis of Deviance Table

| Model         | Log(likelihood) | # Param's | Deviance | Test d.f. | P-value |
|---------------|-----------------|-----------|----------|-----------|---------|
| Full model    | -20.7842        | 3         |          |           |         |
| Fitted model  | -21.1281        | 2         | 0.687832 | 1         |         |
| Reduced model | -39.8916        | 1         | 38.2148  | 2         | <.0001  |
| AIC:          | 46.2563         |           |          |           |         |

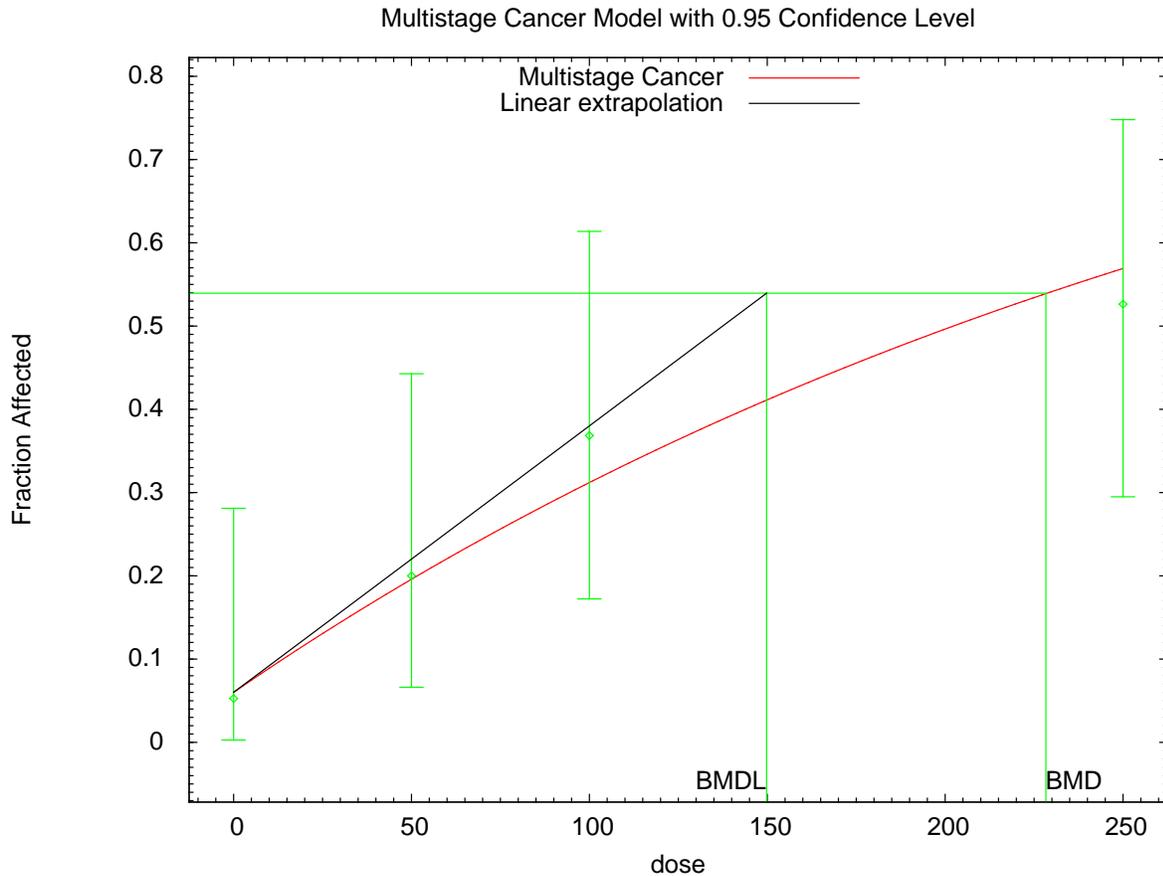
59 Goodness of Fit  
60 Scaled

```

1      Dose      Est._Prob.    Expected    Observed    Size      Residual
2      -----
3      0.0000    0.0505      0.960      1.000      19        0.042
4      50.0000   0.7064     14.127     13.000     20       -0.553
5      100.0000  0.9092     17.275     18.000     19        0.579
6
7      Chi^2 = 0.64      d.f. = 1      P-value = 0.4224
8
9
10     Benchmark Dose Computation
11
12     Specified effect =          0.51
13
14     Risk Type          =      Extra risk
15
16     Confidence level =          0.95
17
18           BMD =          30.3924
19
20           BMDL =          21.4681
21
22           BMDU =          44.3165
23
24     Taken together, (21.4681, 44.3165) is a 90      % two-sided confidence
25     interval for the BMD
26
27     Multistage Cancer Slope Factor =          0.0237562
28
29
30
31

```

1  
2



13:40 12/28 2009

NESNOW\_1984\_DERMAL\_BEAC\_FEMALE.txt

=====  
Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)

Input Data File:

C:\USEPA\IRIS\PAH\dermal\initiation\Nesnow1984\BeACfemale\msc\_NesnowBeACfemal  
e2HDD\_MS\_2\_51.(d)

Gnuplot Plotting File:

C:\USEPA\IRIS\PAH\dermal\initiation\Nesnow1984\BeACfemale\msc\_NesnowBeACfemal  
e2HDD\_MS\_2\_51.plt

Tue Dec 22 16:05:10 2009

=====  
BMD5 Model Run

~~~~~  
The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta1} * \text{dose}^1 - \text{beta2} * \text{dose}^2)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

1
 2 Total number of observations = 4
 3 Total number of records with missing values = 0
 4 Total number of parameters in model = 3
 5 Total number of specified parameters = 0
 6 Degree of polynomial = 2
 7
 8
 9 Maximum number of iterations = 250
 10 Relative Function Convergence has been set to: 2.22045e-016
 11 Parameter Convergence has been set to: 1.49012e-008
 12
 13 **** We are sorry but Relative Function and Parameter Convergence ****
 14 **** are currently unavailable in this model. Please keep checking ****
 15 **** the web sight for model updates which will eventually ****
 16 **** incorporate these convergence criterion. Default values used. ****
 17
 18
 19

20 Default Initial Parameter Values

21 Background = 0.0934237
 22 Beta(1) = 0.00272909
 23 Beta(2) = 0
 24
 25

26 Asymptotic Correlation Matrix of Parameter Estimates

27
 28 (*** The model parameter(s) -Beta(2)
 29 have been estimated at a boundary point, or have been
 30 specified by the user,
 31 and do not appear in the correlation matrix)
 32

	Background	Beta(1)
Background	1	-0.7
Beta(1)	-0.7	1

41 Parameter Estimates

Confidence Interval	Variable	Estimate	Std. Err.	95.0% Wald
				Lower Conf. Limit
Upper Conf. Limit	Background	0.0601262	*	*
*	Beta(1)	0.00312448	*	*
*	Beta(2)	0	*	*
*				

54 * - Indicates that this value is not calculated.

58 Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
-------	-----------------	-----------	----------	-----------	---------

1 Full model -39.5733 4
 2 Fitted model -39.7914 2 0.436272 2
 3 0.804
 4 Reduced model -46.0668 1 12.987 3
 5 0.004665
 6
 7 AIC: 83.5828
 8
 9

10 Goodness of Fit

11 Dose	11 Est._Prob.	11 Expected	11 Observed	11 Size	11 Scaled Residual
12 0.0000	0.0601	1.142	1.000	19	-0.137
13 50.0000	0.1961	3.921	4.000	20	0.044
14 100.0000	0.3123	5.934	7.000	19	0.527
15 250.0000	0.5696	10.823	10.000	19	-0.381

16 Chi^2 = 0.44 d.f. = 2 P-value = 0.8007

17 Benchmark Dose Computation

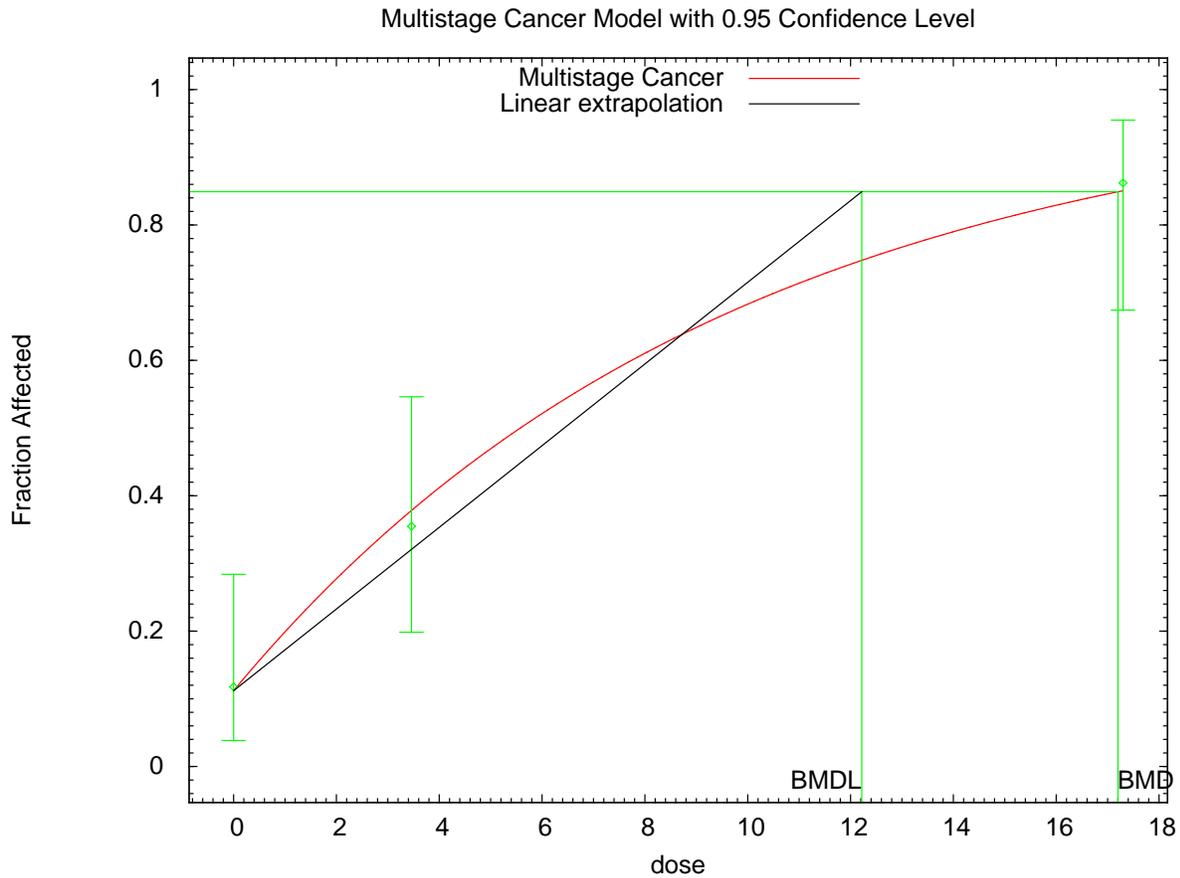
18 Specified effect = 0.51
 19 Risk Type = Extra risk
 20 Confidence level = 0.95
 21 BMD = 228.31
 22 BMDL = 149.811
 23 BMDU = 436.477

24 Taken together, (149.811, 436.477) is a 90 % two-sided confidence interval for the BMD

25 Multistage Cancer Slope Factor = 0.00340429

26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43

1 **D.2. INTRAPERITONEAL BIOASSAYS**



4 07:43 12/28 2009

5

6 lavoie 1994 female lung FA.txt

7

8 =====

9 Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)

10 Input Data File:

11 C:\USEPA\IRIS\PAH\IP\Lavoie1994\FAfemalelung\msc_LaVoieFAfemalelung_MS_1_83.(

12 d)

13 Gnuplot Plotting File:

14 C:\USEPA\IRIS\PAH\IP\Lavoie1994\FAfemalelung\msc_LaVoieFAfemalelung_MS_1_83.p

15 lt

16 Wed Dec 23 11:10:40 2009

17 =====

18

19 BMDS Model Run

20 ~~~~~

21

22 The form of the probability function is:

23

$$24 \quad P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta}1 * \text{dose}^1)]$$

25

26

27 The parameter betas are restricted to be positive

1
2
3 Dependent variable = incidence
4 Independent variable = dose
5
6 Total number of observations = 3
7 Total number of records with missing values = 0
8 Total number of parameters in model = 2
9 Total number of specified parameters = 0
10 Degree of polynomial = 1
11
12
13 Maximum number of iterations = 250
14 Relative Function Convergence has been set to: 2.22045e-016
15 Parameter Convergence has been set to: 1.49012e-008
16
17 **** We are sorry but Relative Function and Parameter Convergence ****
18 **** are currently unavailable in this model. Please keep checking ****
19 **** the web sight for model updates which will eventually ****
20 **** incorporate these convergence criterion. Default values used. ****

21
22
23
24 Default Initial Parameter Values

25 Background = 0.0929049
26 Beta(1) = 0.108473

27
28
29 Asymptotic Correlation Matrix of Parameter Estimates

	Background	Beta(1)
Background	1	-0.48
Beta(1)	-0.48	1

30
31
32
33
34
35
36
37
38
39 Parameter Estimates

			95.0% Wald
Confidence Interval	Variable	Estimate	Std. Err. Lower Conf. Limit
Upper Conf. Limit	Background	0.112498	* *
	Beta(1)	0.103015	* *

40
41
42
43
44
45
46
47
48
49
50 * - Indicates that this value is not calculated.

51
52
53
54 Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-44.1118	3			
Fitted model	-44.1689	2	0.114322	1	
0.7353 Reduced model	-64.1094	1	39.9952	2	<.0001

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37

AIC: 92.3379

Goodness of Fit

Dose	Est._Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.1125	3.825	4.000	34	0.095
3.4600	0.3786	11.737	11.000	31	-0.273
17.3000	0.8507	24.669	25.000	29	0.172

Chi^2 = 0.11 d.f. = 1 P-value = 0.7366

Benchmark Dose Computation

Specified effect = 0.83

Risk Type = Extra risk

Confidence level = 0.95

BMD = 17.201

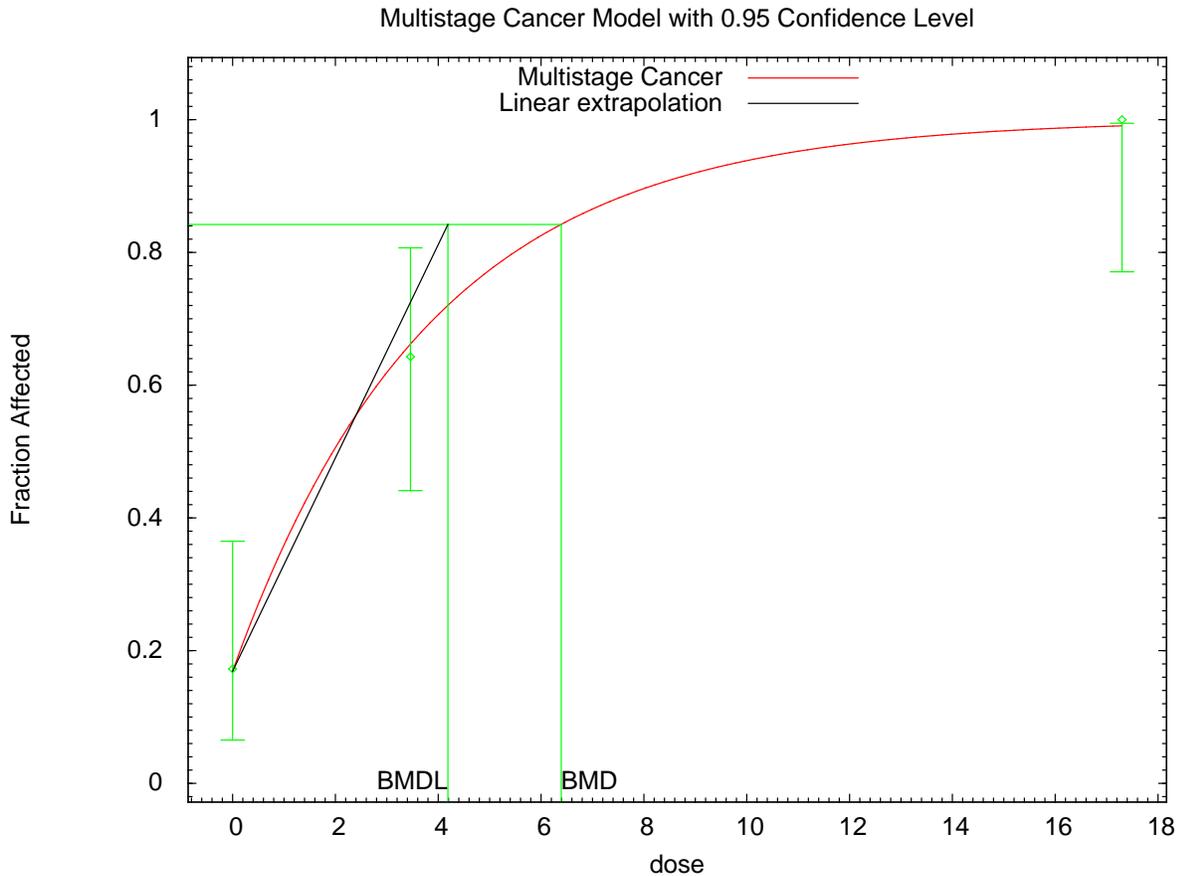
BMDL = 12.2186

BMDU = 25.6067

Taken together, (12.2186, 25.6067) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 0.067929

1
2



3 07:45 12/28 2009

4
5 LAVOIEETAL1994LIVERmale.OUT.txt

6
7 =====
8 Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
9 Input Data File:
10 C:\USEPA\IRIS\PAH\IP\Lavoie1994\FAmaleliver\msc_LaVoieFAmaleliver_MS_1_81.(d)
11 Gnuplot Plotting File:
12 C:\USEPA\IRIS\PAH\IP\Lavoie1994\FAmaleliver\msc_LaVoieFAmaleliver_MS_1_81.plt
13 Wed Dec 23 11:10:41 2009
14 =====

15
16 BMDS Model Run
17 ~~~~~

18
19 The form of the probability function is:
20
21
$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{betal} * \text{dose}^1)]$$

22
23

24 The parameter betas are restricted to be positive
25

26
27 Dependent variable = incidence
28 Independent variable = dose
29

30 Total number of observations = 3

1 Total number of records with missing values = 0
 2 Total number of parameters in model = 2
 3 Total number of specified parameters = 0
 4 Degree of polynomial = 1
 5
 6
 7 Maximum number of iterations = 250
 8 Relative Function Convergence has been set to: 2.22045e-016
 9 Parameter Convergence has been set to: 1.49012e-008
 10
 11 **** We are sorry but Relative Function and Parameter Convergence ****
 12 **** are currently unavailable in this model. Please keep checking ****
 13 **** the web sight for model updates which will eventually ****
 14 **** incorporate these convergence criterion. Default values used. ****

17 Default Initial Parameter Values

18 Background = 0
 19 Beta(1) = 6.19323e+018

22 Asymptotic Correlation Matrix of Parameter Estimates

	Background	Beta(1)
Background	1	-0.47
Beta(1)	-0.47	1

33 Parameter Estimates

Confidence Interval	Variable	Estimate	Std. Err.	95.0% Wald
				Lower Conf. Limit
Upper Conf. Limit	Background	0.168707	*	*
	Beta(1)	0.259821	*	*

44 * - Indicates that this value is not calculated.

48 Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-31.5803	3			
Fitted model	-31.7622	2	0.363803	1	
Reduced model	-51.0494	1	38.9382	2	<.0001
AIC:	67.5244				

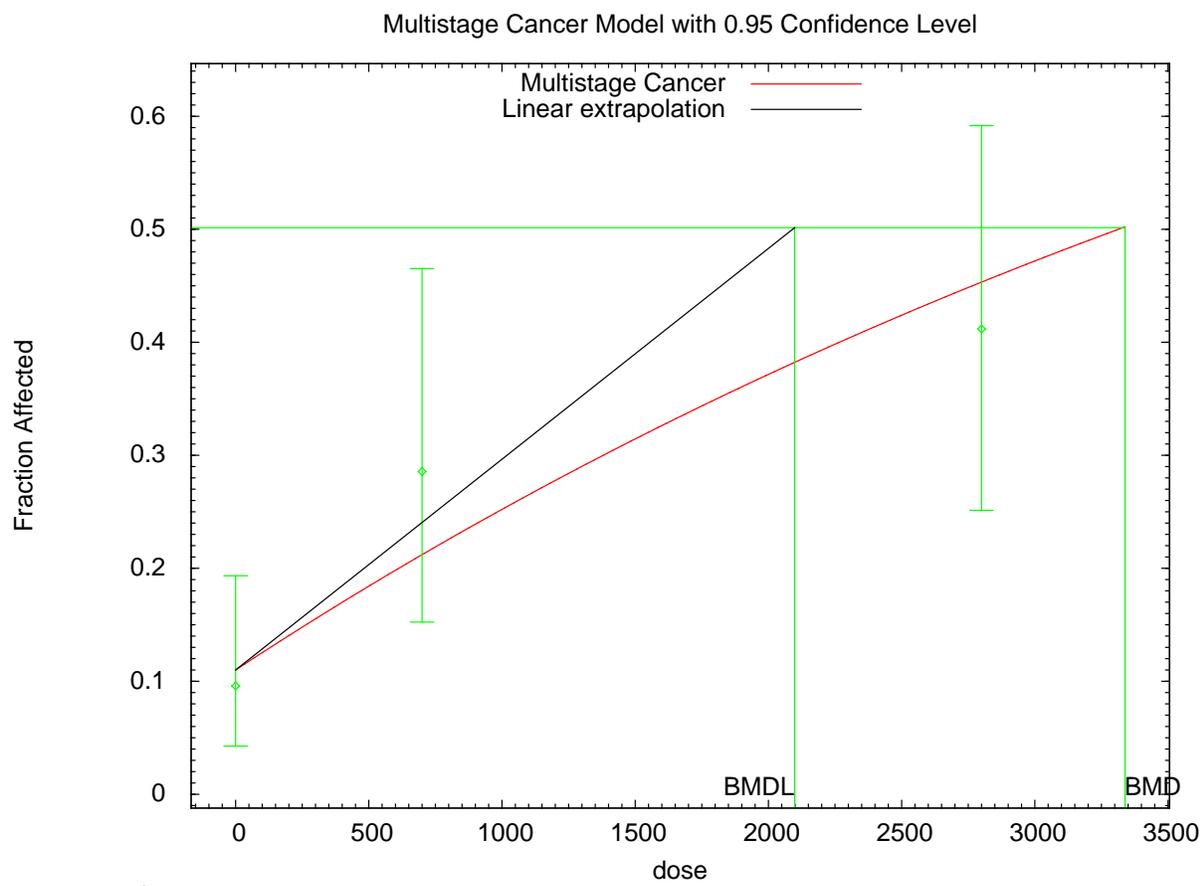
59 Goodness of Fit
60 Scaled

```

1      Dose      Est._Prob.      Expected      Observed      Size      Residual
2      -----
3      0.0000      0.1687      4.893      5.000      29      0.053
4      3.4600      0.6617      18.527      18.000      28      -0.210
5      17.3000      0.9907      16.842      17.000      17      0.399
6
7      Chi^2 = 0.21      d.f. = 1      P-value = 0.6496
8
9
10     Benchmark Dose Computation
11
12     Specified effect =      0.81
13
14     Risk Type      =      Extra risk
15
16     Confidence level =      0.95
17
18           BMD =      6.39184
19
20           BMDL =      4.18834
21
22           BMDU =      10.3811
23
24     Taken together, (4.18834, 10.3811) is a 90      % two-sided confidence
25     interval for the BMD
26
27     Multistage Cancer Slope Factor =      0.193394
28
29
30

```

1
2



07:47 12/28 2009

3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30

WISLOCKI_CHRYSENE_MALE_LIVER.OUT.txt

```
=====  
Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)  
Input Data File:  
C:\USEPA\IRIS\PAH\IP\Wislocki1986\CH\msc_WislockiCHliver_MS_1_44.(d)  
Gnuplot Plotting File:  
C:\USEPA\IRIS\PAH\IP\Wislocki1986\CH\msc_WislockiCHliver_MS_1_44.plt  
Wed Dec 23 11:10:41 2009  
=====
```

BMDS Model Run

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta}1 * \text{dose}^1)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence
Independent variable = dose

1 Total number of observations = 3
 2 Total number of records with missing values = 0
 3 Total number of parameters in model = 2
 4 Total number of specified parameters = 0
 5 Degree of polynomial = 1
 6
 7
 8 Maximum number of iterations = 250
 9 Relative Function Convergence has been set to: 2.22045e-016
 10 Parameter Convergence has been set to: 1.49012e-008
 11
 12 **** We are sorry but Relative Function and Parameter Convergence ****
 13 **** are currently unavailable in this model. Please keep checking ****
 14 **** the web sight for model updates which will eventually ****
 15 **** incorporate these convergence criterion. Default values used. ****

19 Default Initial Parameter Values
 20 Background = 0.147839
 21 Beta(1) = 0.000139419

24 Asymptotic Correlation Matrix of Parameter Estimates

	Background	Beta(1)
Background	1	-0.57
Beta(1)	-0.57	1

34 Parameter Estimates

Confidence Interval	Variable	Estimate	Std. Err.	95.0% Wald
				Lower Conf. Limit
Upper Conf. Limit	Background	0.109703	*	*
	Beta(1)	0.00017367	*	*

45 * - Indicates that this value is not calculated.

49 Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-67.0392	3			
Fitted model	-67.7628	2	1.44719	1	
0.229 Reduced model	-74.516	1	14.9536	2	
0.0005661 AIC:	139.526				

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33

Goodness of Fit

Dose	Est._Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.1097	8.008	7.000	73	-0.378
700.0000	0.2116	7.407	10.000	35	1.073
2800.0000	0.4525	15.387	14.000	34	-0.478

Chi^2 = 1.52 d.f. = 1 P-value = 0.2172

Benchmark Dose Computation

Specified effect = 0.44

Risk Type = Extra risk

Confidence level = 0.95

BMD = 3338.63

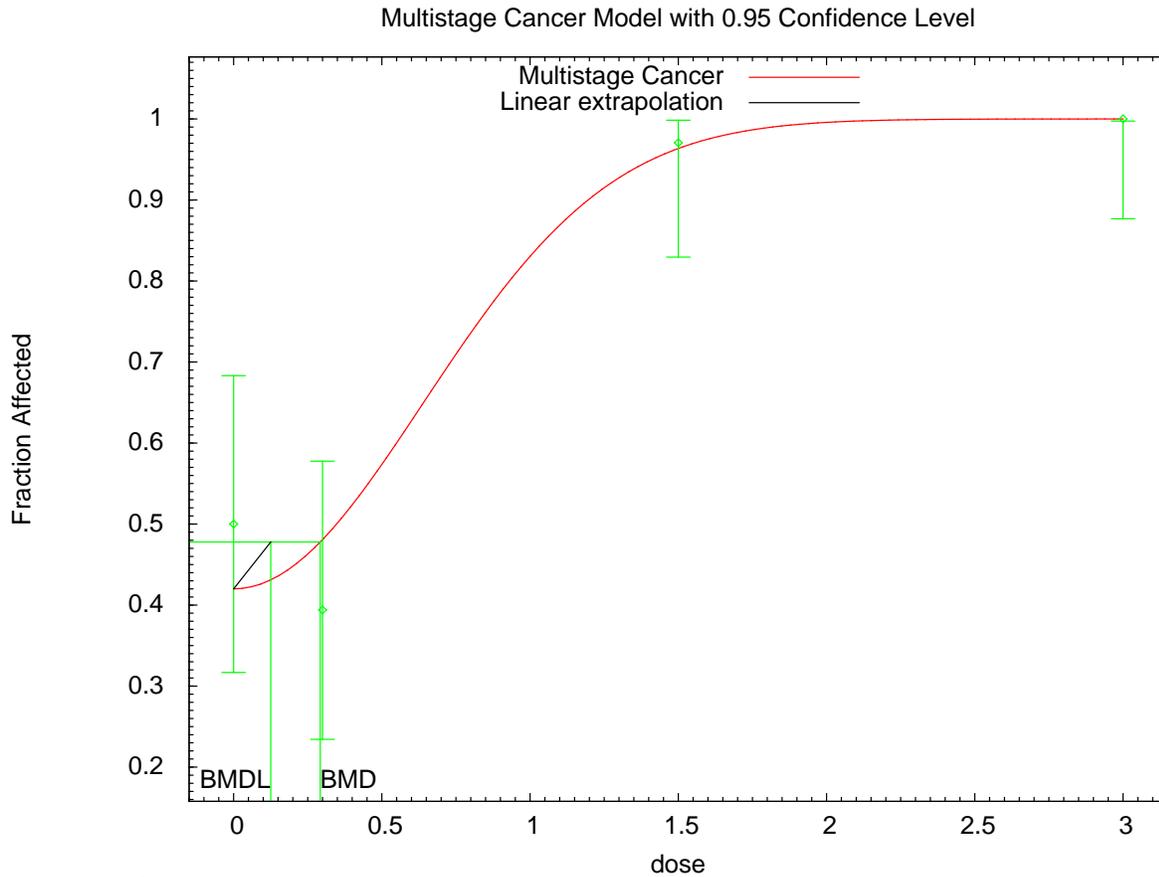
BMDL = 2098.51

BMDU = 6591.77

Taken together, (2098.51, 6591.77) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 0.000209673

1
2
3



4 07:58 12/28 2009

5

6 Nesnow et al. 1998b i.p DBalP male lung High dose dropped

7

8

9

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

25

26

27

28

29

30

```
=====  
Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)  
Input Data File:  
C:\USEPA\IRIS\PAH\IP\Nesnow1998b\DBalP\msc_NesnowDBalPHDD_MS_2_10.(d)  
Gnuplot Plotting File:  
C:\USEPA\IRIS\PAH\IP\Nesnow1998b\DBalP\msc_NesnowDBalPHDD_MS_2_10.plt  
Wed Dec 23 14:50:54 2009  
=====
```

BMDS Model Run

~~~~~

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1 - \text{background}) * [1 - \text{EXP}(-\text{beta1} * \text{dose}^1 - \text{beta2} * \text{dose}^2)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

```

1     Independent variable = dose
2
3     Total number of observations = 4
4     Total number of records with missing values = 0
5     Total number of parameters in model = 3
6     Total number of specified parameters = 0
7     Degree of polynomial = 2
8
9
10    Maximum number of iterations = 250
11    Relative Function Convergence has been set to: 2.22045e-016
12    Parameter Convergence has been set to: 1.49012e-008
13
14    **** We are sorry but Relative Function and Parameter Convergence ****
15    **** are currently unavailable in this model. Please keep checking ****
16    **** the web sight for model updates which will eventually ****
17    **** incorporate these convergence criterion. Default values used. ****
18
19
20

```

Default Initial Parameter Values

```

21
22     Background =          0
23     Beta(1) =           0
24     Beta(2) = 1.14332e+019
25
26

```

Asymptotic Correlation Matrix of Parameter Estimates

```

27
28     ( *** The model parameter(s) -Beta(1)
29     have been estimated at a boundary point, or have been
30 specified by the user,
31 and do not appear in the correlation matrix )
32
33

```

|            | Background | Beta(2) |
|------------|------------|---------|
| Background | 1          | -0.27   |
| Beta(2)    | -0.27      | 1       |

Parameter Estimates

| Confidence Interval | Variable   | Estimate | Std. Err. | 95.0% Wald        |
|---------------------|------------|----------|-----------|-------------------|
|                     |            |          |           | Lower Conf. Limit |
| Upper Conf. Limit   | Background | 0.419864 | *         | *                 |
| *                   | Beta(1)    | 0        | *         | *                 |
| *                   | Beta(2)    | 1.23372  | *         | *                 |

\* - Indicates that this value is not calculated.

Analysis of Deviance Table

60

| Model         | Log(likelihood) | # Param's | Deviance | Test d.f. | P-value |
|---------------|-----------------|-----------|----------|-----------|---------|
| Full model    | -47.4317        | 4         |          |           |         |
| Fitted model  | -48.3498        | 2         | 1.83615  | 2         |         |
| Reduced model | -77.3457        | 1         | 59.8281  | 3         | <.0001  |
| AIC:          |                 | 100.7     |          |           |         |

Goodness of Fit

| Dose   | Est._Prob. | Expected | Observed | Size | Scaled Residual |
|--------|------------|----------|----------|------|-----------------|
| 0.0000 | 0.4199     | 12.596   | 15.000   | 30   | 0.889           |
| 0.3000 | 0.4808     | 15.867   | 13.000   | 33   | -0.999          |
| 1.5000 | 0.9639     | 32.771   | 33.000   | 34   | 0.210           |
| 3.0000 | 1.0000     | 35.000   | 35.000   | 35   | 0.017           |

Chi^2 = 1.83      d.f. = 2      P-value = 0.3998

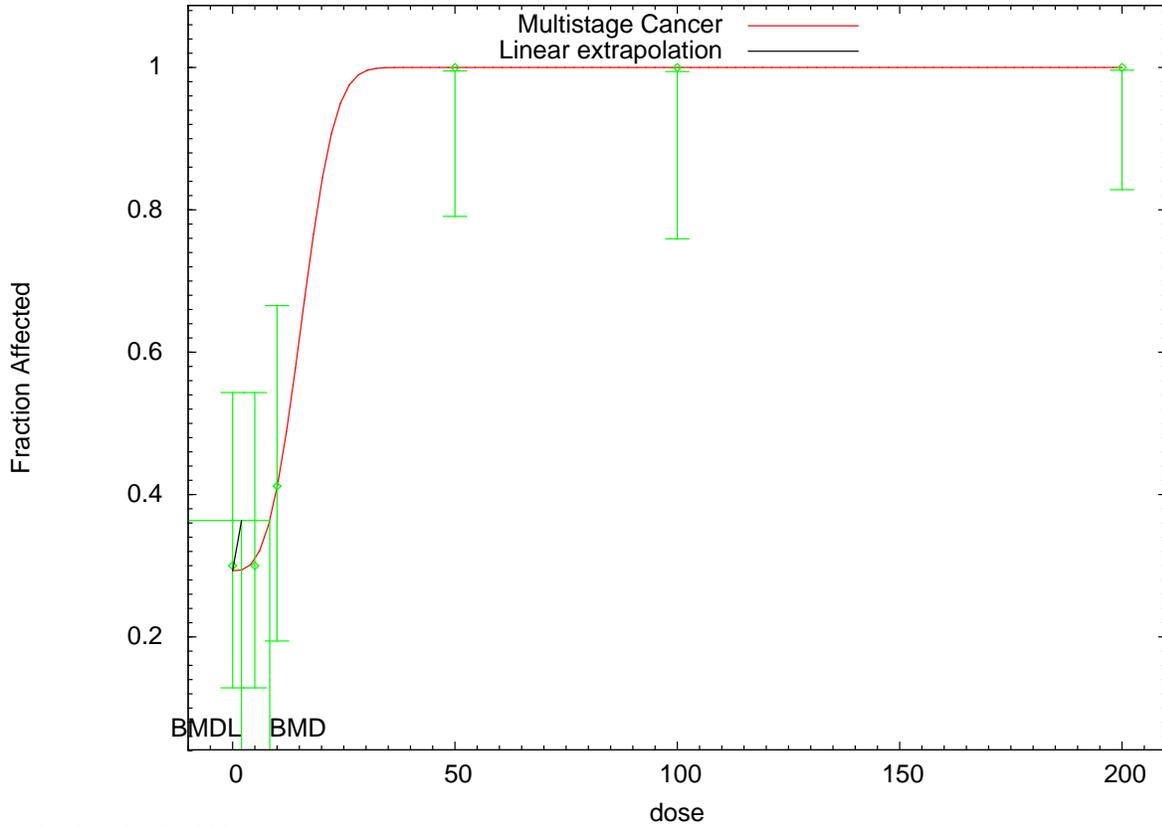
Benchmark Dose Computation

Specified effect = 0.1  
 Risk Type = Extra risk  
 Confidence level = 0.95  
 BMD = 0.292233  
 BMDL = 0.125394  
 BMDU = 0.383954

Taken together, (0.125394, 0.383954) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 0.797488

Multistage Cancer Model with 0.95 Confidence Level



08:01 12/28 2009

Nesnow et al. 1998b i.p BaP male lung

```

=====
      Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
      Input Data File:
11 C:\USEPA\IRIS\PAH\IP\Nesnow1998b\BaP\msc_NesnowBaP_MS_4_10.(d)
      Gnuplot Plotting File:
13 C:\USEPA\IRIS\PAH\IP\Nesnow1998b\BaP\msc_NesnowBaP_MS_4_10.plt
14                               Wed Dec 23 14:46:42 2009
=====
  
```

BMDS Model Run

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\beta_1 * \text{dose}^1 - \beta_2 * \text{dose}^2 - \beta_3 * \text{dose}^3 - \beta_4 * \text{dose}^4)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence  
Independent variable = dose

1 Total number of observations = 6  
 2 Total number of records with missing values = 0  
 3 Total number of parameters in model = 5  
 4 Total number of specified parameters = 0  
 5 Degree of polynomial = 4  
 6  
 7  
 8 Maximum number of iterations = 250  
 9 Relative Function Convergence has been set to: 2.22045e-016  
 10 Parameter Convergence has been set to: 1.49012e-008  
 11  
 12 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 13 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 14 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 15 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

19 Default Initial Parameter Values

20 Background = 1  
 21 Beta(1) = 5.5061e+017  
 22 Beta(2) = 0  
 23 Beta(3) = 0  
 24 Beta(4) = 0

26 Asymptotic Correlation Matrix of Parameter Estimates

27  
 28 ( \*\*\* The model parameter(s) -Beta(1) -Beta(2)  
 29 have been estimated at a boundary point, or have been  
 30 specified by the user,  
 31 and do not appear in the correlation matrix )

|            | Background | Beta(3) | Beta(4) |
|------------|------------|---------|---------|
| Background | 1          | -0.67   | 0.64    |
| Beta(3)    | -0.67      | 1       | -1      |
| Beta(4)    | 0.64       | -1      | 1       |

44 Parameter Estimates

| Confidence Interval |              |           | 95.0% Wald |             |
|---------------------|--------------|-----------|------------|-------------|
| Variable            | Estimate     | Std. Err. | Lower      | Conf. Limit |
| Upper Conf. Limit   |              |           |            |             |
| Background          | 0.29287      | *         | *          |             |
| Beta(1)             | 0            | *         | *          |             |
| Beta(2)             | 0            | *         | *          |             |
| Beta(3)             | 0.000178164  | *         | *          |             |
| Beta(4)             | 3.09556e-007 | *         | *          |             |

1 \* - Indicates that this value is not calculated.

2  
3  
4  
5 Analysis of Deviance Table

| 6 Model          | Log(likelihood) | # Param's | Deviance  | Test d.f. | P-value |
|------------------|-----------------|-----------|-----------|-----------|---------|
| 7 Full model     | -35.952         | 6         |           |           |         |
| 8 Fitted model   | -35.958         | 3         | 0.0120148 | 3         |         |
| 9 0.9997         |                 |           |           |           |         |
| 10 Reduced model | -73.3649        | 1         | 74.8258   | 5         | <.0001  |
| 11 AIC:          | 77.916          |           |           |           |         |

12  
13  
14  
15  
16 Goodness of Fit

| 17 Dose     | Est._Prob. | Expected | Observed | Size | Scaled Residual |
|-------------|------------|----------|----------|------|-----------------|
| 18 0.0000   | 0.2929     | 5.857    | 6.000    | 20   | 0.070           |
| 19 5.0000   | 0.3086     | 6.172    | 6.000    | 20   | -0.083          |
| 20 10.0000  | 0.4101     | 6.972    | 7.000    | 17   | 0.014           |
| 21 50.0000  | 1.0000     | 19.000   | 19.000   | 19   | 0.000           |
| 22 100.0000 | 1.0000     | 16.000   | 16.000   | 16   | 0.000           |
| 23 200.0000 | 1.0000     | 24.000   | 24.000   | 24   | 0.000           |

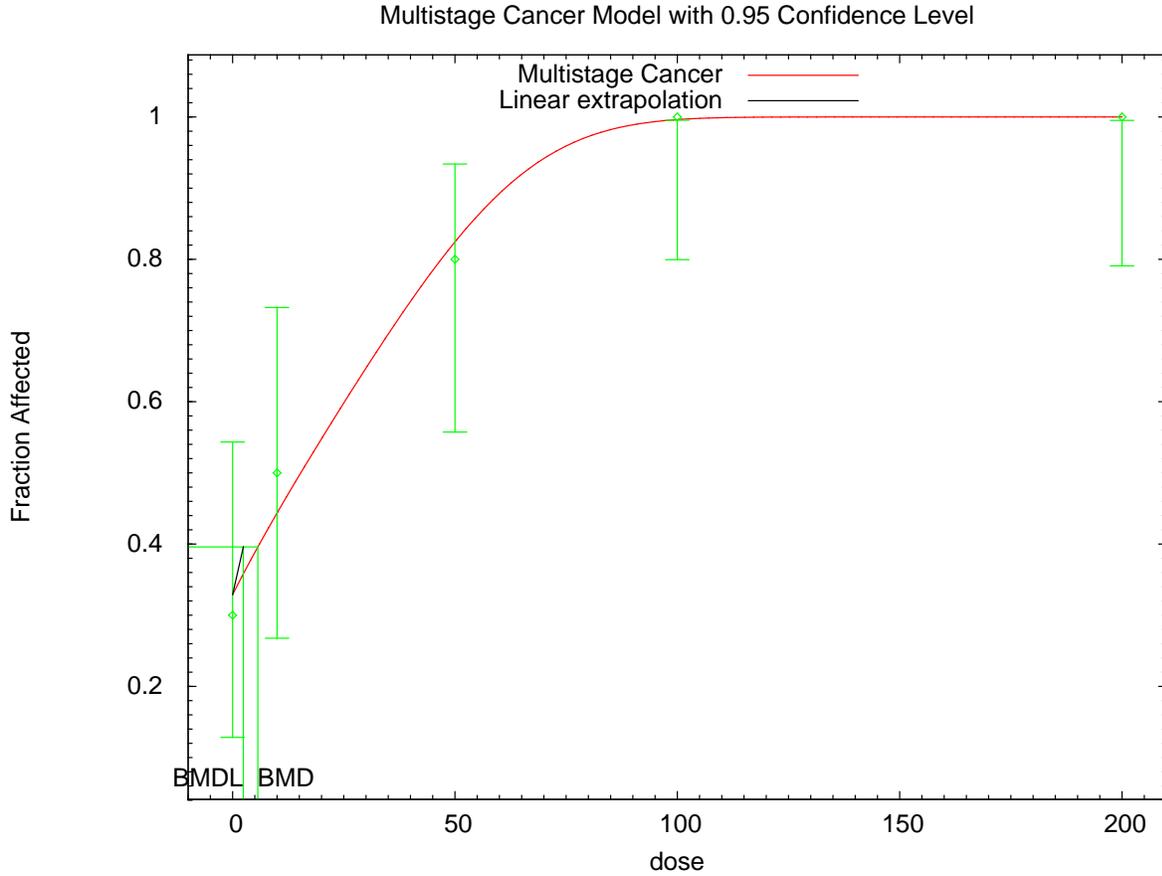
24  
25  
26  
27 Chi^2 = 0.01      d.f. = 3      P-value = 0.9997

28  
29  
30 Benchmark Dose Computation

31 Specified effect = 0.1  
32  
33 Risk Type = Extra risk  
34  
35 Confidence level = 0.95  
36  
37 BMD = 8.35346  
38  
39 BMDL = 2.00564  
40  
41 BMDU = 22.6111  
42

43  
44 Taken together, (2.00564, 22.6111) is a 90 % two-sided confidence  
45 interval for the BMD

46  
47 Multistage Cancer Slope Factor = 0.0498594  
48  
49  
50



2 08:04 12/28 2009  
 3 Nesnow et al. 1998b i.p BbF male lung

```

  4
  5
  6
  7 =====
  8 Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
  9 Input Data File:
 10 C:\USEPA\IRIS\PAH\IP\Nesnow1998b\BbF\msc_NesnowBbF_MS_3.(d)
 11 Gnuplot Plotting File:
 12 C:\USEPA\IRIS\PAH\IP\Nesnow1998b\BbF\msc_NesnowBbF_MS_3.plt
 13 Wed Dec 23 14:46:42 2009
 14 =====
  
```

15  
 16 BMDS Model Run

17 ~~~~~  
 18  
 19 The form of the probability function is:

20  
 21 
$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\beta_1 * \text{dose}^1 - \beta_2 * \text{dose}^2 - \beta_3 * \text{dose}^3)]$$

22  
 23  
 24 The parameter betas are restricted to be positive

25  
 26  
 27 Dependent variable = incidence  
 28 Independent variable = dose

29  
 30 Total number of observations = 5

1 Total number of records with missing values = 0  
 2 Total number of parameters in model = 4  
 3 Total number of specified parameters = 0  
 4 Degree of polynomial = 3  
 5  
 6  
 7 Maximum number of iterations = 250  
 8 Relative Function Convergence has been set to: 2.22045e-016  
 9 Parameter Convergence has been set to: 1.49012e-008  
 10  
 11 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 12 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 13 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 14 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

18 Default Initial Parameter Values

19 Background = 0  
 20 Beta(1) = 5.84708e+017  
 21 Beta(2) = 0  
 22 Beta(3) = 0

25 Asymptotic Correlation Matrix of Parameter Estimates

26  
 27 ( \*\*\* The model parameter(s) -Beta(2)  
 28 have been estimated at a boundary point, or have been  
 29 specified by the user,  
 30 and do not appear in the correlation matrix )

|            | Background | Beta(1) | Beta(3) |
|------------|------------|---------|---------|
| Background | 1          | -0.56   | 0.31    |
| Beta(1)    | -0.56      | 1       | -0.8    |
| Beta(3)    | 0.31       | -0.8    | 1       |

42 Parameter Estimates

| Confidence Interval |              | 95.0% Wald |       |             |
|---------------------|--------------|------------|-------|-------------|
| Variable            | Estimate     | Std. Err.  | Lower | Conf. Limit |
| Upper Conf. Limit   |              |            |       |             |
| Background          | 0.328834     | *          | *     |             |
| Beta(1)             | 0.0184355    | *          | *     |             |
| Beta(2)             | 0            | *          | *     |             |
| Beta(3)             | 3.37339e-006 | *          | *     |             |

57 \* - Indicates that this value is not calculated.

Analysis of Deviance Table

| Model                   | Log(likelihood) | # Param's | Deviance | Test d.f. | P-value |
|-------------------------|-----------------|-----------|----------|-----------|---------|
| Full model              | -34.702         | 5         |          |           |         |
| Fitted model            | -34.9693        | 3         | 0.53462  | 2         |         |
| 0.7654<br>Reduced model | -57.3647        | 1         | 45.3254  | 4         | <.0001  |
| AIC:                    | 75.9386         |           |          |           |         |

Goodness of Fit

| Dose     | Est._Prob. | Expected | Observed | Size | Scaled Residual |
|----------|------------|----------|----------|------|-----------------|
| 0.0000   | 0.3288     | 6.577    | 6.000    | 20   | -0.274          |
| 10.0000  | 0.4437     | 7.987    | 9.000    | 18   | 0.481           |
| 50.0000  | 0.8249     | 16.497   | 16.000   | 20   | -0.293          |
| 100.0000 | 0.9964     | 19.927   | 20.000   | 20   | 0.270           |
| 200.0000 | 1.0000     | 19.000   | 19.000   | 19   | 0.000           |

Chi^2 = 0.47      d.f. = 2      P-value = 0.7925

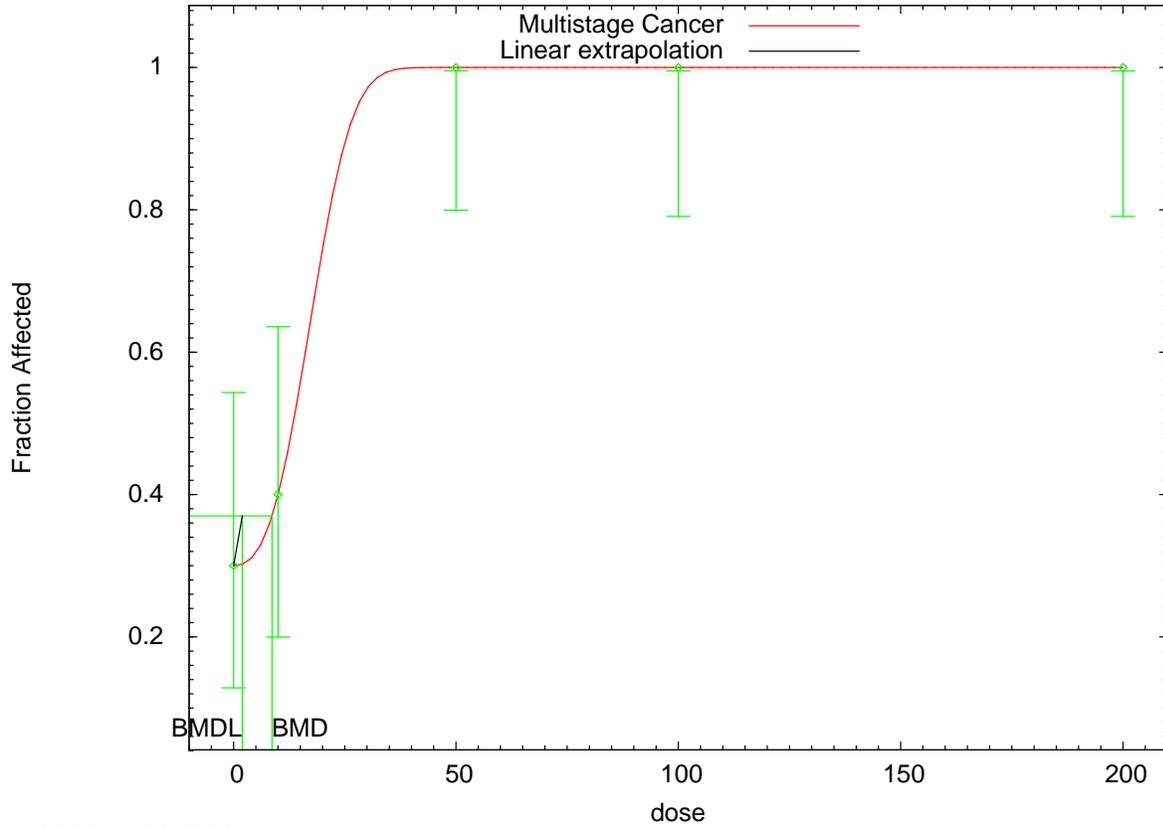
Benchmark Dose Computation

Specified effect = 0.1  
 Risk Type = Extra risk  
 Confidence level = 0.95  
 BMD = 5.68153  
 BMDL = 2.40867  
 BMDU = 28.009

Taken together, (2.40867, 28.009 ) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 0.0415166

Multistage Cancer Model with 0.95 Confidence Level



08:05 12/28 2009

Nesnow et al. 1998b i.p CPcdP male lung

```

=====
      Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
      Input Data File:
11 C:\USEPA\IRIS\PAH\IP\Nesnow1998b\CPcdP\msc_NesnowCPcdP_MS_3.(d)
      Gnuplot Plotting File:
13 C:\USEPA\IRIS\PAH\IP\Nesnow1998b\CPcdP\msc_NesnowCPcdP_MS_3.plt
14                               Wed Dec 23 14:46:43 2009
=====
  
```

BMDS Model Run

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\beta_1 * \text{dose}^1 - \beta_2 * \text{dose}^2 - \beta_3 * \text{dose}^3)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence  
Independent variable = dose

1 Total number of observations = 5  
 2 Total number of records with missing values = 0  
 3 Total number of parameters in model = 4  
 4 Total number of specified parameters = 0  
 5 Degree of polynomial = 3  
 6  
 7  
 8 Maximum number of iterations = 250  
 9 Relative Function Convergence has been set to: 2.22045e-016  
 10 Parameter Convergence has been set to: 1.49012e-008  
 11  
 12 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 13 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 14 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 15 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

19 Default Initial Parameter Values

20 Background = 1  
 21 Beta(1) = 5.02249e+017  
 22 Beta(2) = 0  
 23 Beta(3) = 0

26 Asymptotic Correlation Matrix of Parameter Estimates

27  
 28 ( \*\*\* The model parameter(s) -Beta(1)  
 29 have been estimated at a boundary point, or have been  
 30 specified by the user,  
 31 and do not appear in the correlation matrix )

|            | Background | Beta(2) | Beta(3) |
|------------|------------|---------|---------|
| Background | 1          | -0.13   | 0.025   |
| Beta(2)    | -0.13      | 1       | -0.99   |
| Beta(3)    | 0.025      | -0.99   | 1       |

43 Parameter Estimates

| Confidence Interval |              | 95.0% Wald |                   |  |
|---------------------|--------------|------------|-------------------|--|
| Variable            | Estimate     | Std. Err.  | Lower Conf. Limit |  |
| Upper Conf. Limit   |              |            |                   |  |
| Background          | 0.299994     | *          | *                 |  |
| Beta(1)             | 0            | *          | *                 |  |
| Beta(2)             | 0.000554719  | *          | *                 |  |
| Beta(3)             | 9.86997e-005 | *          | *                 |  |

58 \* - Indicates that this value is not calculated.

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46

Analysis of Deviance Table

| Model         | Log(likelihood) | # Param's | Deviance     | Test d.f. | P-value |
|---------------|-----------------|-----------|--------------|-----------|---------|
| Full model    | -25.6775        | 5         |              |           |         |
| Fitted model  | -25.6775        | 3         | 3.06836e-005 | 2         |         |
| Reduced model | -56.6963        | 1         | 62.0376      | 4         | <.0001  |
| AIC:          | 57.3551         |           |              |           |         |

Goodness of Fit

| Dose     | Est._Prob. | Expected | Observed | Size | Scaled Residual |
|----------|------------|----------|----------|------|-----------------|
| 0.0000   | 0.3000     | 6.000    | 6.000    | 20   | 0.000           |
| 10.0000  | 0.4000     | 8.000    | 8.000    | 20   | -0.000          |
| 50.0000  | 1.0000     | 20.000   | 20.000   | 20   | 0.004           |
| 100.0000 | 1.0000     | 19.000   | 19.000   | 19   | 0.000           |
| 200.0000 | 1.0000     | 19.000   | 19.000   | 19   | 0.000           |

Chi^2 = 0.00      d.f. = 2      P-value = 1.0000

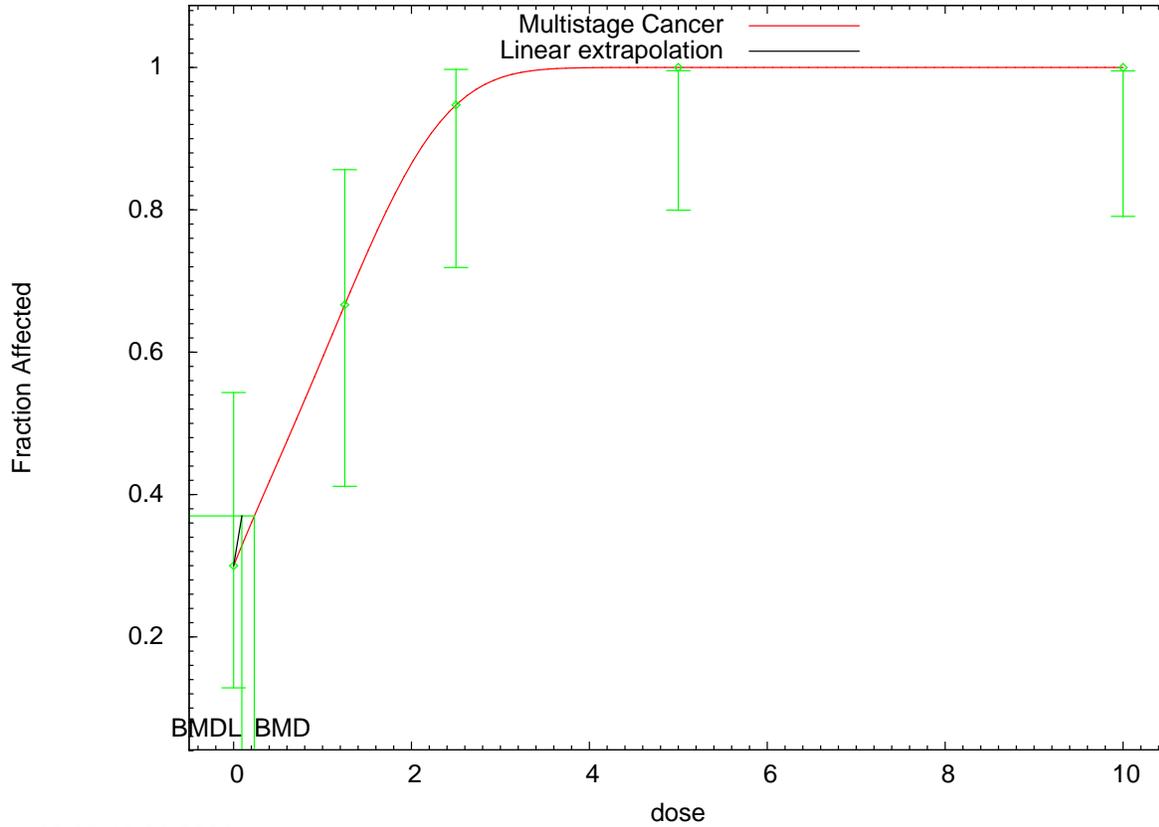
Benchmark Dose Computation

Specified effect = 0.1  
Risk Type = Extra risk  
Confidence level = 0.95  
BMD = 8.64922  
BMDL = 1.95607  
BMDU = 17.5713

Taken together, (1.95607, 17.5713) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 0.0511229

Multistage Cancer Model with 0.95 Confidence Level



08:05 12/28 2009

Nesnow et al. 1998b i.p DBahA male lung

```

=====
      Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
      Input Data File:
10 C:\USEPA\IRIS\PAH\IP\Nesnow1998b\DBahA\msc_NesnowDBahA_MS_3.(d)
      Gnuplot Plotting File:
12 C:\USEPA\IRIS\PAH\IP\Nesnow1998b\DBahA\msc_NesnowDBahA_MS_3.plt
13                               Wed Dec 23 14:46:43 2009
=====

```

BMDS Model Run

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\beta_1 * \text{dose}^1 - \beta_2 * \text{dose}^2 - \beta_3 * \text{dose}^3)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

Total number of observations = 5

1 Total number of records with missing values = 0  
 2 Total number of parameters in model = 4  
 3 Total number of specified parameters = 0  
 4 Degree of polynomial = 3  
 5  
 6  
 7 Maximum number of iterations = 250  
 8 Relative Function Convergence has been set to: 2.22045e-016  
 9 Parameter Convergence has been set to: 1.49012e-008  
 10  
 11 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 12 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 13 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 14 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

18 Default Initial Parameter Values

19 Background = 0  
 20 Beta(1) = 1.2e+019  
 21 Beta(2) = 0  
 22 Beta(3) = 0

25 Asymptotic Correlation Matrix of Parameter Estimates

26  
 27 ( \*\*\* The model parameter(s) -Beta(2)  
 28 have been estimated at a boundary point, or have been  
 29 specified by the user,  
 30 and do not appear in the correlation matrix )

|            | Background | Beta(1) | Beta(3) |
|------------|------------|---------|---------|
| Background | 1          | -0.48   | 0.2     |
| Beta(1)    | -0.48      | 1       | -0.81   |
| Beta(3)    | 0.2        | -0.81   | 1       |

42 Parameter Estimates

| Confidence Interval |           | 95.0% Wald |                   |  |
|---------------------|-----------|------------|-------------------|--|
| Variable            | Estimate  | Std. Err.  | Lower Conf. Limit |  |
| Upper Conf. Limit   |           |            |                   |  |
| Background          | 0.300001  | *          | *                 |  |
| Beta(1)             | 0.446326  | *          | *                 |  |
| Beta(2)             | 0         | *          | *                 |  |
| Beta(3)             | 0.0942115 | *          | *                 |  |

57 \* - Indicates that this value is not calculated.

Analysis of Deviance Table

| Model         | Log(likelihood) | # Param's | Deviance     | Test d.f. | P-value |
|---------------|-----------------|-----------|--------------|-----------|---------|
| Full model    | -27.5922        | 5         |              |           |         |
| Fitted model  | -27.5922        | 3         | 2.31121e-005 | 2         |         |
| Reduced model | -50.4308        | 1         | 45.6773      | 4         | <.0001  |
| AIC:          | 61.1844         |           |              |           |         |

Goodness of Fit

| Dose    | Est._Prob. | Expected | Observed | Size | Scaled Residual |
|---------|------------|----------|----------|------|-----------------|
| 0.0000  | 0.3000     | 6.000    | 6.000    | 20   | -0.000          |
| 1.2500  | 0.6667     | 12.000   | 12.000   | 18   | 0.000           |
| 2.5000  | 0.9474     | 18.000   | 18.000   | 19   | -0.000          |
| 5.0000  | 1.0000     | 20.000   | 20.000   | 20   | 0.003           |
| 10.0000 | 1.0000     | 19.000   | 19.000   | 19   | 0.000           |

Chi^2 = 0.00      d.f. = 2      P-value = 1.0000

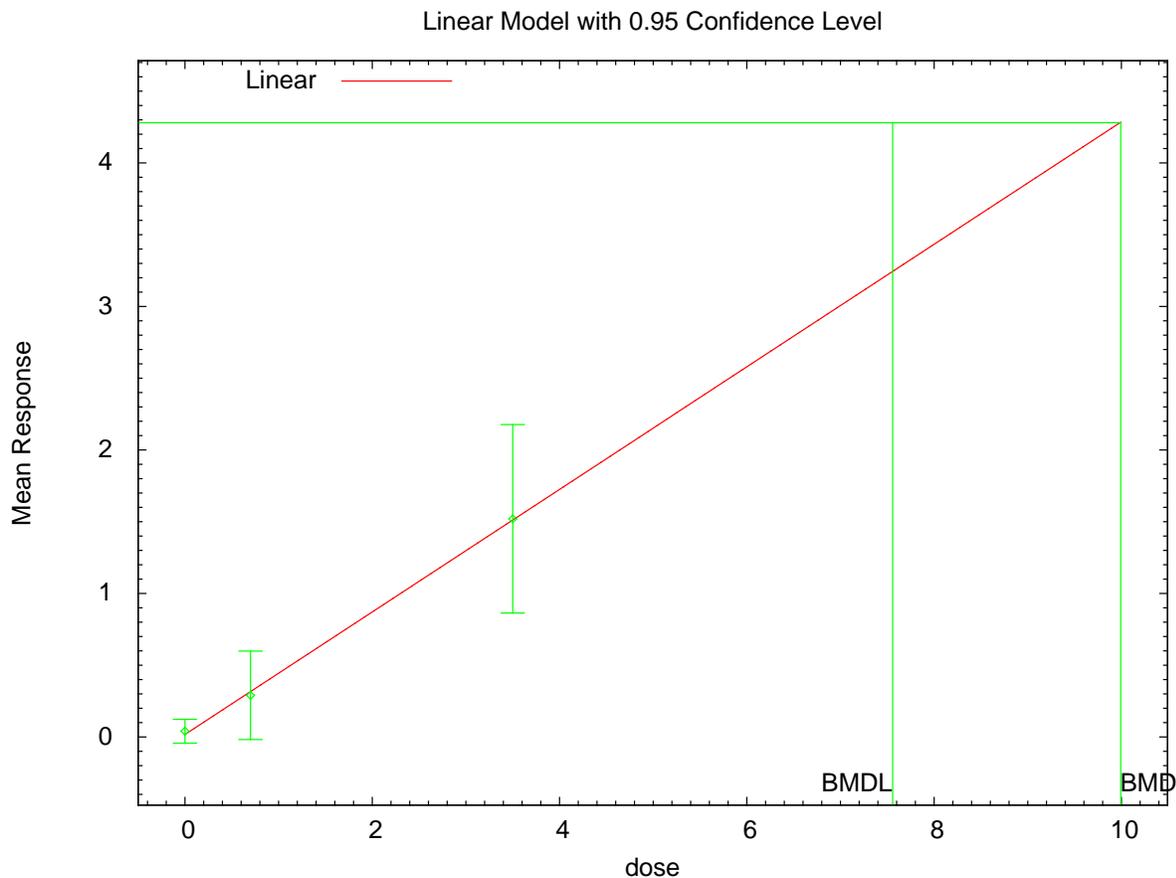
Benchmark Dose Computation

Specified effect = 0.1  
 Risk Type = Extra risk  
 Confidence level = 0.95  
 BMD = 0.233378  
 BMDL = 0.0933198  
 BMDU = 0.955315

Taken together, (0.0933198, 0.955315) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 1.07158

1 Busby 1984 i.p. multiplicity  
 2 FA male  
 3 Linear  
 4 Nonconstant variance  
 5 BMR = lowest statistically significant response in BaP treated animals (after  
 6 control subtracted)  
 7



8 08:12 12/28 2009

9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30

```

=====
      Polynomial Model. (Version: 2.13; Date: 04/08/2008)
      Input Data File:
16 C:\IPmult\Busby1984\FAmale\lin_BusbyFAM_linear_4_28.(d)
      Gnuplot Plotting File:
18 C:\IPmult\Busby1984\FAmale\lin_BusbyFAM_linear_4_28.plt
19                               Wed Dec 23 15:26:52 2009
=====

BMDs Model Run
~~~~~

The form of the response function is:

Y[dose] = beta_0 + beta_1*dose + beta_2*dose^2 + ...

Dependent variable = mean

```

1 Independent variable = dose  
 2 The polynomial coefficients are restricted to be positive  
 3 The variance is to be modeled as  $\text{Var}(i) = \exp(\text{lalpha} + \log(\text{mean}(i))) * \text{rho}$   
 4  
 5 Total number of dose groups = 3  
 6 Total number of records with missing values = 0  
 7 Maximum number of iterations = 250  
 8 Relative Function Convergence has been set to: 1e-008  
 9 Parameter Convergence has been set to: 1e-008

10  
11  
12

Default Initial Parameter Values

13  
14 lalpha = 0.136152  
15 rho = 0  
16 beta\_0 = 0.0180952  
17 beta\_1 = 0.427551  
18

Asymptotic Correlation Matrix of Parameter Estimates

|        | lalpha  | rho    | beta_0 | beta_1  |
|--------|---------|--------|--------|---------|
| lalpha | 1       | 0.65   | 0.015  | 0.00041 |
| rho    | 0.65    | 1      | 0.22   | -0.061  |
| beta_0 | 0.015   | 0.22   | 1      | -0.24   |
| beta_1 | 0.00041 | -0.061 | -0.24  | 1       |

31  
32  
33

Parameter Estimates

| Confidence Interval | Variable | Estimate  | Std. Err. | 95.0% Wald        |
|---------------------|----------|-----------|-----------|-------------------|
|                     |          |           |           | Lower Conf. Limit |
| Upper Conf. Limit   | lalpha   | 0.634298  | 0.204652  | 0.233188          |
| 1.03541             | rho      | 0.923372  | 0.0876305 | 0.751619          |
| 1.09512             | beta_0   | 0.0170376 | 0.0434041 | -0.0680328        |
| 0.102108            | beta_1   | 0.426604  | 0.0861283 | 0.257796          |
| 0.595413            |          |           |           |                   |

48  
49  
50

Table of Data and Estimated Values of Interest

| Dose | N  | Obs Mean | Est Mean | Obs Std Dev | Est Std Dev | Scaled Res. |
|------|----|----------|----------|-------------|-------------|-------------|
| 0    | 27 | 0.04     | 0.017    | 0.21        | 0.21        | 0.57        |
| 0.7  | 31 | 0.29     | 0.316    | 0.84        | 0.806       | -0.177      |
| 3.5  | 27 | 1.52     | 1.51     | 1.66        | 1.66        | 0.0308      |

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

Model Descriptions for likelihoods calculated

Model A1:  $Y_{ij} = \mu(i) + e(ij)$   
 $\text{Var}\{e(ij)\} = \sigma^2$

Model A2:  $Y_{ij} = \mu(i) + e(ij)$   
 $\text{Var}\{e(ij)\} = \sigma(i)^2$

Model A3:  $Y_{ij} = \mu(i) + e(ij)$   
 $\text{Var}\{e(ij)\} = \exp(\alpha + \rho \ln(\mu(i)))$   
Model A3 uses any fixed variance parameters that were specified by the user

Model R:  $Y_i = \mu + e(i)$   
 $\text{Var}\{e(i)\} = \sigma^2$

Likelihoods of Interest

| Model  | Log(likelihood) | # Param's | AIC        |
|--------|-----------------|-----------|------------|
| A1     | -46.759351      | 4         | 101.518703 |
| A2     | -7.114400       | 6         | 26.228800  |
| A3     | -7.317284       | 5         | 24.634569  |
| fitted | -7.329046       | 4         | 22.658093  |
| R      | -59.984569      | 2         | 123.969139 |

Explanation of Tests

- Test 1: Do responses and/or variances differ among Dose levels? (A2 vs. R)
  - Test 2: Are Variances Homogeneous? (A1 vs A2)
  - Test 3: Are variances adequately modeled? (A2 vs. A3)
  - Test 4: Does the Model for the Mean Fit? (A3 vs. fitted)
- (Note: When  $\rho=0$  the results of Test 3 and Test 2 will be the same.)

Tests of Interest

| Test   | -2*log(Likelihood Ratio) | Test df | p-value |
|--------|--------------------------|---------|---------|
| Test 1 | 105.74                   | 4       | <.0001  |
| Test 2 | 79.2899                  | 2       | <.0001  |
| Test 3 | 0.405769                 | 1       | 0.5241  |
| Test 4 | 0.0235238                | 1       | 0.8781  |

The p-value for Test 1 is less than .05. There appears to be a difference between response and/or variances among the dose levels. It seems appropriate to model the data.

The p-value for Test 2 is less than .1. A non-homogeneous variance model appears to be appropriate.

The p-value for Test 3 is greater than .1. The modeled variance appears to be appropriate here.

The p-value for Test 4 is greater than .1. The model chosen seems

1 to adequately describe the data

2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19

Benchmark Dose Computation

Specified effect = 4.28

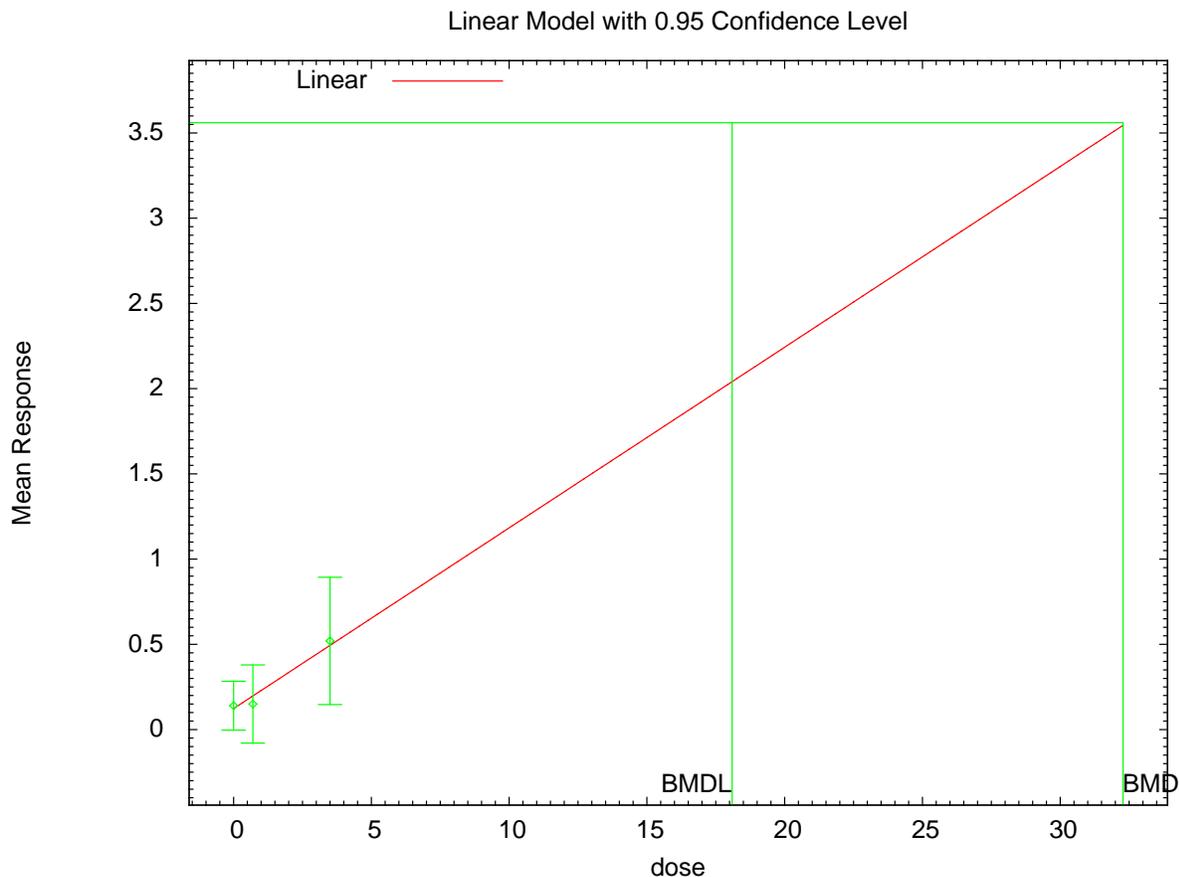
Risk Type = Point risk

Confidence level = 0.95

BMD = 9.99278

BMDL = 7.55762

1 Busby 1984 i.p. multiplicity  
 2 FA female  
 3 Linear  
 4 Nonconstant variance  
 5 BMR = lowest statistically significant response in BaP treated animals (after  
 6 control subtracted)  
 7  
 8



9 08:14 12/28 2009

10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30

```

=====
 Polynomial Model. (Version: 2.13; Date: 04/08/2008)
 Input Data File:
 C:\IPmult\Busby1984\FAfemale\lin_BusbyFAF_linear_3_56.(d)
 Gnuplot Plotting File:
 C:\IPmult\Busby1984\FAfemale\lin_BusbyFAF_linear_3_56.plt
 Wed Dec 23 15:26:52 2009
=====

```

BMDS Model Run

~~~~~

The form of the response function is:

$$Y[\text{dose}] = \text{beta}_0 + \text{beta}_1 \cdot \text{dose} + \text{beta}_2 \cdot \text{dose}^2 + \dots$$

1 Dependent variable = mean  
 2 Independent variable = dose  
 3 The polynomial coefficients are restricted to be positive  
 4 The variance is to be modeled as  $\text{Var}(i) = \exp(\text{lalpha} + \log(\text{mean}(i))) * \text{rho}$   
 5  
 6 Total number of dose groups = 3  
 7 Total number of records with missing values = 0  
 8 Maximum number of iterations = 250  
 9 Relative Function Convergence has been set to: 1e-008  
 10 Parameter Convergence has been set to: 1e-008  
 11  
 12  
 13

14 Default Initial Parameter Values

15 lalpha = -1.11206  
 16 rho = 0  
 17 beta\_0 = 0.108571  
 18 beta\_1 = 0.115306  
 19

20  
21 Asymptotic Correlation Matrix of Parameter Estimates

|        | lalpha | rho    | beta_0 | beta_1 |
|--------|--------|--------|--------|--------|
| lalpha | 1      | 0.94   | 0.036  | -0.047 |
| rho    | 0.94   | 1      | 0.04   | -0.052 |
| beta_0 | 0.036  | 0.04   | 1      | -0.46  |
| beta_1 | -0.047 | -0.052 | -0.46  | 1      |

22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35 Parameter Estimates

| Confidence Interval |          | 95.0% Wald |                   |  |
|---------------------|----------|------------|-------------------|--|
| Variable            | Estimate | Std. Err.  | Lower Conf. Limit |  |
| Upper Conf. Limit   |          |            |                   |  |
| lalpha              | 0.353344 | 0.480274   | -0.587974         |  |
| 1.29466             |          |            |                   |  |
| rho                 | 1.1315   | 0.292904   | 0.557421          |  |
| 1.70558             |          |            |                   |  |
| beta_0              | 0.123135 | 0.0618608  | 0.00189039        |  |
| 0.24438             |          |            |                   |  |
| beta_1              | 0.106469 | 0.0535364  | 0.00153987        |  |
| 0.211399            |          |            |                   |  |

36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51 Table of Data and Estimated Values of Interest

| Dose  | N   | Obs Mean | Est Mean | Obs Std Dev | Est Std Dev | Scaled |
|-------|-----|----------|----------|-------------|-------------|--------|
| Res.  |     |          |          |             |             |        |
| ----- | --- | -----    | -----    | -----       | -----       | -----  |
| -     |     |          |          |             |             |        |
| 0     | 28  | 0.14     | 0.123    | 0.37        | 0.365       | 0.245  |
| 0.7   | 20  | 0.15     | 0.198    | 0.49        | 0.477       | -0.447 |

1 3.5 21 0.52 0.496 0.82 0.802 0.138

5 Model Descriptions for likelihoods calculated

8 Model A1:  $Y_{ij} = \mu(i) + e(ij)$   
9  $\text{Var}\{e(ij)\} = \sigma^2$

11 Model A2:  $Y_{ij} = \mu(i) + e(ij)$   
12  $\text{Var}\{e(ij)\} = \sigma(i)^2$

14 Model A3:  $Y_{ij} = \mu(i) + e(ij)$   
15  $\text{Var}\{e(ij)\} = \exp(\alpha + \rho \ln(\mu(i)))$   
16 Model A3 uses any fixed variance parameters that  
17 were specified by the user

19 Model R:  $Y_i = \mu + e(i)$   
20  $\text{Var}\{e(i)\} = \sigma^2$

23 Likelihoods of Interest

| Model  | Log(likelihood) | # Param's | AIC        |
|--------|-----------------|-----------|------------|
| A1     | 5.399546        | 4         | -2.799091  |
| A2     | 13.307908       | 6         | -14.615816 |
| A3     | 13.189903       | 5         | -16.379806 |
| fitted | 13.167852       | 4         | -18.335705 |
| R      | 2.264796        | 2         | -0.529591  |

33 Explanation of Tests

- 35 Test 1: Do responses and/or variances differ among Dose levels?  
36 (A2 vs. R)
- 37 Test 2: Are Variances Homogeneous? (A1 vs A2)
- 38 Test 3: Are variances adequately modeled? (A2 vs. A3)
- 39 Test 4: Does the Model for the Mean Fit? (A3 vs. fitted)
- 40 (Note: When  $\rho=0$  the results of Test 3 and Test 2 will be the same.)

42 Tests of Interest

| Test   | $-2 \cdot \log(\text{Likelihood Ratio})$ | Test df | p-value   |
|--------|------------------------------------------|---------|-----------|
| Test 1 | 22.0862                                  | 4       | 0.0001927 |
| Test 2 | 15.8167                                  | 2       | 0.0003677 |
| Test 3 | 0.23601                                  | 1       | 0.6271    |
| Test 4 | 0.0441012                                | 1       | 0.8337    |

51 The p-value for Test 1 is less than .05. There appears to be a  
52 difference between response and/or variances among the dose levels  
53 It seems appropriate to model the data

55 The p-value for Test 2 is less than .1. A non-homogeneous variance  
56 model appears to be appropriate

58 The p-value for Test 3 is greater than .1. The modeled variance appears  
59 to be appropriate here

60

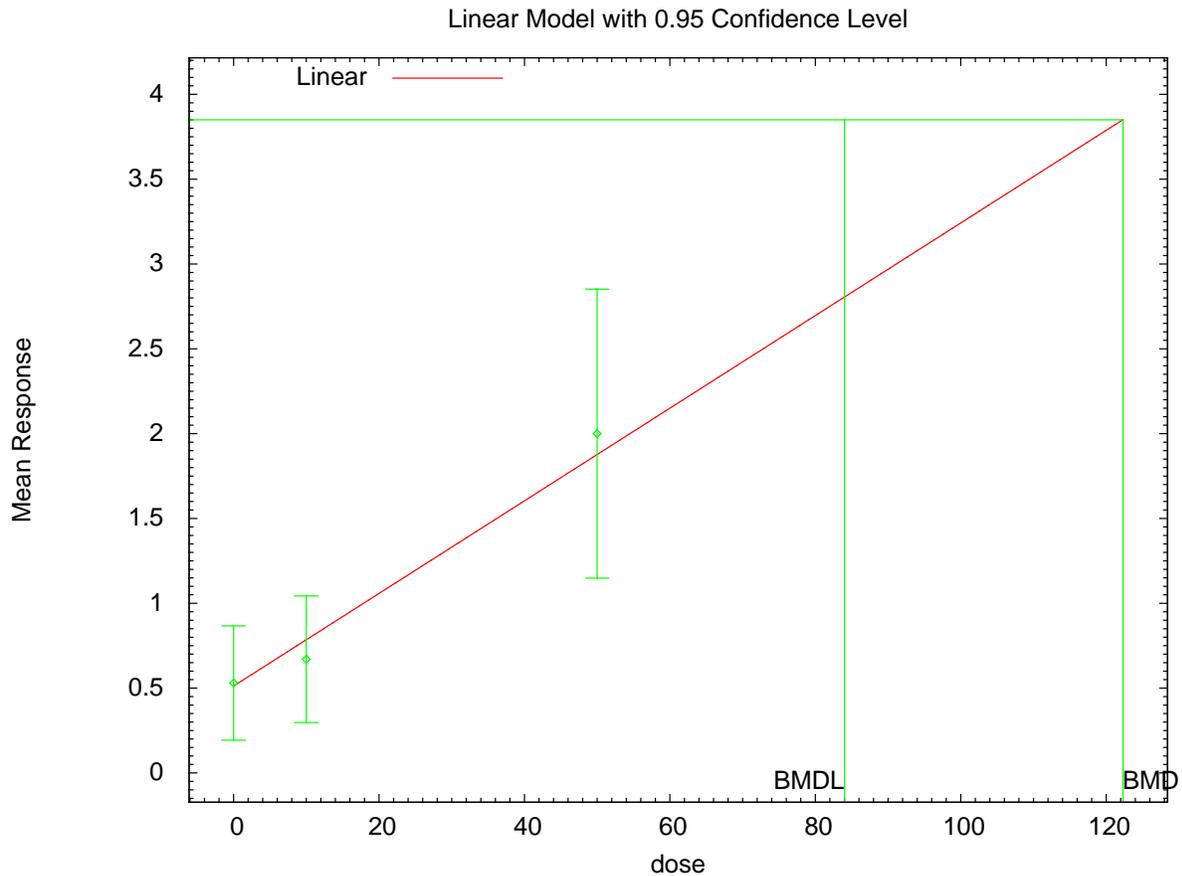
1 The p-value for Test 4 is greater than .1. The model chosen seems  
2 to adequately describe the data

3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19

Benchmark Dose Computation

|                    |            |
|--------------------|------------|
| Specified effect = | 3.56       |
| Risk Type =        | Point risk |
| Confidence level = | 0.95       |
| BMD =              | 32.2804    |
| BMDL =             | 18.094     |

1 Nesnow 1998b i.p. multiplicity  
 2 BbF  
 3 Drop 2 high doses  
 4 Linear  
 5 Nonconstant variance  
 6 BMR = lowest statistically significant response in BaP treated animals (after  
 7 control subtracted)  
 8  
 9



10 08:16 12/28 2009

11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30

```

=====
 Polynomial Model. (Version: 2.13; Date: 04/08/2008)
 Input Data File:
 C:\IPmult\Nesnow1998b\BbF\lin_NesnowBbF_linear_3_85.(d)
 Gnuplot Plotting File:
 C:\IPmult\Nesnow1998b\BbF\lin_NesnowBbF_linear_3_85.plt
 Wed Dec 23 15:26:52 2009
=====

BMDS Model Run
~~~~~

The form of the response function is:
Y[dose] = beta_0 + beta_1*dose + beta_2*dose^2 + ...

```

1 Dependent variable = mean  
 2 Independent variable = dose  
 3 The polynomial coefficients are restricted to be positive  
 4 The variance is to be modeled as  $\text{Var}(i) = \exp(\text{lalpha} + \log(\text{mean}(i))) * \text{rho}$   
 5  
 6 Total number of dose groups = 3  
 7 Total number of records with missing values = 0  
 8 Maximum number of iterations = 250  
 9 Relative Function Convergence has been set to: 1e-008  
 10 Parameter Convergence has been set to: 1e-008  
 11  
 12  
 13

14 Default Initial Parameter Values

15 lalpha = 0.403617  
 16 rho = 0  
 17 beta\_0 = 0.456667  
 18 beta\_1 = 0.0305  
 19  
 20

21 Asymptotic Correlation Matrix of Parameter Estimates

|        | lalpha | rho    | beta_0 | beta_1 |
|--------|--------|--------|--------|--------|
| lalpha | 1      | 0.15   | 0.059  | -0.07  |
| rho    | 0.15   | 1      | -0.059 | 0.006  |
| beta_0 | 0.059  | -0.059 | 1      | -0.49  |
| beta_1 | -0.07  | 0.006  | -0.49  | 1      |

35 Parameter Estimates

| Confidence Interval | Variable | Estimate  | Std. Err.  | 95.0% Wald        |
|---------------------|----------|-----------|------------|-------------------|
|                     |          |           |            | Lower Conf. Limit |
| Upper Conf. Limit   | lalpha   | 0.123284  | 0.188418   | -0.246009         |
| 0.492576            | rho      | 1.49465   | 0.320356   | 0.866761          |
| 2.12253             | beta_0   | 0.511616  | 0.132543   | 0.251836          |
| 0.771396            | beta_1   | 0.0272932 | 0.00827339 | 0.0110776         |
| 0.0435087           |          |           |            |                   |

52 Table of Data and Estimated Values of Interest

| Dose | N  | Obs Mean | Est Mean | Obs Std Dev | Est Std Dev | Scaled Res. |
|------|----|----------|----------|-------------|-------------|-------------|
| 0    | 20 | 0.53     | 0.512    | 0.72        | 0.645       | 0.128       |
| 10   | 18 | 0.67     | 0.785    | 0.75        | 0.887       | -0.548      |

1           50       20               2           1.88           1.82           1.7           0.325

2  
3  
4

5 Model Descriptions for likelihoods calculated

6  
7

8 Model A1:            $Y_{ij} = \mu(i) + e(ij)$

9            $\text{Var}\{e(ij)\} = \sigma^2$

10

11 Model A2:            $Y_{ij} = \mu(i) + e(ij)$

12            $\text{Var}\{e(ij)\} = \sigma(i)^2$

13

14 Model A3:            $Y_{ij} = \mu(i) + e(ij)$

15            $\text{Var}\{e(ij)\} = \exp(\alpha + \rho \ln(\mu(i)))$

16 Model A3 uses any fixed variance parameters that  
17 were specified by the user

18

19 Model R:            $Y_i = \mu + e(i)$

20            $\text{Var}\{e(i)\} = \sigma^2$

21

22

23                           Likelihoods of Interest

24

| 25 | Model  | Log(likelihood) | # Param's | AIC       |
|----|--------|-----------------|-----------|-----------|
| 26 | A1     | -39.164718      | 4         | 86.329436 |
| 27 | A2     | -27.688080      | 6         | 67.376160 |
| 28 | A3     | -27.755992      | 5         | 65.511983 |
| 29 | fitted | -28.699972      | 4         | 65.399945 |
| 30 | R      | -47.123187      | 2         | 98.246375 |

31

32

33                           Explanation of Tests

34

35 Test 1: Do responses and/or variances differ among Dose levels?  
36       (A2 vs. R)

37 Test 2: Are Variances Homogeneous? (A1 vs A2)

38 Test 3: Are variances adequately modeled? (A2 vs. A3)

39 Test 4: Does the Model for the Mean Fit? (A3 vs. fitted)

40 (Note: When  $\rho=0$  the results of Test 3 and Test 2 will be the same.)

41

42                           Tests of Interest

43

| 44 | Test   | -2*log(Likelihood Ratio) | Test df | p-value |
|----|--------|--------------------------|---------|---------|
| 46 | Test 1 | 38.8702                  | 4       | <.0001  |
| 47 | Test 2 | 22.9533                  | 2       | <.0001  |
| 48 | Test 3 | 0.135824                 | 1       | 0.7125  |
| 49 | Test 4 | 1.88796                  | 1       | 0.1694  |

50

51 The p-value for Test 1 is less than .05. There appears to be a  
52 difference between response and/or variances among the dose levels  
53 It seems appropriate to model the data

54

55 The p-value for Test 2 is less than .1. A non-homogeneous variance  
56 model appears to be appropriate

57

58 The p-value for Test 3 is greater than .1. The modeled variance appears  
59 to be appropriate here

60

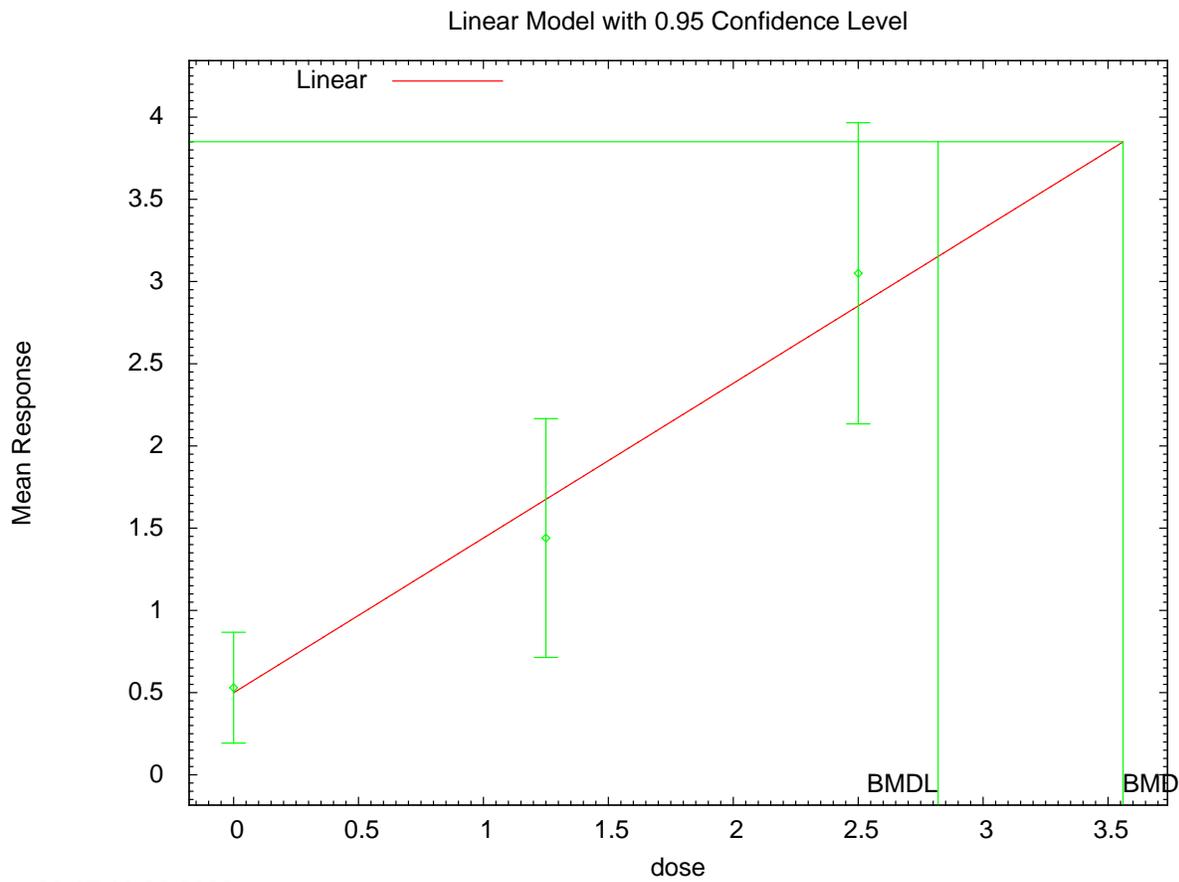
1 The p-value for Test 4 is greater than .1. The model chosen seems  
2 to adequately describe the data

3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20

Benchmark Dose Computation

|                    |            |
|--------------------|------------|
| Specified effect = | 3.85       |
| Risk Type =        | Point risk |
| Confidence level = | 0.95       |
| BMD =              | 122.316    |
| BMDL =             | 84.0259    |

1 Nesnow 1998b i.p. multiplicity  
 2 DBahA  
 3 Drop 2 high doses  
 4 Linear  
 5 Nonconstant variance  
 6 BMR = lowest statistically significant response in BaP treated animals (after  
 7 control subtracted)  
 8



9 08:17 12/28 2009

10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30

```

=====
      Polynomial Model. (Version: 2.13; Date: 04/08/2008)
      Input Data File:
      C:\IPmult\Nesnow1998b\DBahA\lin_NesnowDBahA_linear_3_85.(d)
      Gnuplot Plotting File:
      C:\IPmult\Nesnow1998b\DBahA\lin_NesnowDBahA_linear_3_85.plt
      Wed Dec 23 15:26:52 2009
=====

BMSD Model Run
~~~~~

The form of the response function is:

Y[dose] = beta_0 + beta_1*dose + beta_2*dose^2 + ...

Dependent variable = mean

```

1 Independent variable = dose  
 2 The polynomial coefficients are restricted to be positive  
 3 The variance is to be modeled as  $\text{Var}(i) = \exp(\text{lalpha} + \log(\text{mean}(i))) * \text{rho}$   
 4  
 5 Total number of dose groups = 3  
 6 Total number of records with missing values = 0  
 7 Maximum number of iterations = 250  
 8 Relative Function Convergence has been set to: 1e-008  
 9 Parameter Convergence has been set to: 1e-008

10  
11  
12

Default Initial Parameter Values

13  
 14 lalpha = 0.721148  
 15 rho = 0  
 16 beta\_0 = 0.413333  
 17 beta\_1 = 1.008  
 18

Asymptotic Correlation Matrix of Parameter Estimates

|        | lalpha | rho    | beta_0 | beta_1 |
|--------|--------|--------|--------|--------|
| lalpha | 1      | -0.35  | -0.035 | 0.037  |
| rho    | -0.35  | 1      | 0.073  | -0.083 |
| beta_0 | -0.035 | 0.073  | 1      | -0.49  |
| beta_1 | 0.037  | -0.083 | -0.49  | 1      |

31  
32  
33

Parameter Estimates

| Confidence Interval | Variable | Estimate  | Std. Err. | 95.0% Wald        |
|---------------------|----------|-----------|-----------|-------------------|
|                     |          |           |           | Lower Conf. Limit |
| Upper Conf. Limit   | lalpha   | 0.0932028 | 0.199643  | -0.29809          |
| 0.484496            | rho      | 1.12871   | 0.256611  | 0.625764          |
| 1.63166             | beta_0   | 0.498826  | 0.155419  | 0.19421           |
| 0.803442            | beta_1   | 0.941334  | 0.166649  | 0.614709          |
| 1.26796             |          |           |           |                   |

48  
49  
50

Table of Data and Estimated Values of Interest

| Dose | N  | Obs Mean | Est Mean | Obs Std Dev | Est Std Dev | Scaled Res. |
|------|----|----------|----------|-------------|-------------|-------------|
| 0    | 20 | 0.53     | 0.499    | 0.72        | 0.708       | 0.197       |
| 1.25 | 18 | 1.44     | 1.68     | 1.46        | 1.4         | -0.713      |
| 2.5  | 19 | 3.05     | 2.85     | 1.9         | 1.89        | 0.456       |

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

Model Descriptions for likelihoods calculated

Model A1:  $Y_{ij} = \mu(i) + e(ij)$   
 $\text{Var}\{e(ij)\} = \sigma^2$

Model A2:  $Y_{ij} = \mu(i) + e(ij)$   
 $\text{Var}\{e(ij)\} = \sigma(i)^2$

Model A3:  $Y_{ij} = \mu(i) + e(ij)$   
 $\text{Var}\{e(ij)\} = \exp(\alpha + \rho \ln(\mu(i)))$   
Model A3 uses any fixed variance parameters that were specified by the user

Model R:  $Y_i = \mu + e(i)$   
 $\text{Var}\{e(i)\} = \sigma^2$

Likelihoods of Interest

| Model  | Log(likelihood) | # Param's | AIC        |
|--------|-----------------|-----------|------------|
| A1     | -47.511796      | 4         | 103.023592 |
| A2     | -39.396001      | 6         | 90.792002  |
| A3     | -39.581359      | 5         | 89.162719  |
| fitted | -39.787219      | 4         | 87.574439  |
| R      | -60.336483      | 2         | 124.672966 |

Explanation of Tests

- Test 1: Do responses and/or variances differ among Dose levels? (A2 vs. R)
  - Test 2: Are Variances Homogeneous? (A1 vs A2)
  - Test 3: Are variances adequately modeled? (A2 vs. A3)
  - Test 4: Does the Model for the Mean Fit? (A3 vs. fitted)
- (Note: When  $\rho=0$  the results of Test 3 and Test 2 will be the same.)

Tests of Interest

| Test   | -2*log(Likelihood Ratio) | Test df | p-value   |
|--------|--------------------------|---------|-----------|
| Test 1 | 41.881                   | 4       | <.0001    |
| Test 2 | 16.2316                  | 2       | 0.0002988 |
| Test 3 | 0.370717                 | 1       | 0.5426    |
| Test 4 | 0.41172                  | 1       | 0.5211    |

The p-value for Test 1 is less than .05. There appears to be a difference between response and/or variances among the dose levels. It seems appropriate to model the data.

The p-value for Test 2 is less than .1. A non-homogeneous variance model appears to be appropriate.

The p-value for Test 3 is greater than .1. The modeled variance appears to be appropriate here.

The p-value for Test 4 is greater than .1. The model chosen seems

1 to adequately describe the data

2

3

4 Benchmark Dose Computation

5

6 Specified effect = 3.85

7

8 Risk Type = Point risk

9

10 Confidence level = 0.95

11

12 BMD = 3.56003

13

14  
15 BMDL = 2.81986

16

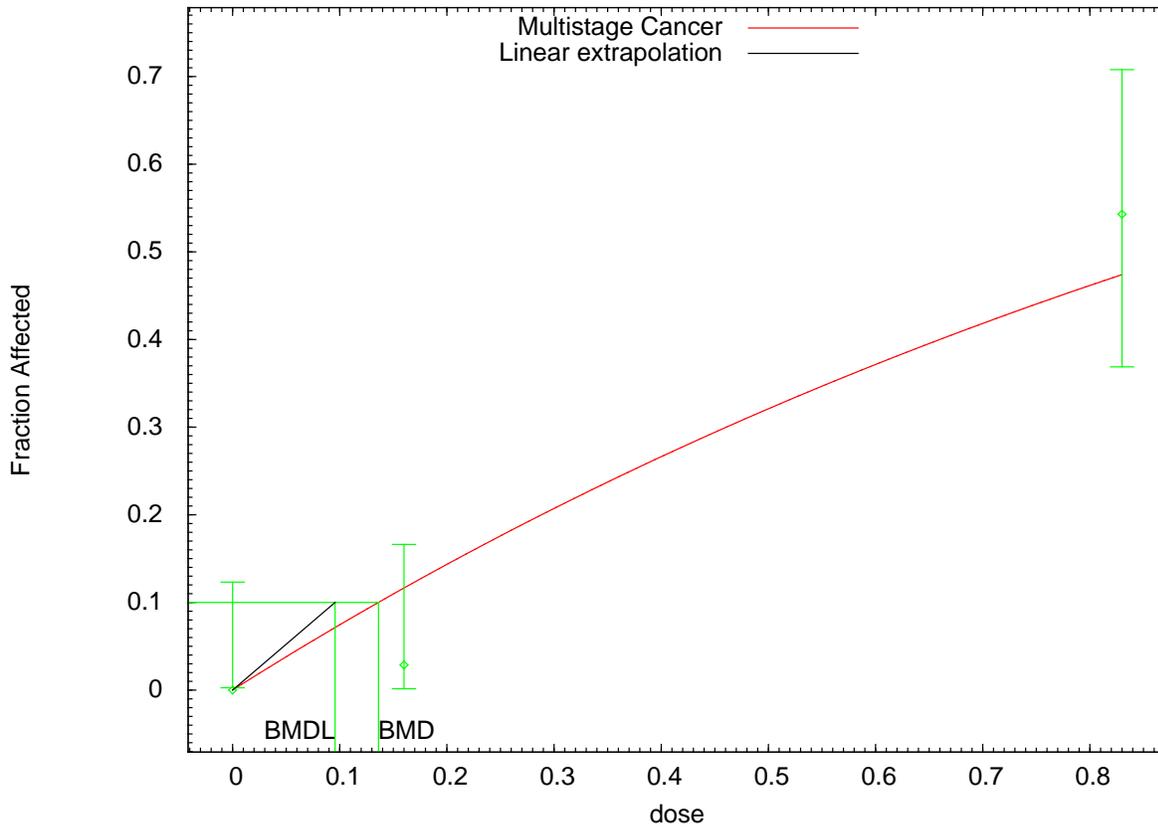
17

18

19 **D.3. LUNG IMPLANTATION BIOASSAYS**

20

Multistage Cancer Model with 0.95 Confidence Level



21

10:49 12/28 2009

22

23

24 DEUTSCH-WENZEL1983AA.OUT.txt

25

26 =====

27 Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)

```

1 Input Data File:
2 C:\USEPA\IRIS\PAH\lungimplant\Deutsch1983\AA\msc_DeutschAA_MS_1_10.(d)
3 Gnuplot Plotting File:
4 C:\USEPA\IRIS\PAH\lungimplant\Deutsch1983\AA\msc_DeutschAA_MS_1_10.plt
5 Wed Dec 23 11:48:09 2009
6 =====
7
8 BMDS Model Run
9 ~~~~~
10
11 The form of the probability function is:
12
13 P[response] = background + (1-background)*[1-EXP(
14 -beta1*dose^1)]
15
16 The parameter betas are restricted to be positive
17
18
19 Dependent variable = incidence
20 Independent variable = dose
21
22 Total number of observations = 3
23 Total number of records with missing values = 0
24 Total number of parameters in model = 2
25 Total number of specified parameters = 0
26 Degree of polynomial = 1
27
28
29 Maximum number of iterations = 250
30 Relative Function Convergence has been set to: 2.22045e-016
31 Parameter Convergence has been set to: 1.49012e-008
32
33 **** We are sorry but Relative Function and Parameter Convergence ****
34 **** are currently unavailable in this model. Please keep checking ****
35 **** the web sight for model updates which will eventually ****
36 **** incorporate these convergence criterion. Default values used. ****
37
38
39
40 Default Initial Parameter Values
41 Background = 0
42 Beta(1) = 0.996523
43
44
45 Asymptotic Correlation Matrix of Parameter Estimates
46
47 (*** The model parameter(s) -Background
48 have been estimated at a boundary point, or have been
49 specified by the user,
50 and do not appear in the correlation matrix)
51
52 Beta(1)
53
54 Beta(1) 1
55
56
57
58 Parameter Estimates
59

```

95.0% Wald

Confidence Interval

| Variable   | Estimate | Std. Err. | Lower Conf. Limit |
|------------|----------|-----------|-------------------|
| Background | 0        | *         | *                 |
| Beta(1)    | 0.773841 | *         | *                 |

\* - Indicates that this value is not calculated.

Analysis of Deviance Table

| Model         | Log(likelihood) | # Param's | Deviance | Test d.f. | P-value |
|---------------|-----------------|-----------|----------|-----------|---------|
| Full model    | -28.6723        | 3         |          |           |         |
| Fitted model  | -30.8245        | 1         | 4.30422  | 2         |         |
| Reduced model | -51.1258        | 1         | 44.907   | 2         | <.0001  |
| AIC:          | 63.6489         |           |          |           |         |

Goodness of Fit

| Dose   | Est._Prob. | Expected | Observed | Size | Scaled Residual |
|--------|------------|----------|----------|------|-----------------|
| 0.0000 | 0.0000     | 0.000    | 0.000    | 35   | 0.000           |
| 0.1600 | 0.1165     | 4.076    | 1.000    | 35   | -1.621          |
| 0.8300 | 0.4739     | 16.587   | 19.000   | 35   | 0.817           |

Chi^2 = 3.29      d.f. = 2      P-value = 0.1926

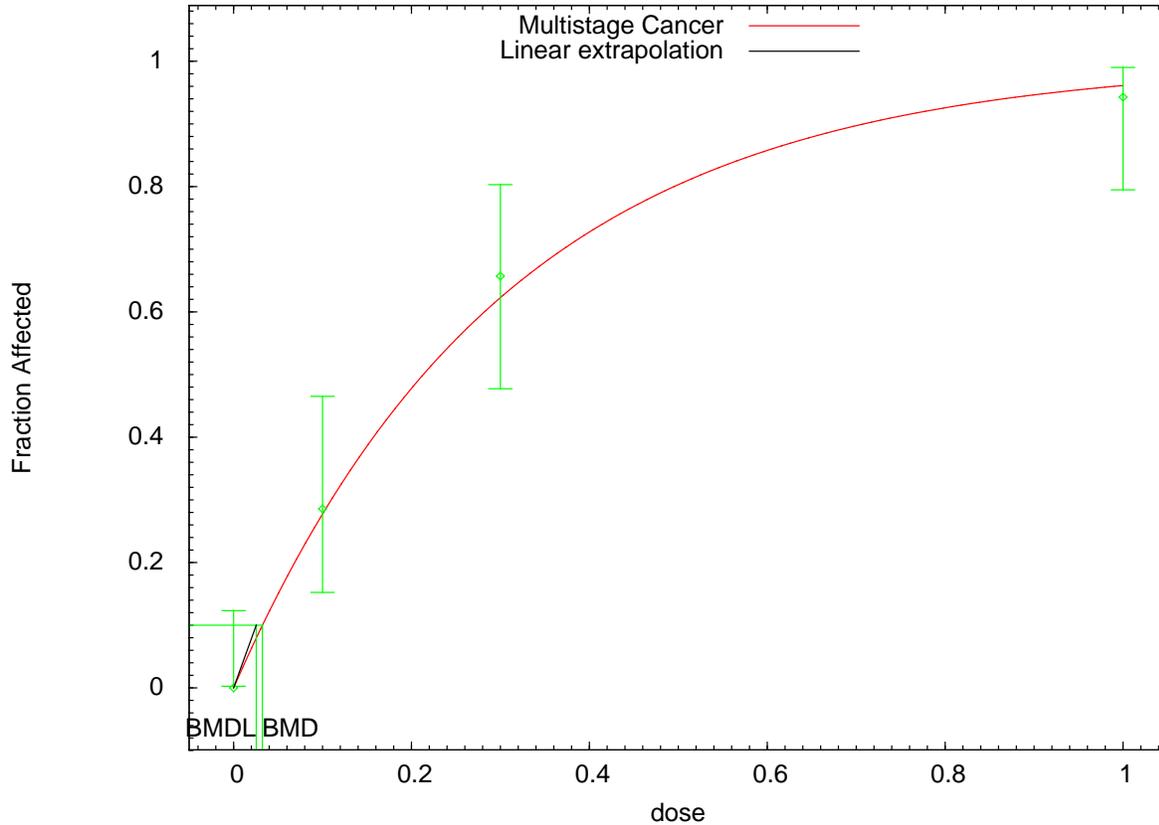
Benchmark Dose Computation

Specified effect = 0.1  
Risk Type = Extra risk  
Confidence level = 0.95  
BMD = 0.136153  
BMDL = 0.0956191  
BMDU = 0.202527

Taken together, (0.0956191, 0.202527) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 1.04582

Multistage Cancer Model with 0.95 Confidence Level



10:50 12/28 2009

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30

DEUTSCH-WENZEL1983BaP.OUT.txt

```

=====
 Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
 Input Data File:
C:\USEPA\IRIS\PAH\lungimplant\Deutsch1983\BaP\msc_DeutschBaP_MS_2_10.(d)
 Gnuplot Plotting File:
C:\USEPA\IRIS\PAH\lungimplant\Deutsch1983\BaP\msc_DeutschBaP_MS_2_10.plt
 Wed Dec 23 11:48:08 2009
=====

```

BMDS Model Run

~~~~~

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta1} * \text{dose}^1 - \text{beta2} * \text{dose}^2)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence  
Independent variable = dose

Total number of observations = 4

1 Total number of records with missing values = 0  
 2 Total number of parameters in model = 3  
 3 Total number of specified parameters = 0  
 4 Degree of polynomial = 2  
 5  
 6  
 7 Maximum number of iterations = 250  
 8 Relative Function Convergence has been set to: 2.22045e-016  
 9 Parameter Convergence has been set to: 1.49012e-008  
 10  
 11 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 12 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 13 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 14 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

18 Default Initial Parameter Values

19 Background = 0.0757681  
 20 Beta(1) = 2.82425  
 21 Beta(2) = 0

23 Asymptotic Correlation Matrix of Parameter Estimates

24 ( \*\*\* The model parameter(s) -Background -Beta(2)  
 25 have been estimated at a boundary point, or have been  
 26 specified by the user,  
 27 and do not appear in the correlation matrix )  
 28  
 29

30  
 31 Beta(1)  
 32  
 33 Beta(1) 1

36 Parameter Estimates

|                     |            | 95.0% Wald |           |                   |
|---------------------|------------|------------|-----------|-------------------|
| Confidence Interval | Variable   | Estimate   | Std. Err. | Lower Conf. Limit |
| Upper Conf. Limit   | Background | 0          | *         | *                 |
|                     | Beta(1)    | 3.25323    | *         | *                 |
|                     | Beta(2)    | 0          | *         | *                 |

48 \* - Indicates that this value is not calculated.

52 Analysis of Deviance Table

| Model                  | Log(likelihood) | # Param's | Deviance | Test d.f. | P-value |
|------------------------|-----------------|-----------|----------|-----------|---------|
| Full model             | -51.1075        | 4         |          |           |         |
| Fitted model           | -51.3412        | 1         | 0.467435 | 3         |         |
| 0.926<br>Reduced model | -96.8119        | 1         | 91.4088  | 3         | <.0001  |

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37

AIC: 104.682

Goodness of Fit

| Dose   | Est._Prob. | Expected | Observed | Size | Scaled Residual |
|--------|------------|----------|----------|------|-----------------|
| 0.0000 | 0.0000     | 0.000    | 0.000    | 35   | 0.000           |
| 0.1000 | 0.2777     | 9.720    | 10.000   | 35   | 0.106           |
| 0.3000 | 0.6232     | 21.811   | 23.000   | 35   | 0.415           |
| 1.0000 | 0.9614     | 33.647   | 33.000   | 35   | -0.568          |

Chi^2 = 0.51      d.f. = 3      P-value = 0.9177

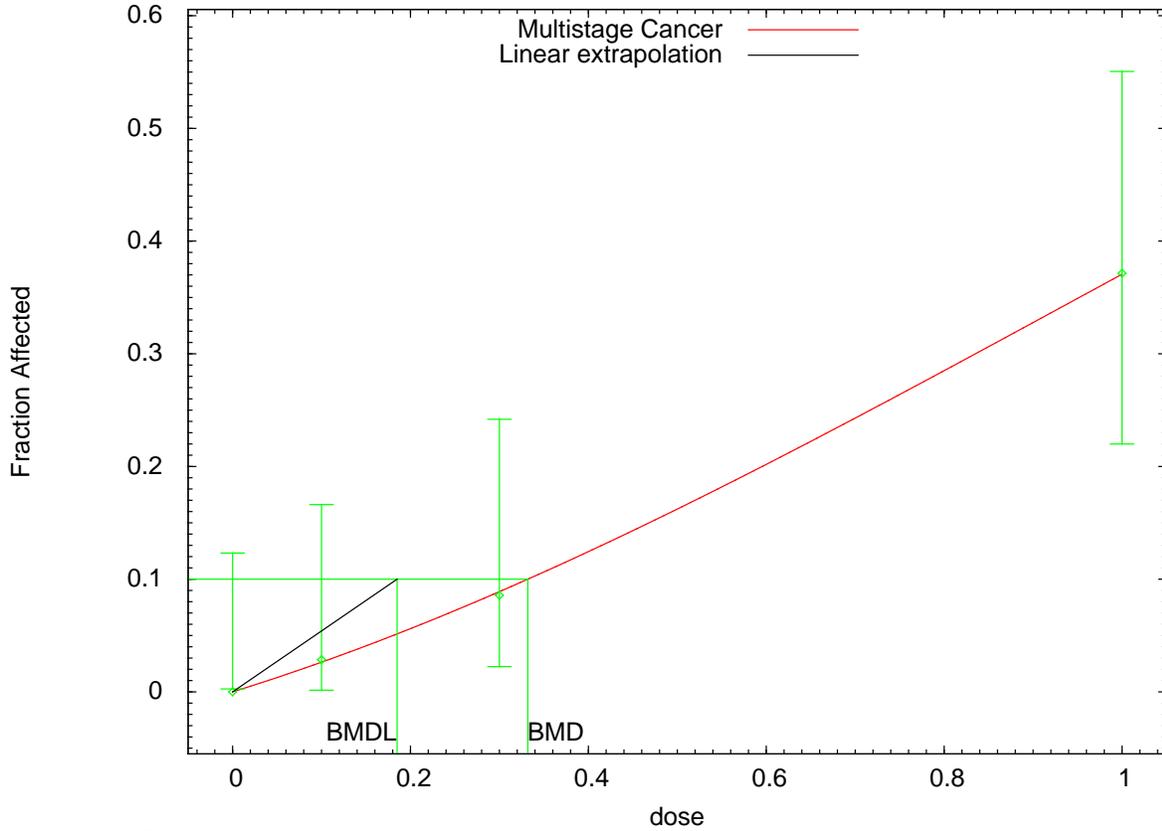
Benchmark Dose Computation

Specified effect = 0.1  
Risk Type = Extra risk  
Confidence level = 0.95  
BMD = 0.0323864  
BMDL = 0.0255063  
BMDU = 0.0445507

Taken together, (0.0255063, 0.0445507) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 3.9206

Multistage Cancer Model with 0.95 Confidence Level



10:51 12/28 2009

DEUTSCH-WENZEL1983BbF.OUT.txt

=====

Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)

Input Data File:

C:\USEPA\IRIS\PAH\lungimplant\Deutsch1983\BbF\msc\_DeutschBbF\_MS\_2\_10.(d)

Gnuplot Plotting File:

C:\USEPA\IRIS\PAH\lungimplant\Deutsch1983\BbF\msc\_DeutschBbF\_MS\_2\_10.plt

Wed Dec 23 11:48:08 2009

=====

BMDS Model Run

~~~~~

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta1} * \text{dose}^{1-\text{beta2}} * \text{dose}^2)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

Total number of observations = 4

Total number of records with missing values = 0

Total number of parameters in model = 3

1 Total number of specified parameters = 0  
 2 Degree of polynomial = 2  
 3  
 4  
 5 Maximum number of iterations = 250  
 6 Relative Function Convergence has been set to: 2.22045e-016  
 7 Parameter Convergence has been set to: 1.49012e-008  
 8  
 9 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 10 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 11 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 12 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

15 Default Initial Parameter Values

17 Background = 0.00149382  
 18 Beta(1) = 0.226374  
 19 Beta(2) = 0.236366

22 Asymptotic Correlation Matrix of Parameter Estimates

23  
 24 ( \*\*\* The model parameter(s) -Background  
 25 have been estimated at a boundary point, or have been  
 26 specified by the user,  
 27 and do not appear in the correlation matrix )

|         | Beta(1) | Beta(2) |
|---------|---------|---------|
| Beta(1) | 1       | -0.97   |
| Beta(2) | -0.97   | 1       |

37 Parameter Estimates

| Confidence Interval | Variable   | Estimate | Std. Err. | 95.0% Wald        |
|---------------------|------------|----------|-----------|-------------------|
|                     |            |          |           | Lower Conf. Limit |
| Upper Conf. Limit   | Background | 0        | *         | *                 |
|                     | Beta(1)    | 0.24518  | *         | *                 |
|                     | Beta(2)    | 0.217701 | *         | *                 |

49 \* - Indicates that this value is not calculated.

54 Analysis of Deviance Table

| Model                   | Log(likelihood) | # Param's | Deviance  | Test d.f. | P-value |
|-------------------------|-----------------|-----------|-----------|-----------|---------|
| Full model              | -37.8686        | 4         |           |           |         |
| Fitted model            | -37.8743        | 2         | 0.0112712 | 2         |         |
| 0.9944<br>Reduced model | -51.7666        | 1         | 27.796    | 3         | <.0001  |

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38

AIC: 79.7485

Goodness of Fit

| Dose   | Est._Prob. | Expected | Observed | Size | Scaled Residual |
|--------|------------|----------|----------|------|-----------------|
| 0.0000 | 0.0000     | 0.000    | 0.000    | 35   | 0.000           |
| 0.1000 | 0.0263     | 0.922    | 1.000    | 35   | 0.082           |
| 0.3000 | 0.0889     | 3.113    | 3.000    | 35   | -0.067          |
| 1.0000 | 0.3705     | 12.969   | 13.000   | 35   | 0.011           |

Chi^2 = 0.01      d.f. = 2      P-value = 0.9943

Benchmark Dose Computation

Specified effect = 0.1

Risk Type = Extra risk

Confidence level = 0.95

BMD = 0.33191

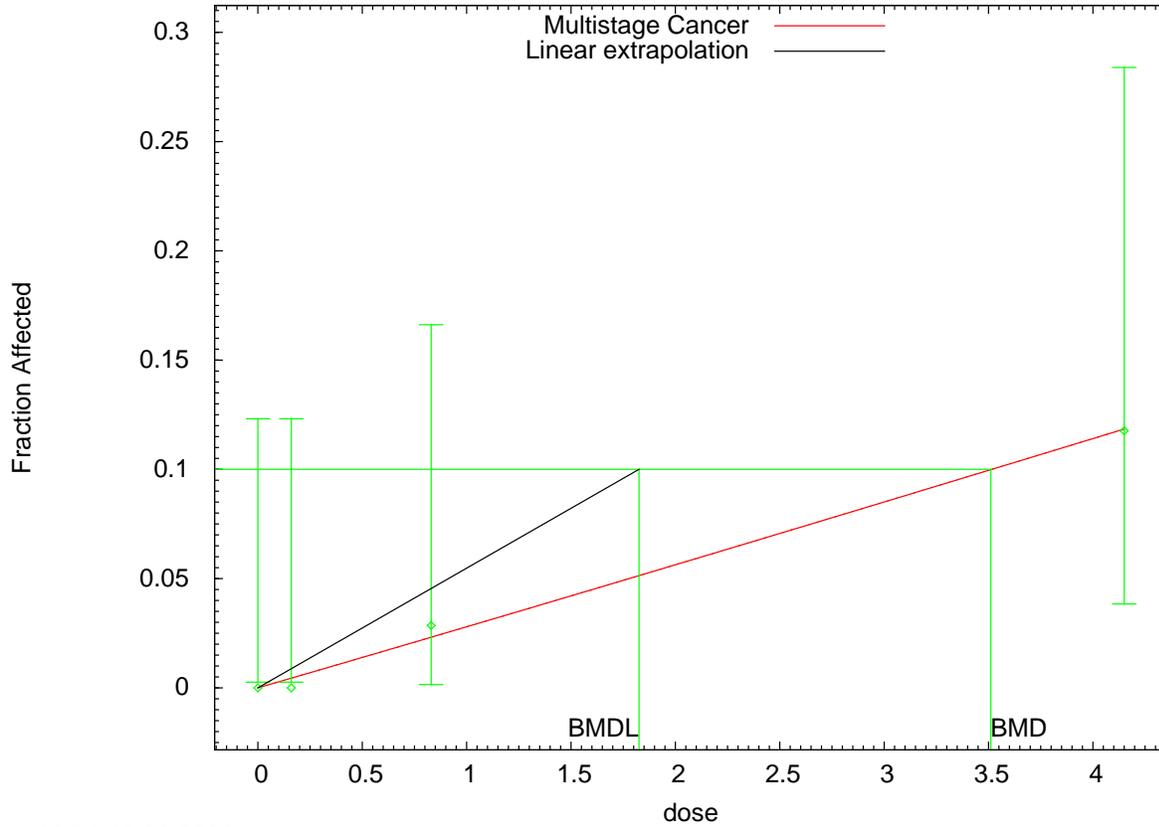
BMDL = 0.184961

BMDU = 0.544229

Taken together, (0.184961, 0.544229) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 0.540655

Multistage Cancer Model with 0.95 Confidence Level



10:52 12/28 2009

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30

DEUTSCH-WENZEL1983BghiP.OUT.txt

```

=====
 Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
 Input Data File:
 C:\USEPA\IRIS\PAH\lungimplant\Deutsch1983\BghiP\msc_DeutschBghiP_MS_2_10.(d)
 Gnuplot Plotting File:
 C:\USEPA\IRIS\PAH\lungimplant\Deutsch1983\BghiP\msc_DeutschBghiP_MS_2_10.plt
 Wed Dec 23 11:48:09 2009
=====

```

BMDS Model Run

~~~~~

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta1} * \text{dose}^1 - \text{beta2} * \text{dose}^2)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

Total number of observations = 4

Total number of records with missing values = 0

1 Total number of parameters in model = 3  
 2 Total number of specified parameters = 0  
 3 Degree of polynomial = 2  
 4  
 5  
 6 Maximum number of iterations = 250  
 7 Relative Function Convergence has been set to: 2.22045e-016  
 8 Parameter Convergence has been set to: 1.49012e-008  
 9  
 10 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 11 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 12 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 13 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

Default Initial Parameter Values

Background = 0  
 Beta(1) = 0.0304801  
 Beta(2) = 0

Asymptotic Correlation Matrix of Parameter Estimates

( \*\*\* The model parameter(s) -Background  
 have been estimated at a boundary point, or have been  
 specified by the user,  
 and do not appear in the correlation matrix )

|         | Beta(1) | Beta(2) |
|---------|---------|---------|
| Beta(1) | 1       | -0.98   |
| Beta(2) | -0.98   | 1       |

Parameter Estimates

|                     |            |             | 95.0% Wald        |
|---------------------|------------|-------------|-------------------|
| Confidence Interval | Variable   | Estimate    | Lower Conf. Limit |
| Upper Conf. Limit   | Background | 0           | *                 |
| *                   | Beta(1)    | 0.0277423   | *                 |
| *                   | Beta(2)    | 0.000645059 | *                 |
| *                   |            |             | *                 |

\* - Indicates that this value is not calculated.

Analysis of Deviance Table

| Model        | Log(likelihood) | # Param's | Deviance | Test d.f. | P-value |
|--------------|-----------------|-----------|----------|-----------|---------|
| Full model   | -16.8561        | 4         |          |           |         |
| Fitted model | -17.033         | 2         | 0.353756 | 2         |         |
| 0.8379       |                 |           |          |           |         |

1 Reduced model -21.5342 1 9.35614 3  
2 0.02491

3  
4 AIC: 38.0659  
5

6  
7 Goodness of Fit

| 8  |        |            |          |          |      |                 |
|----|--------|------------|----------|----------|------|-----------------|
| 9  | Dose   | Est._Prob. | Expected | Observed | Size | Scaled Residual |
| 10 | -----  |            |          |          |      |                 |
| 11 | 0.0000 | 0.0000     | 0.000    | 0.000    | 35   | 0.000           |
| 12 | 0.1600 | 0.0044     | 0.156    | 0.000    | 35   | -0.395          |
| 13 | 0.8300 | 0.0232     | 0.812    | 1.000    | 35   | 0.211           |
| 14 | 4.1500 | 0.1186     | 4.032    | 4.000    | 34   | -0.017          |

15  
16 Chi^2 = 0.20 d.f. = 2 P-value = 0.9043  
17

18  
19 Benchmark Dose Computation

20 Specified effect = 0.1

21 Risk Type = Extra risk

22  
23 Confidence level = 0.95

24  
25 BMD = 3.51117

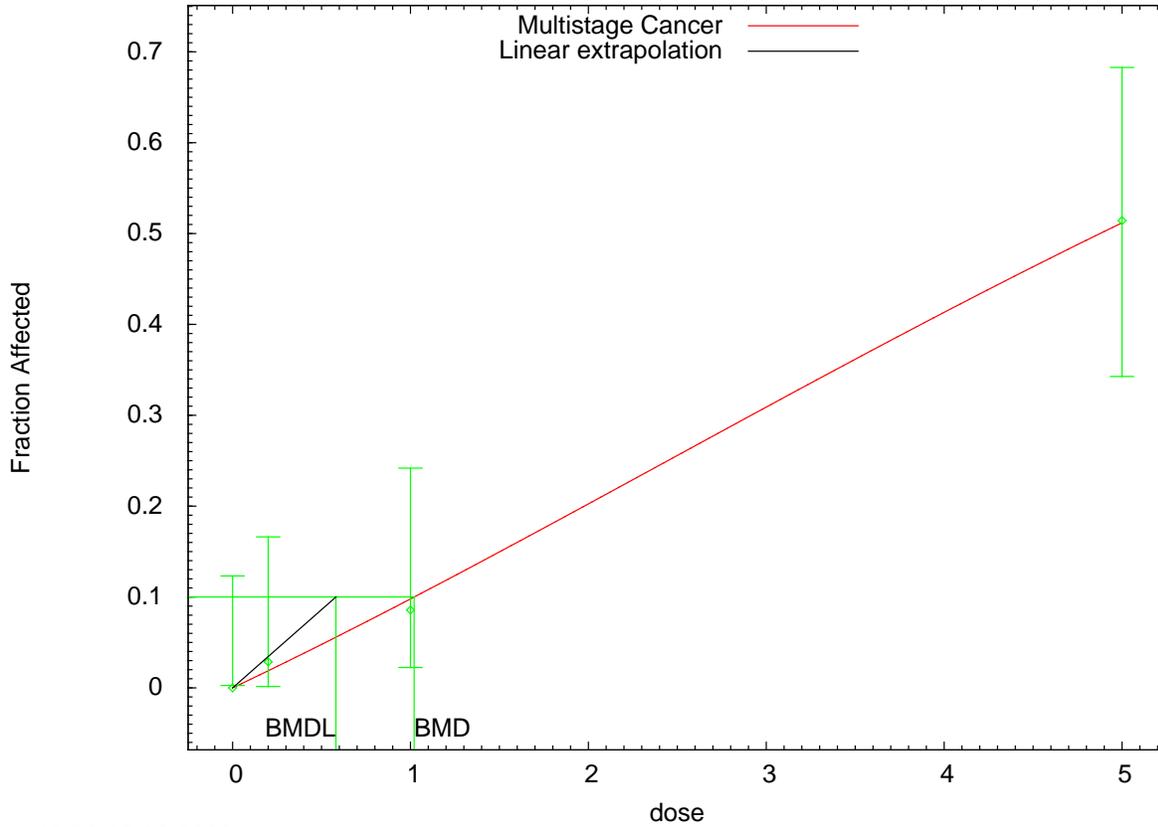
26  
27 BMDL = 1.82558

28  
29 BMDU = 8.33008

30  
31  
32 Taken together, (1.82558, 8.33008) is a 90 % two-sided confidence interval for the BMD

33  
34  
35 Multistage Cancer Slope Factor = 0.0547771  
36  
37  
38  
39  
40

Multistage Cancer Model with 0.95 Confidence Level



10:53 12/28 2009

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30

DEUTSCH-WENZEL1983BjF.OUT.txt

```

=====
 Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
 Input Data File:
 C:\USEPA\IRIS\PAH\lungimplant\Deutsch1983\BjF\msc_DeutschBjF_MS_2_10.(d)
 Gnuplot Plotting File:
 C:\USEPA\IRIS\PAH\lungimplant\Deutsch1983\BjF\msc_DeutschBjF_MS_2_10.plt
 Wed Dec 23 11:48:08 2009
=====

```

BMDS Model Run

~~~~~

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta1} * \text{dose}^1 - \text{beta2} * \text{dose}^2)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

Total number of observations = 4

Total number of records with missing values = 0

1 Total number of parameters in model = 3  
 2 Total number of specified parameters = 0  
 3 Degree of polynomial = 2  
 4  
 5  
 6 Maximum number of iterations = 250  
 7 Relative Function Convergence has been set to: 2.22045e-016  
 8 Parameter Convergence has been set to: 1.49012e-008  
 9  
 10 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 11 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 12 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 13 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

17 Default Initial Parameter Values

18 Background = 0.00616121  
 19 Beta(1) = 0.0709095  
 20 Beta(2) = 0.0144537

23 Asymptotic Correlation Matrix of Parameter Estimates

24  
 25 ( \*\*\* The model parameter(s) -Background  
 26 have been estimated at a boundary point, or have been  
 27 specified by the user,  
 28 and do not appear in the correlation matrix )

|         | Beta(1) | Beta(2) |
|---------|---------|---------|
| Beta(1) | 1       | -0.98   |
| Beta(2) | -0.98   | 1       |

38 Parameter Estimates

|                     |            |           | 95.0% Wald        |
|---------------------|------------|-----------|-------------------|
| Confidence Interval | Variable   | Estimate  | Lower Conf. Limit |
| Upper Conf. Limit   | Background | 0         | *                 |
| *                   | Beta(1)    | 0.0929144 | *                 |
| *                   | Beta(2)    | 0.0101278 | *                 |
| *                   |            |           | *                 |

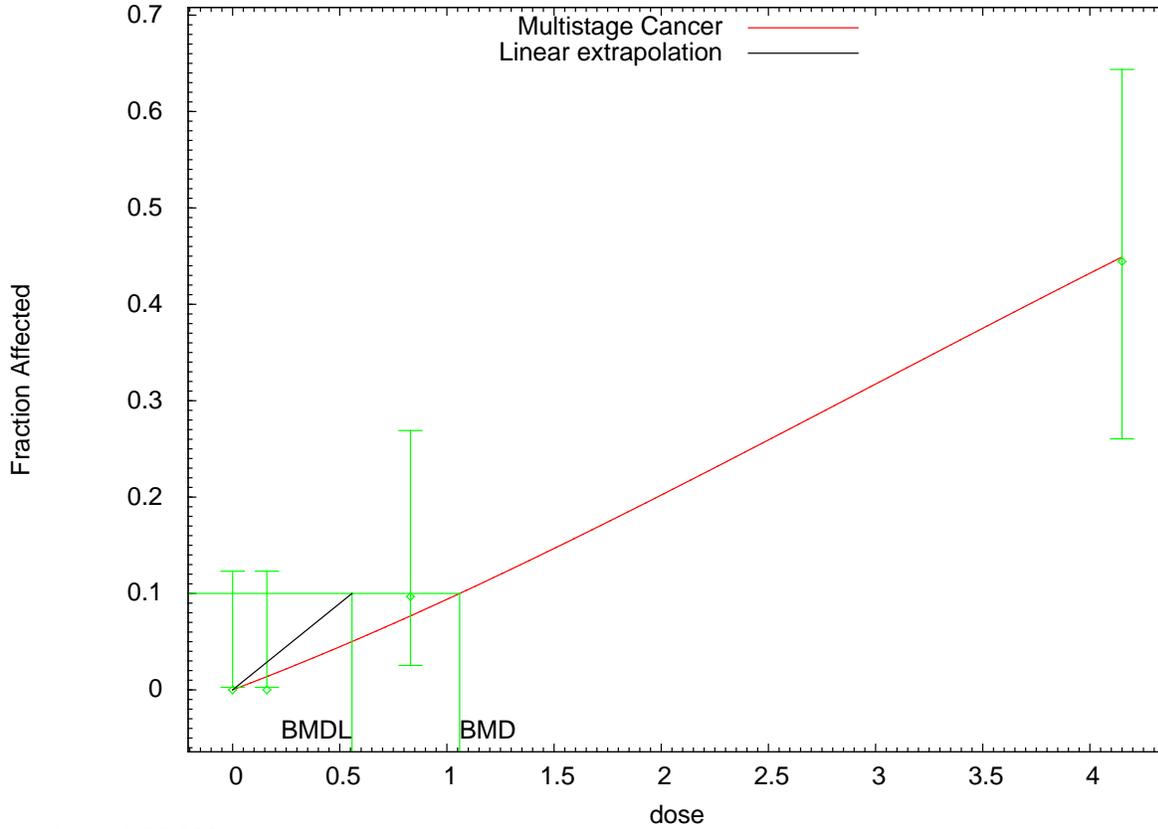
51 \* - Indicates that this value is not calculated.

55 Analysis of Deviance Table

| Model        | Log(likelihood) | # Param's | Deviance | Test d.f. | P-value |
|--------------|-----------------|-----------|----------|-----------|---------|
| Full model   | -39.0246        | 4         |          |           |         |
| Fitted model | -39.1336        | 2         | 0.218103 | 2         |         |
| 0.8967       |                 |           |          |           |         |

1 Reduced model -60.8862 1 43.7233 3 <.0001  
 2  
 3 AIC: 82.2673  
 4  
 5  
 6 Goodness of Fit  
 7  
 8 Dose Est.\_Prob. Expected Observed Size Scaled  
 9 Residual  
 -----  
 10 0.0000 0.0000 0.000 0.000 35 0.000  
 11 0.2000 0.0188 0.658 1.000 35 0.425  
 12 1.0000 0.0979 3.427 3.000 35 -0.243  
 13 5.0000 0.5122 17.926 18.000 35 0.025  
 14  
 15 Chi^2 = 0.24 d.f. = 2 P-value = 0.8868  
 16  
 17  
 18 Benchmark Dose Computation  
 19  
 20 Specified effect = 0.1  
 21  
 22 Risk Type = Extra risk  
 23  
 24 Confidence level = 0.95  
 25  
 26 BMD = 1.02045  
 27  
 28 BMDL = 0.580958  
 29  
 30 BMDU = 2.07945  
 31  
 32 Taken together, (0.580958, 2.07945) is a 90 % two-sided confidence  
 33 interval for the BMD  
 34  
 35 Multistage Cancer Slope Factor = 0.172129  
 36  
 37  
 38  
 39

Multistage Cancer Model with 0.95 Confidence Level



10:54 12/28 2009

DEUTSCH-WENZEL1983BkF.OUT.txt

=====

Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)

Input Data File:

C:\USEPA\IRIS\PAH\lungimplant\Deutsch1983\BkF\msc\_DeutschBkF\_MS\_2\_10.(d)

Gnuplot Plotting File:

C:\USEPA\IRIS\PAH\lungimplant\Deutsch1983\BkF\msc\_DeutschBkF\_MS\_2\_10.plt

Wed Dec 23 11:48:09 2009

=====

BMDS Model Run

~~~~~

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta1} * \text{dose}^1 - \text{beta2} * \text{dose}^2)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

Total number of observations = 4

Total number of records with missing values = 0

Total number of parameters in model = 3

1 Total number of specified parameters = 0  
 2 Degree of polynomial = 2  
 3  
 4  
 5 Maximum number of iterations = 250  
 6 Relative Function Convergence has been set to: 2.22045e-016  
 7 Parameter Convergence has been set to: 1.49012e-008  
 8  
 9 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 10 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 11 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 12 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

15 Default Initial Parameter Values

17 Background = 0  
 18 Beta(1) = 0.126747  
 19 Beta(2) = 0.00410997

22 Asymptotic Correlation Matrix of Parameter Estimates

23  
 24 ( \*\*\* The model parameter(s) -Background  
 25 have been estimated at a boundary point, or have been  
 26 specified by the user,  
 27 and do not appear in the correlation matrix )

|         | Beta(1) | Beta(2) |
|---------|---------|---------|
| Beta(1) | 1       | -0.97   |
| Beta(2) | -0.97   | 1       |

37 Parameter Estimates

| Confidence Interval | Variable   | Estimate  | Std. Err. | 95.0% Wald        |
|---------------------|------------|-----------|-----------|-------------------|
|                     |            |           |           | Lower Conf. Limit |
| Upper Conf. Limit   | Background | 0         | *         | *                 |
|                     | Beta(1)    | 0.0842968 | *         | *                 |
|                     | Beta(2)    | 0.0142917 | *         | *                 |

49 \* - Indicates that this value is not calculated.

54 Analysis of Deviance Table

| Model                   | Log(likelihood) | # Param's | Deviance | Test d.f. | P-value |
|-------------------------|-----------------|-----------|----------|-----------|---------|
| Full model              | -28.404         | 4         |          |           |         |
| Fitted model            | -28.9719        | 2         | 1.1357   | 2         |         |
| 0.5667<br>Reduced model | -46.2443        | 1         | 35.6806  | 3         | <.0001  |

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38

AIC: 61.9437

Goodness of Fit

| Dose   | Est._Prob. | Expected | Observed | Size | Scaled Residual |
|--------|------------|----------|----------|------|-----------------|
| 0.0000 | 0.0000     | 0.000    | 0.000    | 35   | 0.000           |
| 0.1600 | 0.0138     | 0.482    | 0.000    | 35   | -0.699          |
| 0.8300 | 0.0767     | 2.378    | 3.000    | 31   | 0.420           |
| 4.1500 | 0.4490     | 12.122   | 12.000   | 27   | -0.047          |

Chi^2 = 0.67      d.f. = 2      P-value = 0.7165

Benchmark Dose Computation

Specified effect = 0.1

Risk Type = Extra risk

Confidence level = 0.95

BMD = 1.05954

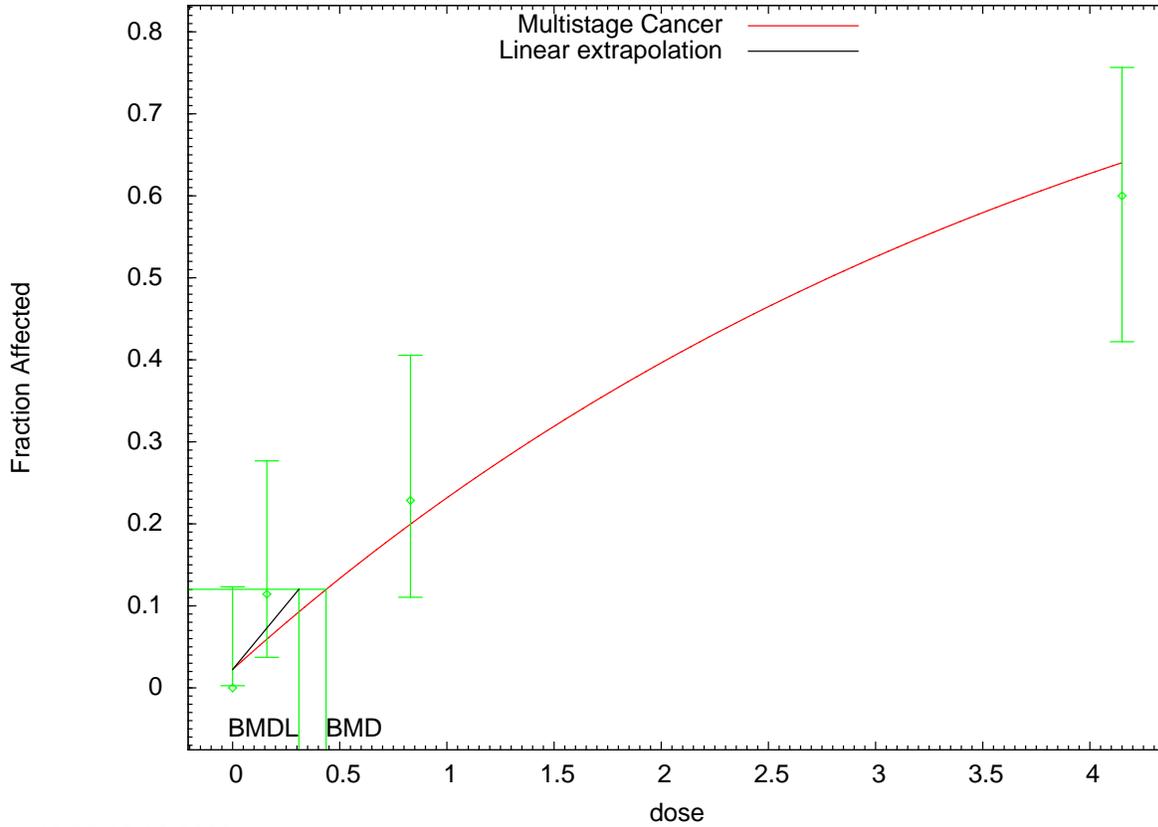
BMDL = 0.557079

BMDU = 1.79525

Taken together, (0.557079, 1.79525) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 0.179508

Multistage Cancer Model with 0.95 Confidence Level



10:55 12/28 2009

DEUTSCH-WENZEL1983IP.OUT.txt

```

=====
 Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
 Input Data File:
 C:\USEPA\IRIS\PAH\lungimplant\Deutsch1983\IP\msc_DeutschIP_MS_2_10.(d)
 Gnuplot Plotting File:
 C:\USEPA\IRIS\PAH\lungimplant\Deutsch1983\IP\msc_DeutschIP_MS_2_10.plt
 Wed Dec 23 11:48:09 2009
=====

```

BMDS Model Run

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1 - \text{background}) * [1 - \text{EXP}(-\text{beta1} * \text{dose}^1 - \text{beta2} * \text{dose}^2)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

Total number of observations = 4

Total number of records with missing values = 0

1 Total number of parameters in model = 3  
 2 Total number of specified parameters = 0  
 3 Degree of polynomial = 2  
 4  
 5  
 6 Maximum number of iterations = 250  
 7 Relative Function Convergence has been set to: 2.22045e-016  
 8 Parameter Convergence has been set to: 1.49012e-008  
 9  
 10 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 11 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 12 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 13 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

17 Default Initial Parameter Values

18 Background = 0.0539703  
 19 Beta(1) = 0.20919  
 20 Beta(2) = 0

23 Asymptotic Correlation Matrix of Parameter Estimates

24  
 25 ( \*\*\* The model parameter(s) -Beta(2)  
 26 have been estimated at a boundary point, or have been  
 27 specified by the user,  
 28 and do not appear in the correlation matrix )

|            | Background | Beta(1) |
|------------|------------|---------|
| Background | 1          | -0.55   |
| Beta(1)    | -0.55      | 1       |

38 Parameter Estimates

|                     |            |           | 95.0% Wald        |
|---------------------|------------|-----------|-------------------|
| Confidence Interval | Variable   | Estimate  | Lower Conf. Limit |
| Upper Conf. Limit   | Background | 0.0224449 | *                 |
| *                   | Beta(1)    | 0.241452  | *                 |
| *                   | Beta(2)    | 0         | *                 |

51 \* - Indicates that this value is not calculated.

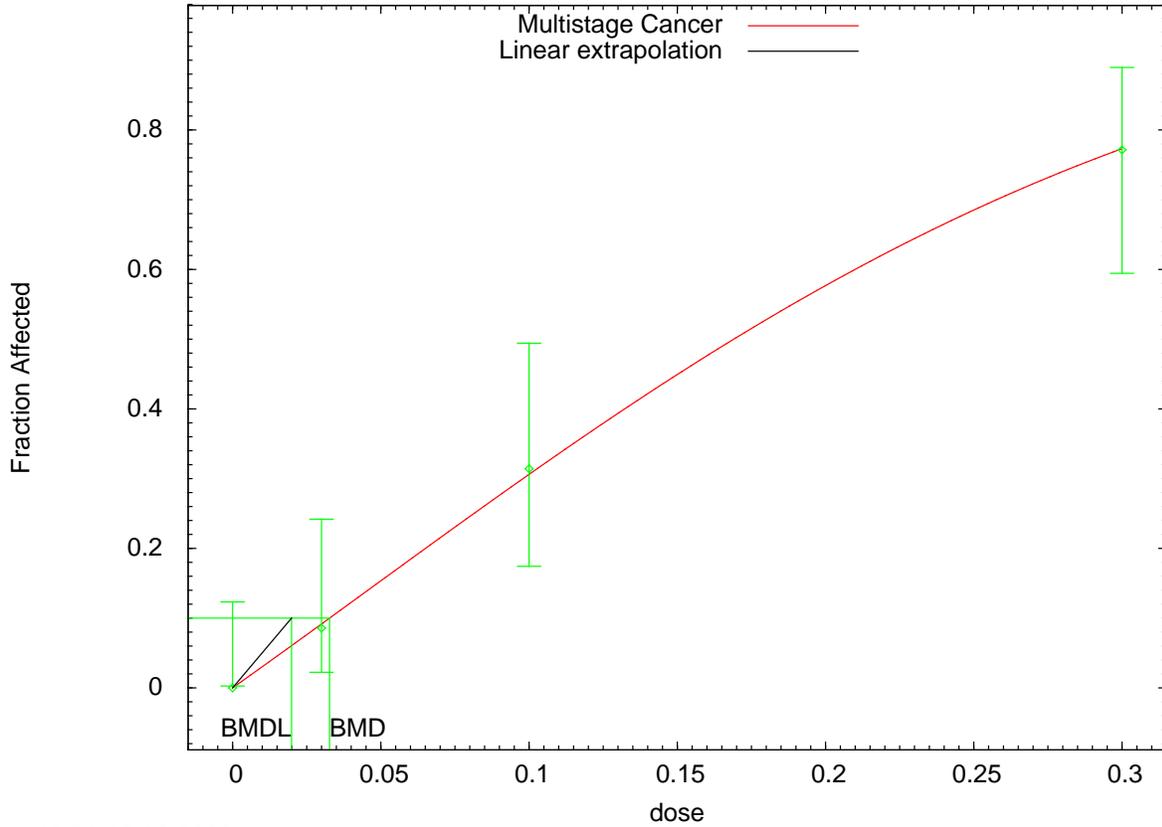
55 Analysis of Deviance Table

| Model        | Log(likelihood) | # Param's | Deviance | Test d.f. | P-value |
|--------------|-----------------|-----------|----------|-----------|---------|
| Full model   | -54.8079        | 4         |          |           |         |
| Fitted model | -56.5662        | 2         | 3.5166   | 2         |         |

60 0.1723

1 Reduced model -76.4525 1 43.2893 3 <.0001  
 2  
 3 AIC: 117.132  
 4  
 5  
 6 Goodness of Fit  
 7  
 8 Dose Est.\_Prob. Expected Observed Size Scaled  
 9 Residual  
 -----  
 10 0.0000 0.0224 0.786 0.000 35 -0.896  
 11 0.1600 0.0595 2.082 4.000 35 1.370  
 12 0.8300 0.2000 6.999 8.000 35 0.423  
 13 4.1500 0.6411 22.439 21.000 35 -0.507  
 14  
 15 Chi^2 = 3.12 d.f. = 2 P-value = 0.2104  
 16  
 17  
 18 Benchmark Dose Computation  
 19  
 20 Specified effect = 0.1  
 21  
 22 Risk Type = Extra risk  
 23  
 24 Confidence level = 0.95  
 25  
 26 BMD = 0.436361  
 27  
 28 BMDL = 0.309504  
 29  
 30 BMDU = 0.819969  
 31  
 32 Taken together, (0.309504, 0.819969) is a 90 % two-sided confidence  
 33 interval for the BMD  
 34  
 35 Multistage Cancer Slope Factor = 0.323098  
 36  
 37  
 38  
 39

Multistage Cancer Model with 0.95 Confidence Level



10:56 12/28 2009

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30

WENZEL-HARTUNG1990BaP.OUT.txt

```

=====
 Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
 Input Data File:
 C:\USEPA\IRIS\PAH\lungimplant\Wenzel1990\BaP\msc_WenzelBaP_MS_2_10.(d)
 Gnuplot Plotting File:
 C:\USEPA\IRIS\PAH\lungimplant\Wenzel1990\BaP\msc_WenzelBaP_MS_2_10.plt
 Wed Dec 23 11:48:09 2009
=====

```

BMDS Model Run

~~~~~

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta1} * \text{dose}^1 - \text{beta2} * \text{dose}^2)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

Total number of observations = 4

Total number of records with missing values = 0

1 Total number of parameters in model = 3  
 2 Total number of specified parameters = 0  
 3 Degree of polynomial = 2  
 4  
 5  
 6 Maximum number of iterations = 250  
 7 Relative Function Convergence has been set to: 2.22045e-016  
 8 Parameter Convergence has been set to: 1.49012e-008  
 9  
 10 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 11 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 12 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 13 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

Default Initial Parameter Values

Background = 0  
 Beta(1) = 3.21631  
 Beta(2) = 5.7325

Asymptotic Correlation Matrix of Parameter Estimates

( \*\*\* The model parameter(s) -Background  
 have been estimated at a boundary point, or have been  
 specified by the user,  
 and do not appear in the correlation matrix )

|         | Beta(1) | Beta(2) |
|---------|---------|---------|
| Beta(1) | 1       | -0.93   |
| Beta(2) | -0.93   | 1       |

Parameter Estimates

|                     |            |          | 95.0% Wald        |
|---------------------|------------|----------|-------------------|
| Confidence Interval | Variable   | Estimate | Lower Conf. Limit |
| Upper Conf. Limit   | Background | 0        | *                 |
| *                   | Beta(1)    | 3.01149  | *                 |
| *                   | Beta(2)    | 6.44644  | *                 |
| *                   |            |          |                   |

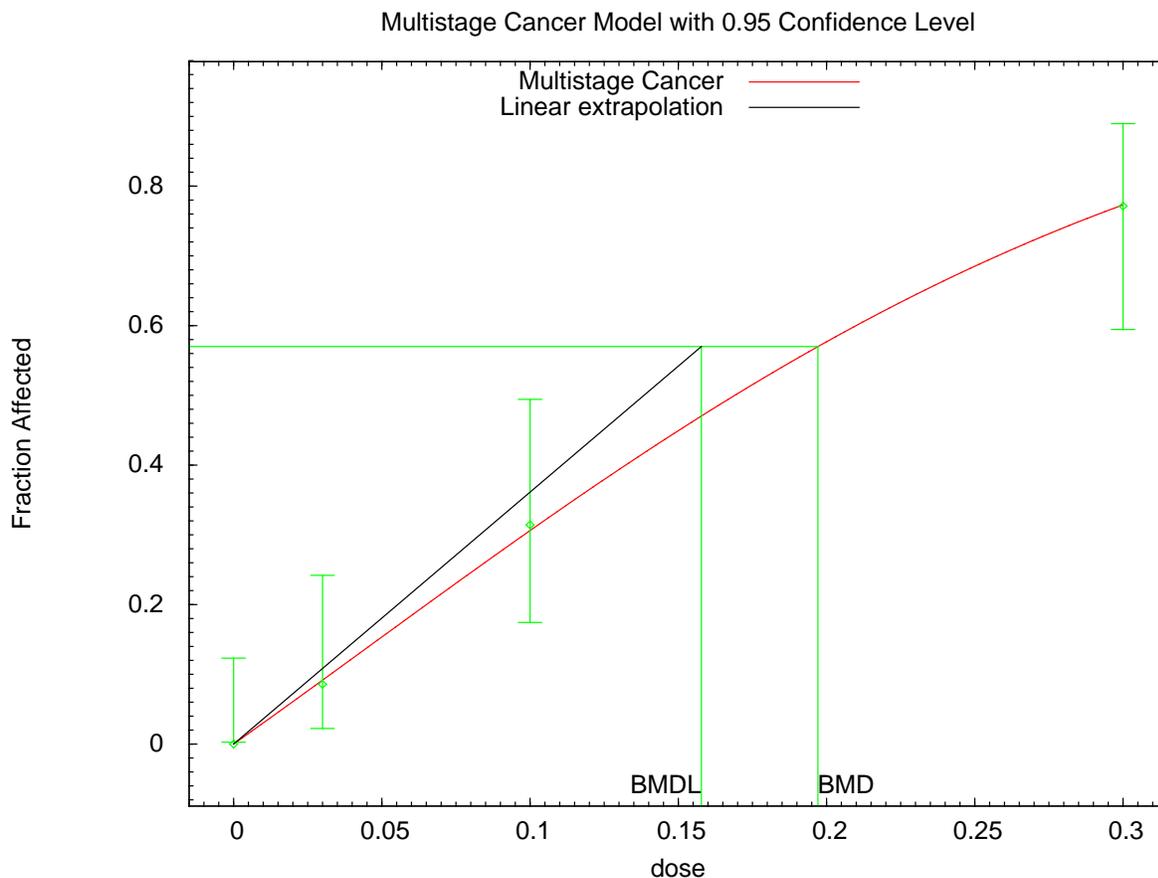
\* - Indicates that this value is not calculated.

Analysis of Deviance Table

| Model        | Log(likelihood) | # Param's | Deviance  | Test d.f. | P-value |
|--------------|-----------------|-----------|-----------|-----------|---------|
| Full model   | -50.8389        | 4         |           |           |         |
| Fitted model | -50.8521        | 2         | 0.0264626 | 2         |         |
| 0.9869       |                 |           |           |           |         |

1 Reduced model -84.6566 1 67.6355 3 <.0001  
2  
3 AIC: 105.704  
4  
5  
6 Goodness of Fit  
7  
8 Dose Est.\_Prob. Expected Observed Size Scaled  
9 ----- Residual  
10 0.0000 0.0000 0.000 0.000 35 0.000  
11 0.0300 0.0917 3.208 3.000 35 -0.122  
12 0.1000 0.3062 10.718 11.000 35 0.103  
13 0.3000 0.7732 27.062 27.000 35 -0.025  
14  
15 Chi^2 = 0.03 d.f. = 2 P-value = 0.9870  
16  
17  
18 Benchmark Dose Computation  
19  
20 Specified effect = 0.1  
21  
22 Risk Type = Extra risk  
23  
24 Confidence level = 0.95  
25  
26 BMD = 0.0326976  
27  
28 BMDL = 0.0198862  
29  
30 BMDU = 0.0559366  
31  
32 Taken together, (0.0198862, 0.0559366) is a 90 % two-sided confidence  
33 interval for the BMD  
34  
35 Multistage Cancer Slope Factor = 5.02861  
36  
37  
38  
39

1  
2



10:58 12/28 2009

WENZEL-HARTUNG1990BaP.OUT.txt - alternative BMR = 0.57

```
=====
Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
Input Data File:
C:\USEPA\IRIS\PAH\lungimplant\Wenzel1990\BaPalt\msc_WenzelBaPalt_MS_2_57.(d)
Gnuplot Plotting File:
C:\USEPA\IRIS\PAH\lungimplant\Wenzel1990\BaPalt\msc_WenzelBaPalt_MS_2_57.plt
Wed Dec 23 11:48:11 2009
=====
```

BMDS Model Run

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\beta_1 * \text{dose} - \beta_2 * \text{dose}^2)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence

Independent variable = dose

```

1
2 Total number of observations = 4
3 Total number of records with missing values = 0
4 Total number of parameters in model = 3
5 Total number of specified parameters = 0
6 Degree of polynomial = 2
7
8
9 Maximum number of iterations = 250
10 Relative Function Convergence has been set to: 2.22045e-016
11 Parameter Convergence has been set to: 1.49012e-008
12
13 **** We are sorry but Relative Function and Parameter Convergence ****
14 **** are currently unavailable in this model. Please keep checking ****
15 **** the web sight for model updates which will eventually ****
16 **** incorporate these convergence criterion. Default values used. ****
17
18
19
20 Default Initial Parameter Values
21 Background = 0
22 Beta(1) = 3.21631
23 Beta(2) = 5.7325
24
25
26 Asymptotic Correlation Matrix of Parameter Estimates
27
28 (*** The model parameter(s) -Background
29 have been estimated at a boundary point, or have been
30 specified by the user,
31 and do not appear in the correlation matrix)
32
33 Beta(1) Beta(2)
34
35 Beta(1) 1 -0.93
36
37 Beta(2) -0.93 1
38
39
40
41 Parameter Estimates
42
43 95.0% Wald
44 Confidence Interval
45 Variable Estimate Std. Err. Lower Conf. Limit
46 Upper Conf. Limit
47 Background 0 * *
48 *
49 Beta(1) 3.01149 * *
50 *
51 Beta(2) 6.44644 * *
52 *
53
54 * - Indicates that this value is not calculated.
55
56
57
58 Analysis of Deviance Table
59
60 Model Log(likelihood) # Param's Deviance Test d.f. P-value

```

1 Full model -50.8389 4  
 2 Fitted model -50.8521 2 0.0264626 2  
 3 0.9869  
 4 Reduced model -84.6566 1 67.6355 3 <.0001  
 5  
 6 AIC: 105.704  
 7  
 8  
 9

Goodness of Fit

| Dose   | Est._Prob. | Expected | Observed | Size | Scaled Residual |
|--------|------------|----------|----------|------|-----------------|
| 0.0000 | 0.0000     | 0.000    | 0.000    | 35   | 0.000           |
| 0.0300 | 0.0917     | 3.208    | 3.000    | 35   | -0.122          |
| 0.1000 | 0.3062     | 10.718   | 11.000   | 35   | 0.103           |
| 0.3000 | 0.7732     | 27.062   | 27.000   | 35   | -0.025          |

18 Chi^2 = 0.03 d.f. = 2 P-value = 0.9870  
 19  
 20

Benchmark Dose Computation

23 Specified effect = 0.57  
 24  
 25 Risk Type = Extra risk  
 26  
 27 Confidence level = 0.95  
 28  
 29 BMD = 0.197095  
 30  
 31 BMDL = 0.157781  
 32  
 33 BMDU = 0.247357  
 34

35 Taken together, (0.157781, 0.247357) is a 90 % two-sided confidence  
 36 interval for the BMD  
 37

38 Multistage Cancer Slope Factor = 3.6126  
 39  
 40  
 41

```

1 WENZEL-HARTUNG1990BaPforDBahA.OUT.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\PAH\BMD ANALYSIS\BIOASSAY\OTHER
5 ROUTE\SETS\WENZEL-HARTUNG1990.(d)
6 Gnuplot Plotting File: C:\PAH\BMD ANALYSIS\BIOASSAY\OTHER
7 ROUTE\SETS\WENZEL-HARTUNG1990.plt
8 Thu Jun 02 09:02:58 2005
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16
$$P[\text{response}] = \text{background} + (1 - \text{background}) * [1 - \text{EXP}(-\text{beta1} * \text{dose}^1 - \text{beta2} * \text{dose}^2)]$$

17
18 The parameter betas are restricted to be positive
19
20
21
22 Dependent variable = responseBaP
23 Independent variable = doseBaP
24
25 Total number of observations = 4
26 Total number of records with missing values = 0
27 Total number of parameters in model = 3
28 Total number of specified parameters = 0
29 Degree of polynomial = 2
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 0
40 Beta(1) = 3.21631
41 Beta(2) = 5.7325
42
43
44 Asymptotic Correlation Matrix of Parameter Estimates
45
46 (*** The model parameter(s) -Background
47 have been estimated at a boundary point, or have been
48 specified by the user,
49 and do not appear in the correlation matrix)
50
51 Beta(1) Beta(2)
52
53 Beta(1) 1 -0.93
54
55 Beta(2) -0.93 1
56
57
58
59 Parameter Estimates
60

```

| Variable   | Estimate | Std. Err. |
|------------|----------|-----------|
| Background | 0        | NA        |
| Beta(1)    | 3.01149  | 2.79594   |
| Beta(2)    | 6.44644  | 10.7674   |

NA - Indicates that this parameter has hit a bound implied by some inequality constraint and thus has no standard error.

Analysis of Deviance Table

| Model         | Log(likelihood) | Deviance  | Test DF | P-value |
|---------------|-----------------|-----------|---------|---------|
| Full model    | -50.8389        |           |         |         |
| Fitted model  | -50.8521        | 0.0264626 | 2       | 0.9869  |
| Reduced model | -84.6566        | 67.6355   | 3       | <.0001  |
| AIC:          | 105.704         |           |         |         |

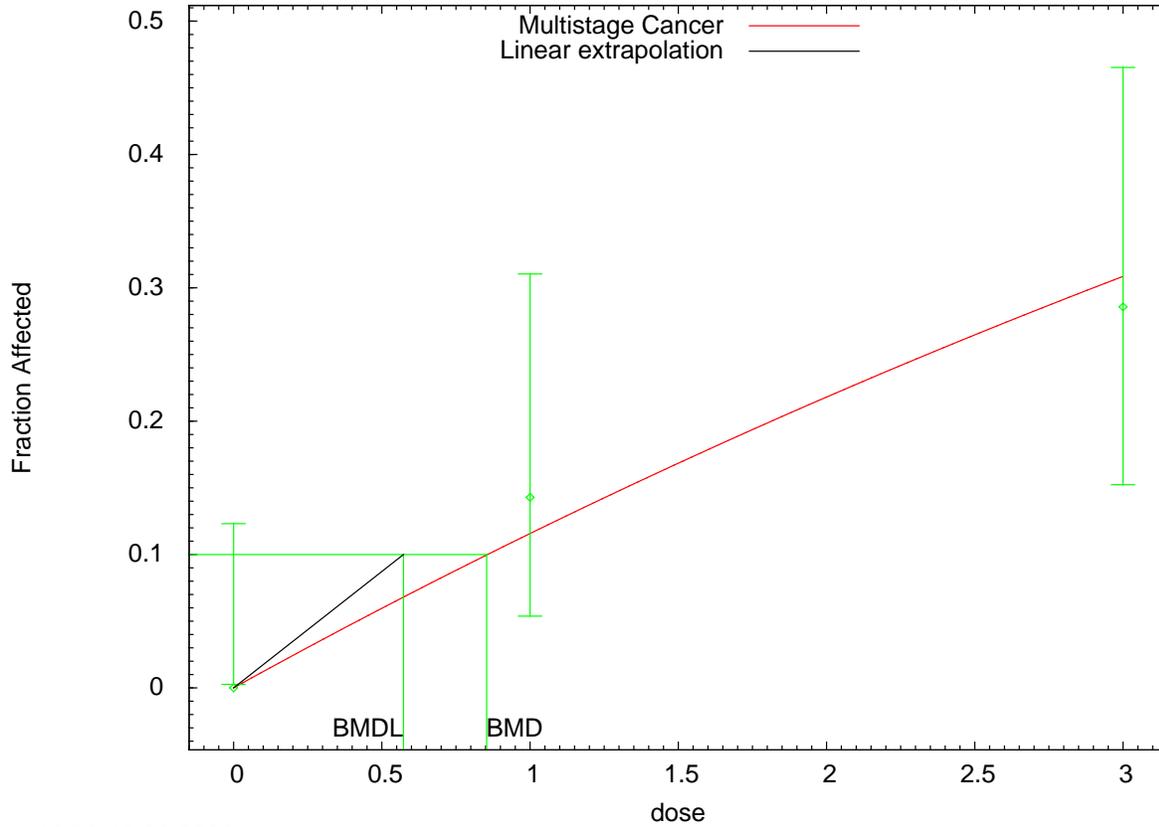
Goodness of Fit

| Dose         | Est._Prob. | Expected | Observed | Size      | Chi^2 Res. |
|--------------|------------|----------|----------|-----------|------------|
| i: 1         | 0.0000     | 0.0000   | 0        | 35        | 0.000      |
| i: 2         | 0.0300     | 0.0917   | 3        | 35        | -0.072     |
| i: 3         | 0.1000     | 0.3062   | 11       | 35        | 0.038      |
| i: 4         | 0.3000     | 0.7732   | 27       | 35        | -0.010     |
| Chi-square = | 0.03       | DF = 2   |          | P-value = | 0.9870     |

Benchmark Dose Computation

|                    |            |
|--------------------|------------|
| Specified effect = | 0.57       |
| Risk Type =        | Extra risk |
| Confidence level = | 0.95       |
| BMD =              | 0.197095   |
| BMDL =             | 0.157781   |

Multistage Cancer Model with 0.95 Confidence Level



10:59 12/28 2009

WENZEL-HARTUNG1990CH.OUT.txt

```

=====
 Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)
 Input Data File:
 C:\USEPA\IRIS\PAH\lungimplant\Wenzel1990\CH\msc_WenzelCH_MS_1_10.(d)
 Gnuplot Plotting File:
 C:\USEPA\IRIS\PAH\lungimplant\Wenzel1990\CH\msc_WenzelCH_MS_1_10.plt
 Wed Dec 23 11:48:10 2009
=====

```

BMDS Model Run

The form of the probability function is:

$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta}1 * \text{dose}^1)]$$

The parameter betas are restricted to be positive

Dependent variable = incidence  
Independent variable = dose

Total number of observations = 3  
Total number of records with missing values = 0  
Total number of parameters in model = 2

1 Total number of specified parameters = 0  
 2 Degree of polynomial = 1  
 3  
 4  
 5 Maximum number of iterations = 250  
 6 Relative Function Convergence has been set to: 2.22045e-016  
 7 Parameter Convergence has been set to: 1.49012e-008  
 8  
 9 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
 10 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
 11 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
 12 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

15 Default Initial Parameter Values

17 Background = 0.0178361  
 18 Beta(1) = 0.109158

21 Asymptotic Correlation Matrix of Parameter Estimates

22  
 23 ( \*\*\* The model parameter(s) -Background  
 24 have been estimated at a boundarypoint, or have been  
 25 specified by the user,  
 26 and do not appear in the correlation matrix )

27  
 28 Beta(1)  
 29  
 30 Beta(1) 1

34 Parameter Estimates

| 37 Confidence Interval |          |           | 95.0% Wald        |
|------------------------|----------|-----------|-------------------|
| 38 Variable            | Estimate | Std. Err. | Lower Conf. Limit |
| 39 Upper Conf. Limit   |          |           |                   |
| 40 Background          | 0        | *         | *                 |
| 41 *                   |          |           |                   |
| 42 Beta(1)             | 0.123432 | *         | *                 |
| 43 *                   |          |           |                   |

45 \* - Indicates that this value is not calculated.

49 Analysis of Deviance Table

| 51 Model         | Log(likelihood) | # Param's | Deviance | Test d.f. | P-value |
|------------------|-----------------|-----------|----------|-----------|---------|
| 52 Full model    | -35.2935        | 3         |          |           |         |
| 53 Fitted model  | -35.455         | 1         | 0.323044 | 2         |         |
| 54 0.8508        |                 |           |          |           |         |
| 55 Reduced model | -43.0622        | 1         | 15.5374  | 2         |         |
| 56 0.0004228     |                 |           |          |           |         |
| 57               |                 |           |          |           |         |
| 58 AIC:          | 72.9101         |           |          |           |         |

```

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31

```

| Goodness of Fit |            |          |          |      |                 |  |
|-----------------|------------|----------|----------|------|-----------------|--|
| Dose            | Est._Prob. | Expected | Observed | Size | Scaled Residual |  |
| 0.0000          | 0.0000     | 0.000    | 0.000    | 35   | 0.000           |  |
| 1.0000          | 0.1161     | 4.064    | 5.000    | 35   | 0.494           |  |
| 3.0000          | 0.3095     | 10.831   | 10.000   | 35   | -0.304          |  |

Chi^2 = 0.34      d.f. = 2      P-value = 0.8453

Benchmark Dose Computation

Specified effect = 0.1

Risk Type = Extra risk

Confidence level = 0.95

BMD = 0.853595

BMDL = 0.57298

BMDU = 1.36494

Taken together, (0.57298, 1.36494) is a 90 % two-sided confidence interval for the BMD

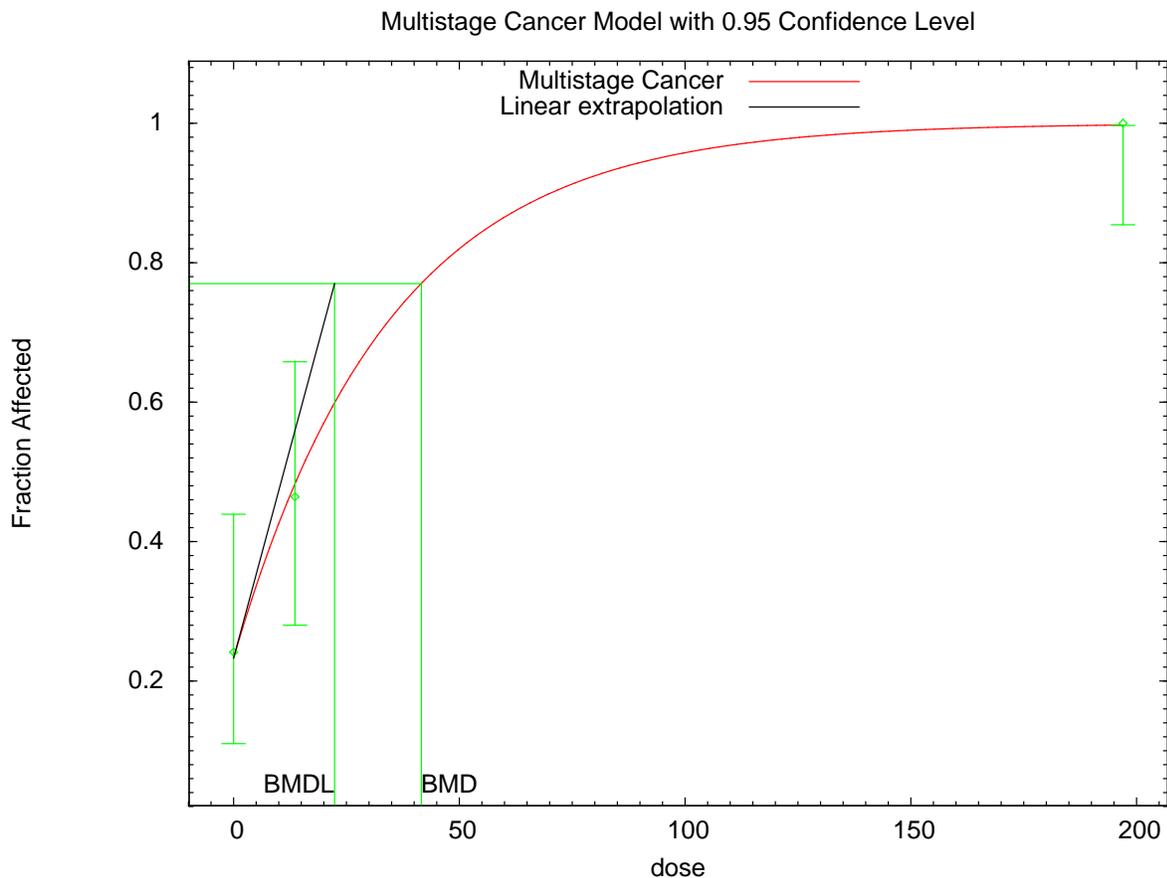
Multistage Cancer Slope Factor = 0.174526

1 **D.4. ORAL BIOASSAYS**

2

3 Weyand et al. 2004 BcFE lung

4



5 11:07 12/28 2009

6

7

8

9

=====

Multistage Cancer Model. (Version: 1.7; Date: 05/16/2008)

Input Data File:

C:\USEPA\IRIS\PAH\oral\Weyand2004\BcFE\msc\_WeyandBcFE\_MS\_1\_70.(d)

Gnuplot Plotting File:

C:\USEPA\IRIS\PAH\oral\Weyand2004\BcFE\msc\_WeyandBcFE\_MS\_1\_70.plt

Wed Dec 23 14:10:13 2009

=====

17

BMSD Model Run

19

~~~~~

20

The form of the probability function is:

22

$$P[\text{response}] = \text{background} + (1 - \text{background}) * [1 - \text{EXP}(-\text{beta}1 * \text{dose}^1)]$$

24

25

1 The parameter betas are restricted to be positive  
2  
3  
4 Dependent variable = incidence  
5 Independent variable = dose  
6  
7 Total number of observations = 3  
8 Total number of records with missing values = 0  
9 Total number of parameters in model = 2  
10 Total number of specified parameters = 0  
11 Degree of polynomial = 1  
12  
13  
14 Maximum number of iterations = 250  
15 Relative Function Convergence has been set to: 2.22045e-016  
16 Parameter Convergence has been set to: 1.49012e-008  
17  
18 \*\*\*\* We are sorry but Relative Function and Parameter Convergence \*\*\*\*  
19 \*\*\*\* are currently unavailable in this model. Please keep checking \*\*\*\*  
20 \*\*\*\* the web sight for model updates which will eventually \*\*\*\*  
21 \*\*\*\* incorporate these convergence criterion. Default values used. \*\*\*\*

22  
23  
24  
25 Default Initial Parameter Values

26 Background = 0  
27 Beta(1) = 5.23754e+017  
28  
29

30 Asymptotic Correlation Matrix of Parameter Estimates

|            | Background | Beta(1) |
|------------|------------|---------|
| Background | 1          | -0.45   |
| Beta(1)    | -0.45      | 1       |

31  
32  
33  
34  
35  
36  
37  
38  
39  
40 Parameter Estimates

| Confidence Interval |           | 95.0% Wald |       |             |
|---------------------|-----------|------------|-------|-------------|
| Variable            | Estimate  | Std. Err.  | Lower | Conf. Limit |
| Background          | 0.233316  | *          | *     |             |
| Beta(1)             | 0.0289518 | *          | *     |             |

41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51 \* - Indicates that this value is not calculated.  
52

Analysis of Deviance Table

| Model         | Log(likelihood) | # Param's | Deviance | Test d.f. | P-value |
|---------------|-----------------|-----------|----------|-----------|---------|
| Full model    | -35.3639        | 3         |          |           |         |
| Fitted model  | -35.4627        | 2         | 0.197606 | 1         |         |
| Reduced model | -58.7707        | 1         | 46.8136  | 2         | <.0001  |
| AIC:          | 74.9254         |           |          |           |         |

Goodness of Fit

| Dose     | Est._Prob. | Expected | Observed | Size | Scaled Residual |
|----------|------------|----------|----------|------|-----------------|
| 0.0000   | 0.2333     | 6.766    | 7.000    | 29   | 0.103           |
| 13.6000  | 0.4829     | 13.520   | 13.000   | 28   | -0.197          |
| 197.0000 | 0.9974     | 28.926   | 29.000   | 29   | 0.273           |

Chi^2 = 0.12      d.f. = 1      P-value = 0.7253

Benchmark Dose Computation

Specified effect = 0.7  
 Risk Type = Extra risk  
 Confidence level = 0.95  
 BMD = 41.5854  
 BMDL = 22.3673  
 BMDU = 81.9344

Taken together, (22.3673, 81.9344) is a 90 % two-sided confidence interval for the BMD

Multistage Cancer Slope Factor = 0.0312958

1 **D.5. BACTERIAL MUTAGENICITY**

2 Hass 1981 bact mut bap.out.txt

3 =====  
4 Polynomial Model. Revision: 2.2 Date: 9/12/2002  
5 Input Data File: C:\BMDS\UNSAVED1.(d)  
6 Gnuplot Plotting File: C:\BMDS\UNSAVED1.plt  
7 Wed Jul 06 11:29:07 2005  
8 =====

9  
10 BMDS MODEL RUN  
11 ~~~~~

12  
13 The form of the response function is:

14  
15  $Y[\text{dose}] = \text{beta}_0 + \text{beta}_1 \cdot \text{dose} + \text{beta}_2 \cdot \text{dose}^2 + \dots$

16  
17  
18 Dependent variable = MEAN  
19 Independent variable = COLUMN1  
20 rho is set to 0  
21 Signs of the polynomial coefficients are not restricted  
22 A constant variance model is fit

23  
24 Total number of dose groups = 4  
25 Total number of records with missing values = 0  
26 Maximum number of iterations = 250  
27 Relative Function Convergence has been set to: 1e-008  
28 Parameter Convergence has been set to: 1e-008  
29

30  
31  
32 Default Initial Parameter Values  
33 alpha = 194.5  
34 rho = 0 Specified  
35 beta\_0 = 121.8  
36 beta\_1 = 297.029  
37

38  
39  
40 Parameter Estimates

41  
42 95.0% Wald  
43 Confidence Interval  
44 Variable Estimate Std. Err. Lower Conf. Limit  
45 Upper Conf. Limit  
46 alpha 132.71 54.1784 26.5217  
47 238.897  
48 beta\_0 121.8 5.15188 111.702  
49 131.898  
50 beta\_1 297.029 8.99387 279.401  
51 314.656

52  
53  
54 Asymptotic Correlation Matrix of Parameter Estimates

55  
56 alpha beta\_0 beta\_1  
57 alpha 1 -1.4e-009 -1.1e-008  
58 beta\_0 -1.4e-009 1 -0.76  
59 beta\_1 -1.1e-008 -0.76 1

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

Table of Data and Estimated Values of Interest

| Dose | N | Obs Mean | Obs Std Dev | Est Mean | Est Std Dev | Chi <sup>2</sup> |
|------|---|----------|-------------|----------|-------------|------------------|
| 0    | 3 | 124      | 8           | 122      | 11.5        | 0.331            |
| 0.25 | 3 | 194      | 16          | 196      | 11.5        | -0.309           |
| 0.5  | 3 | 269      | 13          | 270      | 11.5        | -0.198           |
| 1    | 3 | 420      | 17          | 419      | 11.5        | 0.176            |

Model Descriptions for likelihoods calculated

Model A1:  $Y_{ij} = \mu(i) + e(ij)$   
 $Var\{e(ij)\} = \sigma^2$

Model A2:  $Y_{ij} = \mu(i) + e(ij)$   
 $Var\{e(ij)\} = \sigma(i)^2$

Model R:  $Y_i = \mu + e(i)$   
 $Var\{e(i)\} = \sigma^2$

Likelihoods of Interest

| Model  | Log(likelihood) | DF | AIC        |
|--------|-----------------|----|------------|
| A1     | -35.189802      | 5  | 80.379605  |
| A2     | -34.317788      | 8  | 84.635576  |
| fitted | -35.328976      | 2  | 74.657952  |
| R      | -62.974684      | 2  | 129.949369 |

Test 1: Does response and/or variances differ among dose levels

(A2 vs. R)

Test 2: Are Variances Homogeneous (A1 vs A2)

Test 3: Does the Model for the Mean Fit (A1 vs. fitted)

Tests of Interest

| Test   | -2*log(Likelihood Ratio) | Test df | p-value |
|--------|--------------------------|---------|---------|
| Test 1 | 57.3138                  | 6       | <.0001  |
| Test 2 | 1.74403                  | 3       | 0.6272  |
| Test 3 | 0.278348                 | 2       | 0.8701  |

The p-value for Test 1 is less than .05. There appears to be a difference between response and/or variances among the dose levels.

It seems appropriate to model the data

The p-value for Test 2 is greater than .05. A homogeneous variance model appears to be appropriate here

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22

The p-value for Test 3 is greater than .05. The model chosen appears to adequately describe the data

Benchmark Dose Computation

Specified effect = 1

Risk Type = Estimated standard deviations from the control mean

Confidence level = 0.95

BMD = 0.038784

BMDL = 0.0286028

```

1 HASS_1981_BACT_MUT_BEP.OUT.txt
2 =====
3 Polynomial Model. Revision: 2.2 Date: 9/12/2002
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\HASS_1981_BACT_MUT_BEP.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\HASS_1981_BACT_MUT_BEP.plt
8 Wed Jul 06 13:42:38 2005
9 =====

```

```

10
11 BMDS MODEL RUN
12 ~~~~~

```

```

13
14 The form of the response function is:
15
16 $Y[\text{dose}] = \text{beta}_0 + \text{beta}_1 \cdot \text{dose} + \text{beta}_2 \cdot \text{dose}^2 + \dots$
17
18
19 Dependent variable = MEAN
20 Independent variable = COLUMN1
21 rho is set to 0
22 Signs of the polynomial coefficients are not restricted
23 A constant variance model is fit
24
25 Total number of dose groups = 4
26 Total number of records with missing values = 0
27 Maximum number of iterations = 250
28 Relative Function Convergence has been set to: 1e-008
29 Parameter Convergence has been set to: 1e-008

```

```

30
31
32
33 Default Initial Parameter Values
34 alpha = 117.5
35 rho = 0 Specified
36 beta_0 = 120.75
37 beta_1 = 77.5

```

```

38
39
40
41 Parameter Estimates
42
43 95.0% Wald
44 Confidence Interval
45 Variable Estimate Std. Err. Lower Conf. Limit
46 Upper Conf. Limit
47 alpha 98.6458 40.272 19.7142
48 177.577
49 beta_0 120.75 4.19706 112.524
50 128.976
51 beta_1 77.5 7.66275 62.4813
52 92.5187

```

```

53
54
55 Asymptotic Correlation Matrix of Parameter Estimates
56
57 alpha beta_0 beta_1
58 alpha 1 -8e-012 1.1e-011
59 beta_0 -8e-012 1 -0.73
60 beta_1 1.1e-011 -0.73 1

```

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

Table of Data and Estimated Values of Interest

| Dose | N | Obs Mean | Obs Std Dev | Est Mean | Est Std Dev | Chi <sup>2</sup> |
|------|---|----------|-------------|----------|-------------|------------------|
| 0    | 3 | 124      | 8           | 121      | 9.93        | 0.567            |
| 0.2  | 3 | 129      | 6           | 136      | 9.93        | -1.26            |
| 0.4  | 3 | 156      | 9           | 152      | 9.93        | 0.741            |
| 1    | 3 | 198      | 17          | 198      | 9.93        | -0.0436          |

Model Descriptions for likelihoods calculated

Model A1:  $Y_{ij} = \mu(i) + e(ij)$   
 $\text{Var}\{e(ij)\} = \sigma^2$

Model A2:  $Y_{ij} = \mu(i) + e(ij)$   
 $\text{Var}\{e(ij)\} = \sigma(i)^2$

Model R:  $Y_i = \mu + e(i)$   
 $\text{Var}\{e(i)\} = \sigma^2$

Likelihoods of Interest

| Model  | Log(likelihood) | DF | AIC       |
|--------|-----------------|----|-----------|
| A1     | -32.165839      | 5  | 74.331679 |
| A2     | -30.272126      | 8  | 76.544252 |
| fitted | -33.549216      | 2  | 71.098432 |
| R      | -47.594288      | 2  | 99.188576 |

Test 1: Does response and/or variances differ among dose levels (A2 vs. R)

Test 2: Are Variances Homogeneous (A1 vs A2)

Test 3: Does the Model for the Mean Fit (A1 vs. fitted)

Tests of Interest

| Test   | -2*log(Likelihood Ratio) | Test df | p-value |
|--------|--------------------------|---------|---------|
| Test 1 | 34.6443                  | 6       | <.0001  |
| Test 2 | 3.78743                  | 3       | 0.2854  |
| Test 3 | 2.76675                  | 2       | 0.2507  |

The p-value for Test 1 is less than .05. There appears to be a difference between response and/or variances among the dose levels. It seems appropriate to model the data

The p-value for Test 2 is greater than .05. A homogeneous variance model appears to be appropriate here

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22

The p-value for Test 3 is greater than .05. The model chosen appears to adequately describe the data

Benchmark Dose Computation

Specified effect = 1

Risk Type = Estimated standard deviations from the control mean

Confidence level = 0.95

BMD = 0.128156

BMDL = 0.0923937

```

1 JOHNSEN_1997_BAC_MUT_BAP.OUT.txt
2 =====
3 Polynomial Model. Revision: 2.2 Date: 9/12/2002
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\JOHNSEN_1997_BAC_MUT_BAP.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\JOHNSEN_1997_BAC_MUT_BAP.plt
8 Fri Jul 08 09:02:29 2005
9 =====

```

```

10
11 BMDS MODEL RUN
12 ~~~~~

```

```

13
14 The form of the response function is:
15
16 $Y[\text{dose}] = \text{beta}_0 + \text{beta}_1 \cdot \text{dose} + \text{beta}_2 \cdot \text{dose}^2 + \dots$
17
18
19 Dependent variable = MEAN
20 Independent variable = COLUMN1
21 rho is set to 0
22 Signs of the polynomial coefficients are not restricted
23 A constant variance model is fit
24
25 Total number of dose groups = 3
26 Total number of records with missing values = 0
27 Maximum number of iterations = 250
28 Relative Function Convergence has been set to: 1e-008
29 Parameter Convergence has been set to: 1e-008

```

```

30
31
32
33 Default Initial Parameter Values
34 alpha = 70.2768
35 rho = 0 Specified
36 beta_0 = 115.5
37 beta_1 = 0.65

```

```

38
39
40
41 Parameter Estimates
42
43 95.0% Wald
44 Confidence Interval
45 Variable Estimate Std. Err. Lower Conf. Limit
46 Upper Conf. Limit
47 alpha 59.3512 27.9784 4.51449
48 114.188
49 beta_0 115.5 4.06035 107.542
50 123.458
51 beta_1 0.65 0.314513 0.0335651
52 1.26643

```

```

53
54
55 Asymptotic Correlation Matrix of Parameter Estimates
56
57 alpha beta_0 beta_1
58 alpha 1 -7.9e-010 -3.4e-012
59 beta_0 -7.9e-010 1 -0.77
60 beta_1 -3.4e-012 -0.77 1

```

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

Table of Data and Estimated Values of Interest

| Dose Res. | N | Obs Mean | Obs Std Dev | Est Mean | Est Std Dev | Chi^2  |
|-----------|---|----------|-------------|----------|-------------|--------|
| 0         | 3 | 113      | 9.68        | 115      | 7.7         | -0.562 |
| 10        | 3 | 127      | 4.84        | 122      | 7.7         | 1.12   |
| 20        | 3 | 126      | 9.68        | 128      | 7.7         | -0.562 |

Model Descriptions for likelihoods calculated

Model A1:  $Y_{ij} = \mu(i) + e(ij)$   
 $\text{Var}\{e(ij)\} = \sigma^2$

Model A2:  $Y_{ij} = \mu(i) + e(ij)$   
 $\text{Var}\{e(ij)\} = \sigma(i)^2$

Model R:  $Y_i = \mu + e(i)$   
 $\text{Var}\{e(i)\} = \sigma^2$

Likelihoods of Interest

| Model  | Log(likelihood) | DF | AIC       |
|--------|-----------------|----|-----------|
| A1     | -21.811395      | 4  | 51.622790 |
| A2     | -21.026523      | 6  | 54.053045 |
| fitted | -22.875626      | 2  | 49.751251 |
| R      | -24.653317      | 2  | 53.306634 |

Test 1: Does response and/or variances differ among dose levels (A2 vs. R)

Test 2: Are Variances Homogeneous (A1 vs A2)

Test 3: Does the Model for the Mean Fit (A1 vs. fitted)

Tests of Interest

| Test   | -2*log(Likelihood Ratio) | Test df | p-value |
|--------|--------------------------|---------|---------|
| Test 1 | 7.25359                  | 4       | 0.0266  |
| Test 2 | 1.56974                  | 2       | 0.4562  |
| Test 3 | 2.12846                  | 1       | 0.1446  |

The p-value for Test 1 is less than .05. There appears to be a difference between response and/or variances among the dose levels.

It seems appropriate to model the data

The p-value for Test 2 is greater than .05. A homogeneous variance model appears to be appropriate here

1  
2 The p-value for Test 3 is greater than .05. The model  
3 chosen appears  
4 to adequately describe the data  
5  
6  
7  
8 Benchmark Dose Computation  
9 Specified effect = 1  
10  
11 Risk Type = Estimated standard deviations from the control mean  
12  
13  
14 Confidence level = 0.95  
15  
16 BMD = 11.8523  
17  
18  
19 BMDL = 6.27094  
20  
21  
22  
23

1 **D.6. MAMMALIAN MUTAGENICITY**

2 BARF\_MUT\_BAA.OUT.txt

3 =====  
4 Multistage Model. \$Revision: 2.1 \$ \$Date: 2000/08/21 03:38:21 \$  
5 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH  
6 RPS\MODELING\BARF\_MUT\_BAA.(d)  
7 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY  
8 DOCUMENTS\PAH RPS\MODELING\BARF\_MUT\_BAA.plt  
9 Thu Jun 30 12:46:38 2005  
10 =====

11  
12 BMDS MODEL RUN  
13 ~~~~~

14  
15 The form of the probability function is:

16  
17 
$$P[\text{response}] = \text{background} + (1 - \text{background}) * [1 - \text{EXP}(-\text{beta1} * \text{dose}^1 - \text{beta2} * \text{dose}^2 - \text{beta3} * \text{dose}^3)]$$
  
18

19  
20 The parameter betas are restricted to be positive  
21

22  
23 Dependent variable = COLUMN2  
24 Independent variable = COLUMN1  
25

26 Total number of observations = 5  
27 Total number of records with missing values = 0  
28 Total number of parameters in model = 4  
29 Total number of specified parameters = 0  
30 Degree of polynomial = 3  
31

32  
33 Maximum number of iterations = 250  
34 Relative Function Convergence has been set to: 1e-008  
35 Parameter Convergence has been set to: 1e-008  
36  
37  
38

39 Default Initial Parameter Values

40 Background = 3.89426e-006  
41 Beta(1) = 3.46216e-007  
42 Beta(2) = 0  
43 Beta(3) = 1.93939e-012

44 \*\*\*\* WARNING: Completion code = -2. Optimum not found. Trying new starting  
45 pont\*\*\*\*  
46

47  
48  
49 Asymptotic Correlation Matrix of Parameter Estimates

50  
51 ( \*\*\* The model parameter(s) -Background -Beta(2) -Beta(3)  
52 have been estimated at a boundary point, or have been  
53 specified by the user,  
54 and do not appear in the correlation matrix )  
55

56 Beta(1)  
57  
58 Beta(1) 1  
59

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

Parameter Estimates

| Variable   | Estimate     | Std. Err.    |
|------------|--------------|--------------|
| Background | 0            | NA           |
| Beta(1)    | 4.34385e-007 | 5.43792e-006 |
| Beta(2)    | 0            | NA           |
| Beta(3)    | 0            | NA           |

NA - Indicates that this parameter has hit a bound implied by some inequality constraint and thus has no standard error.

Analysis of Deviance Table

| Model         | Log(likelihood) | Deviance | Test DF | P-value |
|---------------|-----------------|----------|---------|---------|
| Full model    | -1545.82        |          |         |         |
| Fitted model  | -1548.6         | 5.57201  | 4       | 0.2335  |
| Reduced model | -1597.17        | 102.713  | 4       | <.0001  |

AIC: 3099.21

Goodness of Fit

| Dose | Est._Prob. | Expected | Observed | Size    | Chi^2 Res. |
|------|------------|----------|----------|---------|------------|
| i: 1 | 0.0000     | 0.000    | 0        | 1000000 | 0.000      |
| i: 2 | 20.0000    | 8.688    | 12       | 1000000 | 0.381      |
| i: 3 | 50.0000    | 21.719   | 29       | 1000000 | 0.335      |
| i: 4 | 100.0000   | 43.438   | 34       | 1000000 | -0.217     |
| i: 5 | 150.0000   | 65.156   | 64       | 1000000 | -0.018     |

Chi-square = 5.77 DF = 4 P-value = 0.2166

Benchmark Dose Computation

Specified effect = 1e-005  
Risk Type = Extra risk  
Confidence level = 0.95  
BMD = 23.0212

\*\*\*\* WARNING: Completion code = -2. Optimum not found. Trying new starting point\*\*\*\*

\*\*\*\* WARNING 0: Completion code = -2 trying new start\*\*\*\*

\*\*\*\* WARNING 1: Completion code = -2 trying new start\*\*\*\*

1  
2 \*\*\*\* WARNING 2: Completion code = -2 trying new start\*\*\*\*  
3  
4 \*\*\*\* WARNING 3: Completion code = -2 trying new start\*\*\*\*  
5  
6 \*\*\*\* WARNING 4: Completion code = -2 trying new start\*\*\*\*  
7  
8 \*\*\*\* WARNING 5: Completion code = -2 trying new start\*\*\*\*  
9  
10 \*\*\*\* WARNING 6: Completion code = -2 trying new start\*\*\*\*  
11  
12 \*\*\*\* WARNING 7: Completion code = -2 trying new start\*\*\*\*  
13  
14 \*\*\*\* WARNING 8: Completion code = -2 trying new start\*\*\*\*  
15  
16 \*\*\*\* WARNING 9: Completion code = -2 trying new start\*\*\*\*  
17  
18 \*\*\*\* WARNING: Completion code = -2. Optimum not found. Trying new starting  
19 point\*\*\*\*  
20  
21 \*\*\*\* WARNING 0: Completion code = -2 trying new start\*\*\*\*  
22  
23 \*\*\*\* WARNING 1: Completion code = -3 trying new start\*\*\*\*  
24  
25 \*\*\*\* WARNING 2: Completion code = -3 trying new start\*\*\*\*  
26  
27 \*\*\*\* WARNING 3: Completion code = -3 trying new start\*\*\*\*  
28  
29 \*\*\*\* WARNING 4: Completion code = -3 trying new start\*\*\*\*  
30  
31 \*\*\*\* WARNING 5: Completion code = -3 trying new start\*\*\*\*  
32  
33 \*\*\*\* WARNING 6: Completion code = -2 trying new start\*\*\*\*  
34  
35 \*\*\*\* WARNING 7: Completion code = -3 trying new start\*\*\*\*  
36  
37 \*\*\*\* WARNING 8: Completion code = -3 trying new start\*\*\*\*  
38  
39 \*\*\*\* WARNING 9: Completion code = -3 trying new start\*\*\*\*  
40  
41  
42 Warning: completion code still negative  
43 BMDL did not converge for BMR = 0.000010  
44  
45 Program execution is stopped  
46

```

1 BARF_MUT_BAP.OUT.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\BARF_MUT_BAP.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\BARF_MUT_BAP.plt
8 Thu Jun 30 12:40:17 2005
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(
17 -beta1*dose^1-beta2*dose^2)]
18
19 The parameter betas are restricted to be positive
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 4
26 Total number of records with missing values = 0
27 Total number of parameters in model = 3
28 Total number of specified parameters = 0
29 Degree of polynomial = 2
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 1.39884e-006
40 Beta(1) = 5.34042e-006
41 Beta(2) = 0
42
43
44 Asymptotic Correlation Matrix of Parameter Estimates
45
46 (*** The model parameter(s) -Background -Beta(2)
47 have been estimated at a boundary point, or have been
48 specified by the user,
49 and do not appear in the correlation matrix)
50
51 Beta(1)
52
53 Beta(1) 1
54
55
56
57 Parameter Estimates
58
59 Variable Estimate Std. Err.
60 Background 0 NA

```

1           Beta(1)           5.43367e-006           2.68102e-005  
 2           Beta(2)                   0                   NA  
 3

4 NA - Indicates that this parameter has hit a bound  
 5 implied by some inequality constraint and thus  
 6 has no standard error.  
 7  
 8  
 9

10                           Analysis of Deviance Table

| Model         | Log(likelihood) | Deviance | Test DF | P-value |
|---------------|-----------------|----------|---------|---------|
| Full model    | -3273.08        |          |         |         |
| Fitted model  | -3273.96        | 1.75092  | 3       | 0.6257  |
| Reduced model | -3395.25        | 244.327  | 3       | <.0001  |
| AIC:          | 6549.92         |          |         |         |

19                           Goodness of Fit

| Dose         | Est._Prob. | Expected | Observed  | Size    | Chi^2 Res. |
|--------------|------------|----------|-----------|---------|------------|
| i: 1         | 0.0000     | 0.000    | 0         | 1000000 | 0.000      |
| i: 2         | 10.0000    | 54.335   | 51        | 1000000 | -0.061     |
| i: 3         | 20.0000    | 108.668  | 120       | 1000000 | 0.104      |
| i: 4         | 30.0000    | 162.997  | 155       | 1000000 | -0.049     |
| Chi-square = | 1.78       | DF = 3   | P-value = | 0.6195  |            |

36           Benchmark Dose Computation

37 Specified effect =           1e-005  
 38 Risk Type           =           Extra risk  
 39 Confidence level =           0.95  
 40 BMD =           1.84039

41  
 42  
 43  
 44  
 45  
 46 \*\*\*\* WARNING: Completion code = -3. Optimum not found. Trying new starting  
 47 point\*\*\*\*

48  
 49 \*\*\*\* WARNING 0: Completion code = -3 trying new start\*\*\*\*

50  
 51 \*\*\*\* WARNING 1: Completion code = -3 trying new start\*\*\*\*

52  
 53 \*\*\*\* WARNING 2: Completion code = -3 trying new start\*\*\*\*

54  
 55 \*\*\*\* WARNING 3: Completion code = -3 trying new start\*\*\*\*

56  
 57 \*\*\*\* WARNING 4: Completion code = -3 trying new start\*\*\*\*

58  
 59 \*\*\*\* WARNING 5: Completion code = -3 trying new start\*\*\*\*  
 60

```
1 **** WARNING 6: Completion code = -3 trying new start****
2
3 **** WARNING 7: Completion code = -3 trying new start****
4
5 **** WARNING 8: Completion code = -3 trying new start****
6
7 **** WARNING 9: Completion code = -3 trying new start****
8
9 **** WARNING: Completion code = -3. Optimum not found. Trying new starting
10 point****
11
12 **** WARNING 0: Completion code = -1 trying new start****
13
14 **** WARNING 1: Completion code = -1 trying new start****
15
16 **** WARNING 2: Completion code = -1 trying new start****
17
18 BMDL = 1.68248
19
```

```

1 BARF_MUT_CH.OUT.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\BARF_MUT_CH.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\BARF_MUT_CH.plt
8
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(
17 -beta1*dose^1)]
18
19 The parameter betas are restricted to be positive
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 3
26 Total number of records with missing values = 0
27 Total number of parameters in model = 2
28 Total number of specified parameters = 0
29 Degree of polynomial = 1
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 2.60526e-006
40 Beta(1) = 5.02638e-007
41
42
43 Asymptotic Correlation Matrix of Parameter Estimates
44
45 (*** The model parameter(s) -Background
46 have been estimated at a boundary point, or have been
47 specified by the user,
48 and do not appear in the correlation matrix)
49
50 Beta(1)
51
52 Beta(1) 1
53
54
55
56 Parameter Estimates
57
58 Variable Estimate Std. Err.
59 Background 0 NA
60 Beta(1) 6.14293e-007 1.93539e-005

```

1  
 2 NA - Indicates that this parameter has hit a bound  
 3 implied by some inequality constraint and thus  
 4 has no standard error.

5  
 6  
 7  
 8 Analysis of Deviance Table

9

| Model         | Log(likelihood) | Deviance | Test DF | P-value |
|---------------|-----------------|----------|---------|---------|
| Full model    | -504.191        |          |         |         |
| Fitted model  | -505.38         | 2.37752  | 2       | 0.3046  |
| Reduced model | -522.575        | 36.7681  | 2       | <.0001  |

15 AIC: 1012.76

16  
 17  
 18 Goodness of Fit

19

| Dose         | Est._Prob. | Expected | Observed         | Size    | Chi^2 Res. |
|--------------|------------|----------|------------------|---------|------------|
| -----        |            |          |                  |         |            |
| i: 1         | 0.0000     | 0.0000   | 0                | 1000000 | 0.000      |
| i: 2         | 20.0000    | 0.0000   | 12.286           | 1000000 | 0.384      |
| i: 3         | 50.0000    | 0.0000   | 30.714           | 1000000 | -0.153     |
| Chi-square = | 2.53       | DF = 2   | P-value = 0.2819 |         |            |

30  
 31  
 32 Benchmark Dose Computation

33 Specified effect = 1e-005  
 34  
 35 Risk Type = Extra risk  
 36  
 37 Confidence level = 0.95  
 38  
 39 BMD = 16.279  
 40

41  
 42 \*\*\*\* WARNING: Completion code = -1. Optimum not found. Trying new starting  
 43 point\*\*\*\*

- 44  
 45 \*\*\*\* WARNING 0: Completion code = -1 trying new start\*\*\*\*  
 46  
 47 \*\*\*\* WARNING 1: Completion code = -1 trying new start\*\*\*\*  
 48  
 49 \*\*\*\* WARNING 2: Completion code = -1 trying new start\*\*\*\*  
 50  
 51 \*\*\*\* WARNING 3: Completion code = -1 trying new start\*\*\*\*  
 52  
 53 \*\*\*\* WARNING 4: Completion code = -1 trying new start\*\*\*\*  
 54  
 55 \*\*\*\* WARNING 5: Completion code = -1 trying new start\*\*\*\*  
 56  
 57 \*\*\*\* WARNING 6: Completion code = -1 trying new start\*\*\*\*  
 58  
 59 \*\*\*\* WARNING 7: Completion code = -1 trying new start\*\*\*\*  
 60

```
1 **** WARNING 8: Completion code = -1 trying new start****
2
3 **** WARNING 9: Completion code = -1 trying new start****
4
5 **** WARNING: Completion code = -1. Optimum not found. Trying new starting
6 point****
7
8 **** WARNING 0: Completion code = -3 trying new start****
9
10 **** WARNING 1: Completion code = -3 trying new start****
11
12 **** WARNING 2: Completion code = -3 trying new start****
13
14 **** WARNING 3: Completion code = -3 trying new start****
15
16 **** WARNING 4: Completion code = -3 trying new start****
17
18 **** WARNING 5: Completion code = -3 trying new start****
19
20 **** WARNING 6: Completion code = -3 trying new start****
21
22 **** WARNING 7: Completion code = -3 trying new start****
23
24 **** WARNING 8: Completion code = -3 trying new start****
25
26 **** WARNING 9: Completion code = -3 trying new start****
27
28
29 Warning: completion code still negative
30 BMDL did not converge for BMR = 0.000010
31
32 Program execution is stopped
33
```

```

1 BARF_MUT_FA.OUT.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\BARF_MUT_FA.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\BARF_MUT_FA.plt
8
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(
17 -beta1*dose^1)]
18
19 The parameter betas are restricted to be positive
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 3
26 Total number of records with missing values = 0
27 Total number of parameters in model = 2
28 Total number of specified parameters = 0
29 Degree of polynomial = 1
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 6.6658e-007
40 Beta(1) = 2.50006e-006
41
42
43 Asymptotic Correlation Matrix of Parameter Estimates
44
45 (*** The model parameter(s) -Background
46 have been estimated at a boundary point, or have been
47 specified by the user,
48 and do not appear in the correlation matrix)
49
50 Beta(1)
51
52 Beta(1) 1
53
54
55
56 Parameter Estimates
57
58 Variable Estimate Std. Err.
59 Background 0 NA
60 Beta(1) 2.56672e-006 4.49565e-005

```

1  
 2 NA - Indicates that this parameter has hit a bound  
 3 implied by some inequality constraint and thus  
 4 has no standard error.  
 5  
 6  
 7

8 Analysis of Deviance Table

9

| 10 Model         | Log(likelihood) | Deviance | Test DF | P-value |
|------------------|-----------------|----------|---------|---------|
| 11 Full model    | -856.204        |          |         |         |
| 12 Fitted model  | -856.255        | 0.103    | 2       | 0.9498  |
| 13 Reduced model | -890.913        | 69.419   | 2       | <.0001  |

14  
 15 AIC: 1714.51  
 16

17 Goodness of Fit

18  
 19

| 20 Dose         | Est._Prob. | Expected | Observed | Size             | Chi^2 Res. |
|-----------------|------------|----------|----------|------------------|------------|
| 21 -----        |            |          |          |                  |            |
| 22 i: 1         |            |          |          |                  |            |
| 23 0.0000       | 0.0000     | 0.000    | 0        | 1000000          | 0.000      |
| 24 i: 2         |            |          |          |                  |            |
| 25 10.0000      | 0.0000     | 25.667   | 27       | 1000000          | 0.052      |
| 26 i: 3         |            |          |          |                  |            |
| 27 20.0000      | 0.0001     | 51.333   | 50       | 1000000          | -0.026     |
| 28              |            |          |          |                  |            |
| 29 Chi-square = | 0.10       | DF = 2   |          | P-value = 0.9494 |            |

30  
 31 Benchmark Dose Computation

32 Specified effect = 1e-005  
 33  
 34 Risk Type = Extra risk  
 35  
 36 Confidence level = 0.95  
 37  
 38 BMD = 3.89604  
 39

40  
 41  
 42 \*\*\*\* WARNING: Completion code = -1. Optimum not found. Trying new starting  
 43 point\*\*\*\*  
 44

45 \*\*\*\* WARNING 0: Completion code = -1 trying new start\*\*\*\*  
 46

47 \*\*\*\* WARNING 1: Completion code = -5 trying new start\*\*\*\*  
 48

49 BMDL = 0  
 50  
 51

```

1 BARF_MUT_TPHEN.OUT.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\BARF_MUT_TPHEN.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\BARF_MUT_TPHEN.plt
8 Thu Jun 30 12:52:56 2005
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(
17 -beta1*dose^1-beta2*dose^2)]
18
19 The parameter betas are restricted to be positive
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 4
26 Total number of records with missing values = 0
27 Total number of parameters in model = 3
28 Total number of specified parameters = 0
29 Degree of polynomial = 2
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 9.99937e-007
40 Beta(1) = 1.74289e-007
41 Beta(2) = 0
42
43
44 Asymptotic Correlation Matrix of Parameter Estimates
45
46 (*** The model parameter(s) -Background -Beta(2)
47 have been estimated at a boundary point, or have been
48 specified by the user,
49 and do not appear in the correlation matrix)
50
51 Beta(1)
52
53 Beta(1) 1
54
55
56
57 Parameter Estimates
58
59 Variable Estimate Std. Err.
60 Background 0 NA

```

1           Beta(1)           1.85717e-007           4.42148e-006  
 2           Beta(2)                           0                   NA  
 3

4 NA - Indicates that this parameter has hit a bound  
 5 implied by some inequality constraint and thus  
 6 has no standard error.  
 7  
 8  
 9

10                           Analysis of Deviance Table

| Model         | Log(likelihood) | Deviance | Test DF | P-value |
|---------------|-----------------|----------|---------|---------|
| Full model    | -755.63         |          |         |         |
| Fitted model  | -755.773        | 0.2868   | 3       | 0.9625  |
| Reduced model | -781.782        | 52.3039  | 3       | <.0001  |
| AIC:          | 1513.55         |          |         |         |

19                           Goodness of Fit

| Dose         | Est._Prob. | Expected | Observed  | Size    | Chi^2 Res. |
|--------------|------------|----------|-----------|---------|------------|
| i: 1         | 0.0000     | 0.000    | 0         | 1000000 | 0.000      |
| i: 2         | 50.0000    | 9.286    | 10        | 1000000 | 0.077      |
| i: 3         | 100.0000   | 18.572   | 20        | 1000000 | 0.077      |
| i: 4         | 200.0000   | 37.143   | 35        | 1000000 | -0.058     |
| Chi-square = | 0.29       | DF = 3   | P-value = | 0.9622  |            |

36                           Benchmark Dose Computation

37 Specified effect =           1e-005  
 38 Risk Type           =           Extra risk  
 39 Confidence level =           0.95  
 40 BMD =           53.8457

41  
 42  
 43  
 44  
 45  
 46 \*\*\*\* WARNING: Completion code = -2. Optimum not found. Trying new starting  
 47 point\*\*\*\*

48  
 49 \*\*\*\* WARNING 0: Completion code = -2 trying new start\*\*\*\*

50  
 51 \*\*\*\* WARNING 1: Completion code = -2 trying new start\*\*\*\*

52  
 53 \*\*\*\* WARNING 2: Completion code = -2 trying new start\*\*\*\*

54  
 55 \*\*\*\* WARNING 3: Completion code = -2 trying new start\*\*\*\*

56  
 57 \*\*\*\* WARNING 4: Completion code = -2 trying new start\*\*\*\*

58  
 59 \*\*\*\* WARNING 5: Completion code = -2 trying new start\*\*\*\*  
 60

1 \*\*\*\* WARNING 6: Completion code = -2 trying new start\*\*\*\*  
2  
3 \*\*\*\* WARNING 7: Completion code = -2 trying new start\*\*\*\*  
4  
5 \*\*\*\* WARNING 8: Completion code = -2 trying new start\*\*\*\*  
6  
7 \*\*\*\* WARNING 9: Completion code = -2 trying new start\*\*\*\*  
8  
9 \*\*\*\* WARNING: Completion code = -2. Optimum not found. Trying new starting  
10 point\*\*\*\*  
11  
12 \*\*\*\* WARNING 0: Completion code = -2 trying new start\*\*\*\*  
13  
14 \*\*\*\* WARNING 1: Completion code = -5 trying new start\*\*\*\*  
15  
16 \*\*\*\* WARNING 2: Completion code = -2 trying new start\*\*\*\*  
17  
18 \*\*\*\* WARNING 3: Completion code = -2 trying new start\*\*\*\*  
19  
20 \*\*\*\* WARNING 4: Completion code = -2 trying new start\*\*\*\*  
21  
22 \*\*\*\* WARNING 5: Completion code = -2 trying new start\*\*\*\*  
23  
24 \*\*\*\* WARNING 6: Completion code = -2 trying new start\*\*\*\*  
25  
26 \*\*\*\* WARNING 7: Completion code = -5 trying new start\*\*\*\*  
27  
28 \*\*\*\* WARNING 8: Completion code = -2 trying new start\*\*\*\*  
29  
30 \*\*\*\* WARNING 9: Completion code = -5 trying new start\*\*\*\*  
31  
32  
33 Warning: completion code still negative  
34 BMDL did not converge for BMR = 0.000010  
35  
36 Program execution is stopped  
37

```

1 RAVEH_HUB_MUT_BAP.OUT.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\RAVEH_HUB_MUT_BAP.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\RAVEH_HUB_MUT_BAP.plt
8 Wed Jun 29 12:15:41 2005
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(
17 -beta1*dose^1)]
18
19 The parameter betas are restricted to be positive
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 3
26 Total number of records with missing values = 0
27 Total number of parameters in model = 2
28 Total number of specified parameters = 0
29 Degree of polynomial = 1
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 0
40 Beta(1) = 0.00102082
41 **** WARNING: Completion code = -2. Optimum not found. Trying new starting
42 pont****
43
44 **** WARNING 0: Completion code = -2 trying new start****
45
46 **** WARNING 1: Completion code = -2 trying new start****
47
48 **** WARNING 2: Completion code = -2 trying new start****
49
50 **** WARNING 3: Completion code = -2 trying new start****
51
52 **** WARNING 4: Completion code = -2 trying new start****
53
54 **** WARNING 5: Completion code = -2 trying new start****
55
56 **** WARNING 6: Completion code = -2 trying new start****
57
58 **** WARNING 7: Completion code = -2 trying new start****
59
60 **** WARNING 8: Completion code = -2 trying new start****

```

1  
 2 \*\*\*\* WARNING 9: Completion code = -2 trying new start\*\*\*\*  
 3  
 4 \*\*\*\* WARNING: Completion code = -2. Optimum not found. Trying new starting  
 5 point\*\*\*\*  
 6  
 7 \*\*\*\* WARNING 0: Completion code = -2 trying new start\*\*\*\*  
 8  
 9 \*\*\*\* WARNING 1: Completion code = -2 trying new start\*\*\*\*  
 10  
 11 \*\*\*\* WARNING 2: Completion code = -2 trying new start\*\*\*\*  
 12  
 13 \*\*\*\* WARNING 3: Completion code = -2 trying new start\*\*\*\*  
 14  
 15  
 16

17 Asymptotic Correlation Matrix of Parameter Estimates

|            | Background | Beta(1) |
|------------|------------|---------|
| Background | 1          | -0.71   |
| Beta(1)    | -0.71      | 1       |

26 Parameter Estimates

| Variable   | Estimate    | Std. Err.  |
|------------|-------------|------------|
| Background | 2.6399e-005 | 0.00257721 |
| Beta(1)    | 0.000947187 | 0.00419869 |

34 Analysis of Deviance Table

| Model         | Log(likelihood) | Deviance | Test DF | P-value |
|---------------|-----------------|----------|---------|---------|
| Full model    | -1077.99        |          |         |         |
| Fitted model  | -1078.81        | 1.63811  | 1       | 0.2006  |
| Reduced model | -1144.43        | 132.88   | 2       | <.0001  |

42 AIC: 2161.62

44 Goodness of Fit

| Dose | Est._Prob. | Expected | Observed | Size   | Chi^2 Res. |
|------|------------|----------|----------|--------|------------|
| i: 1 | 0.0000     | 2.640    | 3        | 100000 | 0.136      |
| i: 2 | 0.3000     | 31.051   | 25       | 100000 | -0.195     |
| i: 3 | 1.0000     | 97.311   | 103      | 100000 | 0.059      |

56 Chi-square = 1.56 DF = 1 P-value = 0.2115

59 Benchmark Dose Computation

1 Specified effect = 0.0001  
2  
3 Risk Type = Extra risk  
4  
5 Confidence level = 0.95  
6  
7 BMD = 0.105581  
8  
9 BMDL = 0.0908465  
10

```

1 RAVEH_HUB_MUT_cpdp.OUT.txt
2 =====
3 Quantal Linear Model $Revision: 2.2 $ $Date: 2000/03/17 22:27:16 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\RAVEH_HUB_MUT_BAP.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\RAVEH_HUB_MUT_BAP.plt
8 Wed Jun 29 12:09:01 2005
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(-slope*dose)]
17
18
19 Dependent variable = COLUMN2
20 Independent variable = COLUMN1
21
22 Total number of observations = 3
23 Total number of records with missing values = 0
24 Maximum number of iterations = 250
25 Relative Function Convergence has been set to: 1e-008
26 Parameter Convergence has been set to: 1e-008
27
28
29
30 Default Initial (and Specified) Parameter Values
31 Background = 3.49997e-005
32 Slope = 0.000170019
33 Power = 1 Specified
34
35
36 Asymptotic Correlation Matrix of Parameter Estimates
37
38 (*** The model parameter(s) -Power
39 have been estimated at a boundary point, or have been
40 specified by the user,
41 and do not appear in the correlation matrix)
42
43 Background Slope
44
45 Background 1 -0.51
46
47 Slope -0.51 1
48
49
50
51 Parameter Estimates
52
53 Variable Estimate Std. Err.
54 Background 3.16959e-005 1.69176e-005
55 Slope 0.000173022 4.78826e-005
56
57
58
59 Analysis of Deviance Table
60

```

```

1 Model Log(likelihood) Deviance Test DF P-value
2 Full model -317.426
3 Fitted model -317.46 0.0679084 1 0.7944
4 Reduced model -324.664 14.4766 2 0.0007185
5
6 AIC: 638.919
7
8
9 Goodness of Fit
10
11
12 Dose Est._Prob. Expected Observed Size Scaled
13 -----
14 0.0000 0.0000 3.170 3 100000 -0.09526
15 0.3000 0.0001 8.360 9 100000 0.2214
16 1.0000 0.0002 20.470 20 100000 -0.1038
17
18 Chi-square = 0.07 DF = 1 P-value = 0.7930
19
20
21 Benchmark Dose Computation
22
23 Specified effect = 0.0001
24
25 Risk Type = Extra risk
26
27 Confidence level = 0.95
28
29 BMD = 0.577991
30
31 BMDL = 0.390507
32
33

```

```

1 RAVEH_MUT_bap.OUT.txt
2 =====
3 Quantal Linear Model $Revision: 2.2 $ $Date: 2000/03/17 22:27:16 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\RAVEH_MUT_CPCDP.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\RAVEH_MUT_CPCDP.plt
8 Wed Jun 29 12:33:35 2005
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(-slope*dose)]
17
18
19 Dependent variable = COLUMN2
20 Independent variable = COLUMN1
21
22 Total number of observations = 3
23 Total number of records with missing values = 0
24 Maximum number of iterations = 250
25 Relative Function Convergence has been set to: 1e-008
26 Parameter Convergence has been set to: 1e-008
27
28
29
30 Default Initial (and Specified) Parameter Values
31 Background = 7.49999e-006
32 Slope = 6.70027e-005
33 Power = 1 Specified
34
35
36 Asymptotic Correlation Matrix of Parameter Estimates
37
38 (*** The model parameter(s) -Power
39 have been estimated at a boundary point, or have been
40 specified by the user,
41 and do not appear in the correlation matrix)
42
43 Background Slope
44
45 Background 1 -0.38
46
47 Slope -0.38 1
48
49
50
51 Parameter Estimates
52
53 Variable Estimate Std. Err.
54 Background 6.11766e-006 2.23574e-006
55 Slope 6.35766e-005 8.04156e-006
56
57
58
59 Analysis of Deviance Table
60

```

```

1 Model Log(likelihood) Deviance Test DF P-value
2 Full model -1104.33
3 Fitted model -1105.09 1.53413 1 0.2155
4 Reduced model -1141.2 73.7415 2 <.0001
5
6 AIC: 2214.19
7
8
9 Goodness of Fit
10
11
12 Dose Est._Prob. Expected Observed Size Scaled
13 -----
14 0.0000 0.0000 6.118 7 1000000 0.3567
15 0.3000 0.0000 25.190 20 1000000 -1.034
16 1.0000 0.0001 69.692 74 1000000 0.5161
17
18 Chi-square = 1.46 DF = 1 P-value = 0.2264
19
20
21 Benchmark Dose Computation
22
23 Specified effect = 1e-005
24
25 Risk Type = Extra risk
26
27 Confidence level = 0.95
28
29 BMD = 0.157291
30
31 BMDL = 0.12931
32
33

```

```

1 RAVEH_MUT_CPCDP.OUT.txt
2 =====
3 Quantal Linear Model $Revision: 2.2 $ $Date: 2000/03/17 22:27:16 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\RAVEH_MUT_CPCDP.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\RAVEH_MUT_CPCDP.plt
8 Wed Jun 29 12:31:46 2005
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(-slope*dose)]
17
18
19 Dependent variable = COLUMN2
20 Independent variable = COLUMN1
21
22 Total number of observations = 4
23 Total number of records with missing values = 0
24 Maximum number of iterations = 250
25 Relative Function Convergence has been set to: 1e-008
26 Parameter Convergence has been set to: 1e-008
27
28
29
30 Default Initial (and Specified) Parameter Values
31 Background = 1.5e-006
32 Slope = 9.00013e-006
33 Power = 1 Specified
34
35
36 Asymptotic Correlation Matrix of Parameter Estimates
37
38 (*** The model parameter(s) -Power
39 have been estimated at a boundary point, or have been
40 specified by the user,
41 and do not appear in the correlation matrix)
42
43 Background Slope
44
45 Background 1 -0.43
46
47 Slope -0.43 1
48
49
50
51 Parameter Estimates
52
53 Variable Estimate Std. Err.
54 Background 1.26496e-006 1.07098e-006
55 Slope 9.05599e-006 1.68076e-006
56
57
58
59 Analysis of Deviance Table
60

```

```

1 Model Log(likelihood) Deviance Test DF P-value
2 Full model -527.507
3 Fitted model -527.666 0.317201 2 0.8533
4 Reduced model -546.375 37.7352 3 <.0001
5
6 AIC: 1059.33
7
8
9 Goodness of Fit
10
11
12 Dose Est._Prob. Expected Observed Size Scaled
13 -----
14 0.0000 0.0000 1.265 1 1000000 -0.2356
15 0.3000 0.0000 3.982 5 1000000 0.5103
16 1.0000 0.0000 10.321 10 1000000 -0.09989
17 3.0000 0.0000 28.433 28 1000000 -0.08112
18
19 Chi-square = 0.33 DF = 2 P-value = 0.8469
20
21
22 Benchmark Dose Computation
23
24 Specified effect = 1e-005
25
26 Risk Type = Extra risk
27
28 Confidence level = 0.95
29
30 BMD = 1.10425
31
32 BMDL = 0.835597
33
34

```

```

1 SLAGA_MUT_BAA.OUT.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\SLAGA_MUT_BAA.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\SLAGA_MUT_BAA.plt
8
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(
17 -beta1*dose^1)]
18
19 The parameter betas are restricted to be positive
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 3
26 Total number of records with missing values = 0
27 Total number of parameters in model = 2
28 Total number of specified parameters = 0
29 Degree of polynomial = 1
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 7.29666e-005
40 Beta(1) = 3.12233e-006
41 **** WARNING: Completion code = 7. Optimum not found. Trying new starting
42 pont****
43
44 **** WARNING 0: Completion code = 7 trying new start****
45
46 **** WARNING 1: Completion code = -2 trying new start****
47
48 **** WARNING 2: Completion code = -2 trying new start****
49
50 **** WARNING 3: Completion code = -2 trying new start****
51
52 **** WARNING 4: Completion code = 7 trying new start****
53
54 **** WARNING 5: Completion code = -2 trying new start****
55
56 **** WARNING 6: Completion code = -2 trying new start****
57
58 **** WARNING 7: Completion code = -2 trying new start****
59
60 **** WARNING 8: Completion code = -2 trying new start****

```

1  
 2 \*\*\*\* WARNING 9: Completion code = 7 trying new start\*\*\*\*  
 3  
 4 \*\*\*\* WARNING: Completion code = -2. Optimum not found. Trying new starting  
 5 point\*\*\*\*  
 6  
 7 \*\*\*\* WARNING 0: Completion code = -2 trying new start\*\*\*\*  
 8  
 9

10  
 11 Asymptotic Correlation Matrix of Parameter Estimates

|            | Background | Beta(1) |
|------------|------------|---------|
| Background | 1          | -0.63   |
| Beta(1)    | -0.63      | 1       |

12  
 13  
 14  
 15  
 16  
 17  
 18  
 19  
 20  
 21 Parameter Estimates

| Variable   | Estimate     | Std. Err.    |
|------------|--------------|--------------|
| Background | 7.26607e-005 | 0.0023585    |
| Beta(1)    | 3.14129e-006 | 9.25599e-005 |

22  
 23  
 24  
 25  
 26  
 27  
 28  
 29 Analysis of Deviance Table

| Model         | Log(likelihood) | Deviance  | Test DF | P-value |
|---------------|-----------------|-----------|---------|---------|
| Full model    | -365.644        |           |         |         |
| Fitted model  | -365.656        | 0.0243422 | 1       | 0.876   |
| Reduced model | -370.021        | 8.75326   | 2       | 0.01257 |
| AIC:          | 735.312         |           |         |         |

30  
 31  
 32  
 33  
 34  
 35  
 36  
 37  
 38  
 39 Goodness of Fit

| Dose         | Est._Prob. | Expected | Observed | Size             | Chi^2 Res. |
|--------------|------------|----------|----------|------------------|------------|
| i: 1         | 0.0000     | 7.266    | 7        | 100000           | -0.037     |
| i: 2         | 4.4000     | 8.648    | 9        | 100000           | 0.041      |
| i: 3         | 44.0000    | 21.086   | 21       | 100000           | -0.004     |
| Chi-square = | 0.02       | DF = 1   |          | P-value = 0.8758 |            |

40  
 41  
 42  
 43  
 44  
 45  
 46  
 47  
 48  
 49  
 50  
 51  
 52  
 53 Benchmark Dose Computation

54 Specified effect = 0.0001  
 55  
 56 Risk Type = Extra risk  
 57  
 58 Confidence level = 0.95  
 59  
 60

1                    BMD =            31.8356  
2  
3                    BMDL =           19.0163  
4

```

1 SLAGA_MUT_BAP.OUT.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\SLAGA_MUT_BAP.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\SLAGA_MUT_BAP.plt
8 Wed Jun 29 13:01:31 2005
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(
17 -beta1*dose^1-beta2*dose^2)]
18
19 The parameter betas are restricted to be positive
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 4
26 Total number of records with missing values = 0
27 Total number of parameters in model = 3
28 Total number of specified parameters = 0
29 Degree of polynomial = 2
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 0.000214668
40 Beta(1) = 0.00154564
41 Beta(2) = 0.00022152
42
43
44 Asymptotic Correlation Matrix of Parameter Estimates
45
46 (*** The model parameter(s) -Background
47 have been estimated at a boundary point, or have been
48 specified by the user,
49 and do not appear in the correlation matrix)
50
51 Beta(1) Beta(2)
52
53 Beta(1) 1 -0.98
54
55 Beta(2) -0.98 1
56
57
58
59 Parameter Estimates
60

```

| Variable   | Estimate     | Std. Err.  |
|------------|--------------|------------|
| Background | 0            | NA         |
| Beta(1)    | 0.00207246   | 0.0109511  |
| Beta(2)    | 9.74689e-005 | 0.00286413 |

NA - Indicates that this parameter has hit a bound implied by some inequality constraint and thus has no standard error.

Warning: Likelihood for the fitted model larger than the Likelihood for the full model.  
 Error in computing chi-square; returning 2

Analysis of Deviance Table

| Model         | Log(likelihood) | Deviance | Test DF | P-value |
|---------------|-----------------|----------|---------|---------|
| Full model    | -823.498        |          |         |         |
| Fitted model  | -816.691        | -13.6145 | 2       | 2       |
| Reduced model | -907.084        | 167.172  | 3       | <.0001  |

AIC: 1637.38

Goodness of Fit

| Dose | Est._Prob. | Expected | Observed | Size              | Chi^2 Res. |
|------|------------|----------|----------|-------------------|------------|
| i: 1 | 0.0000     | 0.0000   | 1        | 1000070000000.000 |            |
| i: 2 | 0.4000     | 8.442    | 11       | 10000             | 0.303      |
| i: 3 | 1.3000     | 28.548   | 25       | 10000             | -0.125     |
| i: 4 | 4.0000     | 98.010   | 99       | 10000             | 0.010      |

Chi-square = 1.23    DF = 2    P-value = 0.5412

Benchmark Dose Computation

Specified effect = 0.0001  
 Risk Type = Extra risk  
 Confidence level = 0.95  
 BMD = 0.0481451  
 BMDL = 0.0370516

1 **D.7. MALIGNANT TRANSFORMATION**

2 CASTO\_MT\_BAP.OUT.txt

3 =====  
4 Multistage Model. \$Revision: 2.1 \$ \$Date: 2000/08/21 03:38:21 \$  
5 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH  
6 RPS\MODELING\CASTO\_MT\_BAP.(d)  
7 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY  
8 DOCUMENTS\PAH RPS\MODELING\CASTO\_MT\_BAP.plt  
9 Thu Jun 23 13:30:59 2005  
10 =====

11 BMD5 MODEL RUN  
12 ~~~~~

13  
14  
15 The form of the probability function is:

16  
17  $P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\text{beta}1 * \text{dose}^1)]$   
18

19  
20 The parameter betas are restricted to be positive  
21

22  
23 Dependent variable = COLUMN2  
24 Independent variable = COLUMN1  
25

26 Total number of observations = 3  
27 Total number of records with missing values = 0  
28 Total number of parameters in model = 2  
29 Total number of specified parameters = 0  
30 Degree of polynomial = 1  
31

32  
33 Maximum number of iterations = 250  
34 Relative Function Convergence has been set to: 1e-008  
35 Parameter Convergence has been set to: 1e-008  
36  
37  
38

39 Default Initial Parameter Values  
40 Background = 1.02144e-005  
41 Beta(1) = 7.98743e-005  
42  
43

44 Asymptotic Correlation Matrix of Parameter Estimates

45  
46 ( \*\*\* The model parameter(s) -Background  
47 have been estimated at a boundary point, or have been  
48 specified by the user,  
49 and do not appear in the correlation matrix )  
50

51 Beta(1)  
52  
53 Beta(1) 1  
54  
55

56  
57 Parameter Estimates

58  
59 Variable Estimate Std. Err.

1 Background 0 NA  
 2 Beta(1) 9.62612e-005 0.00234809  
 3  
 4 NA - Indicates that this parameter has hit a bound  
 5 implied by some inequality constraint and thus  
 6 has no standard error.  
 7  
 8  
 9

10 Analysis of Deviance Table

| 11 Model         | Log(likelihood) | Deviance | Test DF | P-value   |
|------------------|-----------------|----------|---------|-----------|
| 12 Full model    | -185.57         |          |         |           |
| 14 Fitted model  | -186.065        | 0.988828 | 2       | 0.6099    |
| 15 Reduced model | -192.98         | 14.82    | 2       | 0.0006052 |
| 17 AIC:          | 374.13          |          |         |           |

19 Goodness of Fit

| 21 Dose         | Est._Prob. | Expected | Observed | Size             | Chi^2 Res. |
|-----------------|------------|----------|----------|------------------|------------|
| 24 i: 1         | 0.0000     | 0.000    | 0        | 100000           | 0.000      |
| 26 i: 2         | 0.6200     | 5.968    | 8        | 100000           | 0.340      |
| 28 i: 3         | 1.2500     | 12.032   | 10       | 100000           | -0.169     |
| 31 Chi-square = | 1.04       | DF = 2   |          | P-value = 0.5960 |            |

33 Benchmark Dose Computation

34 Specified effect = 1e-005  
 35  
 36 Risk Type = Extra risk  
 37  
 38 Confidence level = 0.95  
 39  
 40 BMD = 0.103885  
 41  
 42

43  
 44 \*\*\*\* WARNING: Completion code = -5. Optimum not found. Trying new starting  
 45 point\*\*\*\*  
 46  
 47 \*\*\*\* WARNING 0: Completion code = -5 trying new start\*\*\*\*  
 48  
 49 \*\*\*\* WARNING 1: Completion code = -5 trying new start\*\*\*\*  
 50  
 51 \*\*\*\* WARNING 2: Completion code = -5 trying new start\*\*\*\*  
 52  
 53 \*\*\*\* WARNING 3: Completion code = -5 trying new start\*\*\*\*  
 54  
 55 \*\*\*\* WARNING 4: Completion code = -5 trying new start\*\*\*\*  
 56  
 57 \*\*\*\* WARNING 5: Completion code = -5 trying new start\*\*\*\*  
 58  
 59 \*\*\*\* WARNING 6: Completion code = -5 trying new start\*\*\*\*  
 60

```
1 **** WARNING 7: Completion code = -5 trying new start****
2
3 **** WARNING 8: Completion code = -5 trying new start****
4
5 **** WARNING 9: Completion code = -5 trying new start****
6
7 **** WARNING: Completion code = -5. Optimum not found. Trying new starting
8 point****
9
10 BMDL = 0.0721753
11
```

```

1 CASTO_MT_DBAHA.OUT.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\CASTO_MT_DBAHA.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\CASTO_MT_DBAHA.plt
8 Thu Jun 23 13:32:00 2005
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(
17 -beta1*dose^1)]
18
19 The parameter betas are restricted to be positive
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 3
26 Total number of records with missing values = 0
27 Total number of parameters in model = 2
28 Total number of specified parameters = 0
29 Degree of polynomial = 1
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 6.92924e-008
40 Beta(1) = 3.99789e-006
41 **** WARNING: Completion code = -2. Optimum not found. Trying new starting
42 pont****
43
44 **** WARNING 0: Completion code = -2 trying new start****
45
46 **** WARNING 1: Completion code = -2 trying new start****
47
48 **** WARNING 2: Completion code = -2 trying new start****
49
50 **** WARNING 3: Completion code = -2 trying new start****
51
52 **** WARNING 4: Completion code = -2 trying new start****
53
54 **** WARNING 5: Completion code = -2 trying new start****
55
56 **** WARNING 6: Completion code = -2 trying new start****
57
58 **** WARNING 7: Completion code = -2 trying new start****
59
60 **** WARNING 8: Completion code = -2 trying new start****

```

1  
 2 \*\*\*\* WARNING 9: Completion code = -2 trying new start\*\*\*\*  
 3  
 4 \*\*\*\* WARNING: Completion code = -2. Optimum not found. Trying new starting  
 5 point\*\*\*\*  
 6  
 7  
 8

9 Asymptotic Correlation Matrix of Parameter Estimates

10  
 11 ( \*\*\* The model parameter(s) -Background  
 12 have been estimated at a boundary point, or have been  
 13 specified by the user,  
 14 and do not appear in the correlation matrix )  
 15

16 Beta(1)  
 17  
 18 Beta(1) 1  
 19

20  
 21  
 22 Parameter Estimates

23  
 24 Variable Estimate Std. Err.  
 25 Background 0 NA  
 26 Beta(1) 4.05407e-006 0.000361631  
 27

28 NA - Indicates that this parameter has hit a bound  
 29 implied by some inequality constraint and thus  
 30 has no standard error.  
 31  
 32  
 33

34 Analysis of Deviance Table

35  
 36 Model Log(likelihood) Deviance Test DF P-value  
 37 Full model -191.16  
 38 Fitted model -191.162 0.00552866 2 0.9972  
 39 Reduced model -198.091 13.863 2 0.0009765  
 40

41 AIC: 384.325  
 42  
 43

44 Goodness of Fit

45  
 46 Dose Est.\_Prob. Expected Observed Size Chi^2 Res.  
 47 -----  
 48 i: 1  
 49 0.0000 0.0000 0.000 0 1000000 0.000  
 50 i: 2  
 51 1.2000 0.0000 4.865 5 1000000 0.028  
 52 i: 3  
 53 2.5000 0.0000 10.135 10 1000000 -0.013  
 54  
 55 Chi-square = 0.01 DF = 2 P-value = 0.9972  
 56  
 57

58 Benchmark Dose Computation

59 Specified effect = 1e-005  
 60

1  
2 Risk Type = Extra risk  
3  
4 Confidence level = 0.95  
5  
6 BMD = 2.46667  
7  
8 \*\*\*\* WARNING: Completion code = -5. Optimum not found. Trying new starting  
9 point\*\*\*\*  
10  
11 \*\*\*\* WARNING 0: Completion code = -1 trying new start\*\*\*\*  
12  
13 \*\*\*\* WARNING 1: Completion code = -1 trying new start\*\*\*\*  
14  
15 \*\*\*\* WARNING 2: Completion code = -1 trying new start\*\*\*\*  
16  
17 \*\*\*\* WARNING 3: Completion code = -1 trying new start\*\*\*\*  
18  
19 \*\*\*\* WARNING 4: Completion code = -1 trying new start\*\*\*\*  
20  
21 \*\*\*\* WARNING 5: Completion code = -1 trying new start\*\*\*\*  
22  
23 \*\*\*\* WARNING 6: Completion code = -1 trying new start\*\*\*\*  
24  
25 \*\*\*\* WARNING 7: Completion code = -1 trying new start\*\*\*\*  
26  
27 \*\*\*\* WARNING 8: Completion code = -1 trying new start\*\*\*\*  
28  
29 \*\*\*\* WARNING 9: Completion code = -1 trying new start\*\*\*\*  
30  
31 \*\*\*\* WARNING: Completion code = -1. Optimum not found. Trying new starting  
32 point\*\*\*\*  
33  
34 BMDL = 1.65901  
35

```

1 EMURA_MT_Baa.OUT.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\EMURA_MT_BBF.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\EMURA_MT_BBF.plt
8 Thu Jun 23 15:46:49 2005
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(
17 -beta1*dose^1-beta2*dose^2-beta3*dose^3-beta4*dose^4)]
18
19 The parameter betas are restricted to be positive
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 6
26 Total number of records with missing values = 0
27 Total number of parameters in model = 5
28 Total number of specified parameters = 0
29 Degree of polynomial = 4
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 6.24839e-005
40 Beta(1) = 0.000973789
41 Beta(2) = 0
42 Beta(3) = 0
43 Beta(4) = 0
44
45
46 Asymptotic Correlation Matrix of Parameter Estimates
47
48 (*** The model parameter(s) -Background -Beta(2) -Beta(3)
49 -Beta(4)
50 have been estimated at a boundary point, or have been
51 specified by the user,
52 and do not appear in the correlation matrix)
53
54 Beta(1)
55
56 Beta(1) 1
57
58
59
60 Parameter Estimates

```

| Variable   | Estimate   | Std. Err. |
|------------|------------|-----------|
| Background | 0          | NA        |
| Beta(1)    | 0.00117377 | 0.0091424 |
| Beta(2)    | 0          | NA        |
| Beta(3)    | 0          | NA        |
| Beta(4)    | 0          | NA        |

NA - Indicates that this parameter has hit a bound implied by some inequality constraint and thus has no standard error.

Analysis of Deviance Table

| Model         | Log(likelihood) | Deviance | Test DF | P-value  |
|---------------|-----------------|----------|---------|----------|
| Full model    | -184.252        |          |         |          |
| Fitted model  | -185.671        | 2.83903  | 5       | 0.7248   |
| Reduced model | -196.039        | 23.575   | 5       | 0.000262 |
| AIC:          | 373.342         |          |         |          |

Goodness of Fit

| Dose | Est._Prob. | Expected | Observed | Size  | Chi^2 Res. |
|------|------------|----------|----------|-------|------------|
| i: 1 | 0.0000     | 0.0000   | 0        | 10000 | 0.000      |
| i: 2 | 0.0250     | 0.0000   | 0        | 10000 | -1.000     |
| i: 3 | 0.1000     | 0.0001   | 3        | 10000 | 1.556      |
| i: 4 | 0.2500     | 0.0003   | 3        | 10000 | 0.023      |
| i: 5 | 0.5000     | 0.0006   | 6        | 10000 | 0.023      |
| i: 6 | 1.0000     | 0.0012   | 10       | 10000 | -0.148     |

Chi-square = 3.40      DF = 5      P-value = 0.6392

Benchmark Dose Computation

Specified effect = 0.001  
 Risk Type = Extra risk  
 Confidence level = 0.95  
 BMD = 0.85238  
 BMDL = 0.611981  
 EMURA\_MT\_BBF.OUT.txt

=====  
 Multistage Model. \$Revision: 2.1 \$ \$Date: 2000/08/21 03:38:21 \$  
 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH  
 RPS\MODELING\EMURA\_MT\_BBF.(d)

1 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY  
2 DOCUMENTS\PAH RPS\MODELING\EMURA\_MT\_BBF.plt

3 Thu Jun 23 15:37:20 2005

4 =====  
5  
6 BMDS MODEL RUN  
7 ~~~~~

8  
9 The form of the probability function is:

10  
11  $P[\text{response}] = \text{background} + (1 - \text{background}) * [1 - \text{EXP}(\text{-beta1} * \text{dose}^1 - \text{beta2} * \text{dose}^2 - \text{beta3} * \text{dose}^3 - \text{beta4} * \text{dose}^4)]$   
12

13  
14 The parameter betas are restricted to be positive

15  
16  
17 Dependent variable = COLUMN2  
18 Independent variable = COLUMN1

19  
20 Total number of observations = 6  
21 Total number of records with missing values = 0  
22 Total number of parameters in model = 5  
23 Total number of specified parameters = 0  
24 Degree of polynomial = 4

25  
26  
27 Maximum number of iterations = 250  
28 Relative Function Convergence has been set to: 1e-008  
29 Parameter Convergence has been set to: 1e-008

30  
31  
32  
33 Default Initial Parameter Values

34 Background = 6.48647e-005  
35 Beta(1) = 0.00111706  
36 Beta(2) = 0  
37 Beta(3) = 1.51794e-005  
38 Beta(4) = 0

39  
40  
41 Asymptotic Correlation Matrix of Parameter Estimates

42  
43 ( \*\*\* The model parameter(s) -Background -Beta(2) -Beta(3)  
44 -Beta(4)  
45 have been estimated at a boundary point, or have been  
46 specified by the user,  
47 and do not appear in the correlation matrix )

48  
49 Beta(1)  
50  
51 Beta(1) 1

52  
53  
54  
55 Parameter Estimates

| 56 Variable   | 57 Estimate | 58 Std. Err. |
|---------------|-------------|--------------|
| 58 Background | 0           | NA           |
| 59 Beta(1)    | 0.00133391  | 0.00909075   |
| 60 Beta(2)    | 0           | NA           |

1           Beta(3)                           0                   NA  
 2           Beta(4)                           0                   NA  
 3  
 4 NA - Indicates that this parameter has hit a bound  
 5 implied by some inequality constraint and thus  
 6 has no standard error.  
 7  
 8  
 9

10                                           Analysis of Deviance Table

| Model         | Log(likelihood) | Deviance | Test DF | P-value |
|---------------|-----------------|----------|---------|---------|
| Full model    | -205.838        |          |         |         |
| Fitted model  | -208.019        | 4.36272  | 5       | 0.4985  |
| Reduced model | -219.575        | 27.4752  | 5       | <.0001  |
| AIC:          | 418.038         |          |         |         |

19                                           Goodness of Fit

| Dose         | Est._Prob. | Expected | Observed  | Size   | Chi^2 Res. |
|--------------|------------|----------|-----------|--------|------------|
| -----        |            |          |           |        |            |
| i: 1         | 0.0000     | 0.0000   | 0         | 10000  | 0.000      |
| i: 2         | 0.0250     | 0.333    | 0         | 10000  | -1.000     |
| i: 3         | 0.1000     | 1.334    | 4         | 10000  | 1.999      |
| i: 4         | 0.2500     | 3.334    | 3         | 10000  | -0.100     |
| i: 5         | 0.5000     | 6.667    | 6         | 10000  | -0.100     |
| i: 6         | 1.0000     | 13.330   | 12        | 10000  | -0.100     |
| Chi-square = | 5.90       | DF = 5   | P-value = | 0.3164 |            |

39                                           Benchmark Dose Computation

40 Specified effect =                   0.001  
 41  
 42 Risk Type                   =           Extra risk  
 43  
 44 Confidence level =                   0.95  
 45  
 46                   BMD =               0.750052  
 47                   BMDL =              0.54909  
 48  
 49  
 50

```

1 EMURA_MT_I_BAP.OUT.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\EMURA_MT_I_BAP.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\EMURA_MT_I_BAP.plt
8 Thu Jun 23 15:28:17 2005
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(
17 -beta1*dose^1-beta2*dose^2-beta3*dose^3)]
18
19 The parameter betas are restricted to be positive
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 5
26 Total number of records with missing values = 0
27 Total number of parameters in model = 4
28 Total number of specified parameters = 0
29 Degree of polynomial = 3
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 6.51885e-005
40 Beta(1) = 0.021934
41 Beta(2) = 0
42 Beta(3) = 0
43
44
45 Asymptotic Correlation Matrix of Parameter Estimates
46
47 (*** The model parameter(s) -Background -Beta(2) -Beta(3)
48 have been estimated at a boundary point, or have been
49 specified by the user,
50 and do not appear in the correlation matrix)
51
52 Beta(1)
53
54 Beta(1) 1
55
56
57
58 Parameter Estimates
59
60 Variable Estimate Std. Err.

```

```

1 Background 0 NA
2 Beta(1) 0.0227293 0.0369378
3 Beta(2) 0 NA
4 Beta(3) 0 NA

```

```

5
6 NA - Indicates that this parameter has hit a bound
7 implied by some inequality constraint and thus
8 has no standard error.
9

```

```

10
11
12 Analysis of Deviance Table
13

```

| Model         | Log(likelihood) | Deviance | Test DF | P-value |
|---------------|-----------------|----------|---------|---------|
| Full model    | -614.919        |          |         |         |
| Fitted model  | -618.123        | 6.40862  | 4       | 0.1706  |
| Reduced model | -677.621        | 125.404  | 4       | <.0001  |
| AIC:          | 1238.25         |          |         |         |

```

21
22 Goodness of Fit
23

```

| Dose         | Est._Prob. | Expected | Observed  | Size   | Chi^2 Res. |
|--------------|------------|----------|-----------|--------|------------|
| i: 1         | 0.0000     | 0.000    | 0         | 10000  | 0.000      |
| i: 2         | 0.0100     | 2.273    | 0         | 10000  | -1.000     |
| i: 3         | 0.0500     | 11.358   | 11        | 10000  | -0.032     |
| i: 4         | 0.1000     | 22.703   | 29        | 10000  | 0.278      |
| i: 5         | 0.2500     | 56.662   | 53        | 10000  | -0.065     |
| Chi-square = | 4.27       | DF = 4   | P-value = | 0.3703 |            |

```

36
37
38
39
40 Benchmark Dose Computation
41

```

```

42 Specified effect = 0.001
43
44 Risk Type = Extra risk
45
46 Confidence level = 0.95
47
48 BMD = 0.0440182
49
50 BMDL = 0.037291
51

```

```

1 EMURA_MT_II_BAP.OUT.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\EMURA_MT_II_BAP.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\EMURA_MT_II_BAP.plt
8 Thu Jun 23 15:54:16 2005
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(
17 -beta1*dose^1-beta2*dose^2-beta3*dose^3)]
18
19 The parameter betas are restricted to be positive
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 5
26 Total number of records with missing values = 0
27 Total number of parameters in model = 4
28 Total number of specified parameters = 0
29 Degree of polynomial = 3
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 0.0002687
40 Beta(1) = 0.0184676
41 Beta(2) = 0
42 Beta(3) = 0
43
44
45 Asymptotic Correlation Matrix of Parameter Estimates
46
47 (*** The model parameter(s) -Background -Beta(2) -Beta(3)
48 have been estimated at a boundary point, or have been
49 specified by the user,
50 and do not appear in the correlation matrix)
51
52 Beta(1)
53
54 Beta(1) 1
55
56
57
58 Parameter Estimates
59
60 Variable Estimate Std. Err.

```

```

1 Background 0 NA
2 Beta(1) 0.021747 0.0381969
3 Beta(2) 0 NA
4 Beta(3) 0 NA

```

```

5
6 NA - Indicates that this parameter has hit a bound
7 implied by some inequality constraint and thus
8 has no standard error.
9

```

```

10
11
12 Analysis of Deviance Table

```

| Model         | Log(likelihood) | Deviance | Test DF | P-value |
|---------------|-----------------|----------|---------|---------|
| Full model    | -606.226        |          |         |         |
| Fitted model  | -608.64         | 4.82649  | 4       | 0.3056  |
| Reduced model | -652.392        | 92.3321  | 4       | <.0001  |
| AIC:          | 1219.28         |          |         |         |

```

21
22 Goodness of Fit

```

| Dose         | Est._Prob. | Expected | Observed  | Size   | Chi^2 Res. |
|--------------|------------|----------|-----------|--------|------------|
| i: 1         | 0.0000     | 0.000    | 0         | 10000  | 0.000      |
| i: 2         | 0.0100     | 2.174    | 4         | 10000  | 0.840      |
| i: 3         | 0.0500     | 10.868   | 10        | 10000  | -0.080     |
| i: 4         | 0.1000     | 21.723   | 29        | 10000  | 0.336      |
| i: 5         | 0.2500     | 54.220   | 46        | 10000  | -0.152     |
| Chi-square = | 5.30       | DF = 4   | P-value = | 0.2581 |            |

```

39
40 Benchmark Dose Computation

```

```

41
42 Specified effect = 0.001
43
44 Risk Type = Extra risk
45
46 Confidence level = 0.95
47
48 BMD = 0.0460064
49
50 BMDL = 0.0388361
51

```

```

1 EMURA_MT_IP.OUT.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\EMURA_MT_IP.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\EMURA_MT_IP.plt
8
9 Thu Jun 23 15:50:44 2005
10 =====
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(
17 -beta1*dose^1-beta2*dose^2-beta3*dose^3-beta4*dose^4)]
18
19 The parameter betas are restricted to be positive
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 6
26 Total number of records with missing values = 0
27 Total number of parameters in model = 5
28 Total number of specified parameters = 0
29 Degree of polynomial = 4
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 7.12074e-005
40 Beta(1) = 0.00099924
41 Beta(2) = 0
42 Beta(3) = 0
43 Beta(4) = 0
44
45
46 Asymptotic Correlation Matrix of Parameter Estimates
47
48 (*** The model parameter(s) -Background -Beta(2) -Beta(3)
49 -Beta(4)
50 have been estimated at a boundary point, or have been
51 specified by the user,
52 and do not appear in the correlation matrix)
53
54 Beta(1)
55
56 Beta(1) 1
57
58
59
60 Parameter Estimates

```

| Variable   | Estimate   | Std. Err.  |
|------------|------------|------------|
| Background | 0          | NA         |
| Beta(1)    | 0.00122714 | 0.00918598 |
| Beta(2)    | 0          | NA         |
| Beta(3)    | 0          | NA         |
| Beta(4)    | 0          | NA         |

NA - Indicates that this parameter has hit a bound implied by some inequality constraint and thus has no standard error.

Analysis of Deviance Table

| Model         | Log(likelihood) | Deviance | Test DF | P-value   |
|---------------|-----------------|----------|---------|-----------|
| Full model    | -191.591        |          |         |           |
| Fitted model  | -193.089        | 2.99724  | 5       | 0.7004    |
| Reduced model | -203.928        | 24.6739  | 5       | 0.0001611 |
| AIC:          | 388.178         |          |         |           |

Goodness of Fit

| Dose | Est._Prob. | Expected | Observed | Size  | Chi^2 Res. |
|------|------------|----------|----------|-------|------------|
| i: 1 | 0.0000     | 0.0000   | 0        | 10000 | 0.000      |
| i: 2 | 0.0250     | 0.307    | 0        | 10000 | -1.000     |
| i: 3 | 0.1000     | 1.227    | 3        | 10000 | 1.445      |
| i: 4 | 0.2500     | 3.067    | 3        | 10000 | -0.022     |
| i: 5 | 0.5000     | 6.134    | 7        | 10000 | 0.141      |
| i: 6 | 1.0000     | 12.264   | 10       | 10000 | -0.185     |

Chi-square = 3.41      DF = 5      P-value = 0.6369

Benchmark Dose Computation

|                    |            |
|--------------------|------------|
| Specified effect = | 0.001      |
| Risk Type =        | Extra risk |
| Confidence level = | 0.95       |
| BMD =              | 0.815309   |
| BMDL =             | 0.589412   |

```

1 LUBET_MT_BAP.OUT.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\LUBET_MT_BAP.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\LUBET_MT_BAP.plt
8 Thu Jun 23 16:11:06 2005
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(
17 -beta1*dose^1-beta2*dose^2)]
18
19 The parameter betas are restricted to be positive
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 4
26 Total number of records with missing values = 0
27 Total number of parameters in model = 3
28 Total number of specified parameters = 0
29 Degree of polynomial = 2
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 0.0617408
40 Beta(1) = 0.0378355
41 Beta(2) = 0
42
43
44 Asymptotic Correlation Matrix of Parameter Estimates
45
46 (*** The model parameter(s) -Background -Beta(2)
47 have been estimated at a boundary point, or have been
48 specified by the user,
49 and do not appear in the correlation matrix)
50
51 Beta(1)
52
53 Beta(1) 1
54
55
56
57 Parameter Estimates
58
59 Variable Estimate Std. Err.
60 Background 0 NA

```

1           Beta(1)                   0.056828                   0.0340172  
 2           Beta(2)                   0                            NA  
 3  
 4 NA - Indicates that this parameter has hit a bound  
 5 implied by some inequality constraint and thus  
 6 has no standard error.  
 7  
 8  
 9

10                                   Analysis of Deviance Table

| Model         | Log(likelihood) | Deviance | Test DF | P-value |
|---------------|-----------------|----------|---------|---------|
| Full model    | -21.9204        |          |         |         |
| Fitted model  | -22.8416        | 1.84243  | 3       | 0.6057  |
| Reduced model | -27.0337        | 10.2266  | 3       | 0.01674 |
| AIC:          | 47.6832         |          |         |         |

19                                   Goodness of Fit

| Dose         | Est._Prob. | Expected | Observed | Size      | Chi^2 Res. |
|--------------|------------|----------|----------|-----------|------------|
| i: 1         | 0.0000     | 0.0000   | 0        | 15        | 0.000      |
| i: 2         | 1.0000     | 0.0552   | 1        | 15        | 0.219      |
| i: 3         | 3.0000     | 0.1567   | 4        | 15        | 0.832      |
| i: 4         | 10.0000    | 0.4335   | 5        | 15        | -0.408     |
| Chi-square = | 2.02       | DF = 3   |          | P-value = | 0.5679     |

36                                   Benchmark Dose Computation

37  
 38 Specified effect =                   0.1  
 39  
 40 Risk Type                   =           Extra risk  
 41  
 42 Confidence level =                   0.95  
 43  
 44                   BMD =               1.85403  
 45  
 46                   BMDL =              1.14367  
 47

```

1 LUBET_MT_BeP.OUT.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\LUBET_MT_BAP.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\LUBET_MT_BAP.plt
8 Thu Jun 23 16:14:09 2005
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(
17 -beta1*dose^1-beta2*dose^2)]
18
19 The parameter betas are restricted to be positive
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 4
26 Total number of records with missing values = 0
27 Total number of parameters in model = 3
28 Total number of specified parameters = 0
29 Degree of polynomial = 2
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 0
40 Beta(1) = 0.000632445
41 Beta(2) = 5.70088e-005
42
43
44 Asymptotic Correlation Matrix of Parameter Estimates
45
46 (*** The model parameter(s) -Background -Beta(1)
47 have been estimated at a boundary point, or have been
48 specified by the user,
49 and do not appear in the correlation matrix)
50
51 Beta(2)
52
53 Beta(2) 1
54
55
56
57 Parameter Estimates
58
59 Variable Estimate Std. Err.
60 Background 0 NA

```

1           Beta(1)                           0                           NA  
 2           Beta(2)                   6.35618e-005                   3.53139e-005  
 3  
 4 NA - Indicates that this parameter has hit a bound  
 5 implied by some inequality constraint and thus  
 6 has no standard error.  
 7  
 8  
 9

10                                           Analysis of Deviance Table

| Model         | Log(likelihood) | Deviance | Test DF | P-value   |
|---------------|-----------------|----------|---------|-----------|
| Full model    | -14.0378        |          |         |           |
| Fitted model  | -14.1501        | 0.224517 | 3       | 0.9735    |
| Reduced model | -23.5605        | 19.0453  | 3       | 0.0002676 |
| AIC:          | 30.3001         |          |         |           |

19                                           Goodness of Fit

| Dose         | Est._Prob. | Expected | Observed         | Size | Chi^2 Res. |
|--------------|------------|----------|------------------|------|------------|
| -----        |            |          |                  |      |            |
| i: 1         | 0.0000     | 0.0000   | 0                | 15   | 0.000      |
| i: 2         | 10.0000    | 0.0063   | 0                | 15   | -1.006     |
| i: 3         | 30.0000    | 0.0556   | 1                | 15   | 0.211      |
| i: 4         | 100.0000   | 0.4704   | 7                | 15   | -0.015     |
| Chi-square = | 0.13       | DF = 3   | P-value = 0.9878 |      |            |

36                                           Benchmark Dose Computation

37  
 38 Specified effect =                   0.1  
 39  
 40 Risk Type                   =           Extra risk  
 41  
 42 Confidence level =                   0.95  
 43  
 44                   BMD =               40.7137  
 45  
 46                   BMDL =              18.2541  
 47

```

1 MOHAPATRA_MT_BJAC.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS_PAH
5 RPS\MODELING\MOHAPATRA_MT_BJAC.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS_PAH RPS\MODELING\MOHAPATRA_MT_BJAC.plt
8 Thu Feb 08 10:11:06 2007
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16
$$P[\text{response}] = \text{background} + (1 - \text{background}) * [1 - \text{EXP}(-\beta_1 * \text{dose}^1 - \beta_2 * \text{dose}^2 - \beta_3 * \text{dose}^3 - \beta_4 * \text{dose}^4)]$$

17
18 The parameter betas are restricted to be positive
19
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 6
26 Total number of records with missing values = 0
27 Total number of parameters in model = 5
28 Total number of specified parameters = 0
29 Degree of polynomial = 4
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 0
40 Beta(1) = 0
41 Beta(2) = 0
42 Beta(3) = 0
43 Beta(4) = 6.31048e+018
44
45
46 Asymptotic Correlation Matrix of Parameter Estimates
47
48 (*** The model parameter(s) -Background -Beta(2) -Beta(3)
49 have been estimated at a boundary point, or have been
50 specified by the user,
51 and do not appear in the correlation matrix)
52
53 Beta(1) Beta(4)
54
55 Beta(1) 1 -0.73
56
57 Beta(4) -0.73 1
58
59
60

```

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57

Parameter Estimates

| Variable   | Estimate | Std. Err. |
|------------|----------|-----------|
| Background | 0        | NA        |
| Beta(1)    | 2.44509  | 0.568863  |
| Beta(2)    | 0        | NA        |
| Beta(3)    | 0        | NA        |
| Beta(4)    | 0.332129 | 0.778407  |

NA - Indicates that this parameter has hit a bound implied by some inequality constraint and thus has no standard error.

Analysis of Deviance Table

| Model         | Log(likelihood) | Deviance | Test DF | P-value |
|---------------|-----------------|----------|---------|---------|
| Full model    | -64.5493        |          |         |         |
| Fitted model  | -64.8387        | 0.578751 | 4       | 0.9654  |
| Reduced model | -198.931        | 268.764  | 5       | <.0001  |

AIC: 133.677

Goodness of Fit

| Dose | Est._Prob. | Expected | Observed | Size | Chi^2 Res. |
|------|------------|----------|----------|------|------------|
| i: 1 | 0.0000     | 0.0000   | 0        | 48   | 0.000      |
| i: 2 | 0.0100     | 0.0242   | 2        | 48   | 0.743      |
| i: 3 | 0.0500     | 0.1151   | 5        | 48   | -0.107     |
| i: 4 | 0.5000     | 0.7116   | 34       | 48   | -0.016     |
| i: 5 | 1.0000     | 0.9378   | 45       | 48   | -0.005     |
| i: 6 | 2.0000     | 1.0000   | 47.998   | 48   | 1.000      |

Chi-square = 0.68    DF = 4    P-value = 0.9532

Benchmark Dose Computation

Specified effect = 0.92  
Risk Type = Extra risk  
Confidence level = 0.95  
BMD = 0.930952  
BMDL = 0.766826

```

1 MOHAPATRA_MT_BLAC.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS_PAH
5 RPS\MODELING\MOHAPATRA_MT_BLAC.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS_PAH RPS\MODELING\MOHAPATRA_MT_BLAC.plt
8 Thu Feb 08 10:13:14 2007
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16
$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\beta_1 * \text{dose}^1 - \beta_2 * \text{dose}^2 - \beta_3 * \text{dose}^3 - \beta_4 * \text{dose}^4)]$$

17
18 The parameter betas are restricted to be positive
19
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 6
26 Total number of records with missing values = 0
27 Total number of parameters in model = 5
28 Total number of specified parameters = 0
29 Degree of polynomial = 4
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 0.0997842
40 Beta(1) = 0.189801
41 Beta(2) = 0
42 Beta(3) = 0
43 Beta(4) = 0
44
45
46 Asymptotic Correlation Matrix of Parameter Estimates
47
48 (*** The model parameter(s) -Background -Beta(2) -Beta(3)
49 -Beta(4)
50 have been estimated at a boundary point, or have been
51 specified by the user,
52 and do not appear in the correlation matrix)
53
54 Beta(1)
55
56 Beta(1) 1
57
58
59
60 Parameter Estimates

```

| Variable   | Estimate | Std. Err. |
|------------|----------|-----------|
| Background | 0        | NA        |
| Beta(1)    | 0.237265 | 0.0278061 |
| Beta(2)    | 0        | NA        |
| Beta(3)    | 0        | NA        |
| Beta(4)    | 0        | NA        |

NA - Indicates that this parameter has hit a bound implied by some inequality constraint and thus has no standard error.

Analysis of Deviance Table

| Model         | Log(likelihood) | Deviance | Test DF | P-value |
|---------------|-----------------|----------|---------|---------|
| Full model    | -159.727        |          |         |         |
| Fitted model  | -161.509        | 3.56545  | 5       | 0.6135  |
| Reduced model | -243.072        | 166.691  | 5       | <.0001  |
| AIC:          | 325.019         |          |         |         |

Goodness of Fit

| Dose | Est._Prob. | Expected | Observed | Size | Chi^2 Res. |
|------|------------|----------|----------|------|------------|
| i: 1 | 0.0000     | 0.0000   | 0        | 60   | 0.000      |
| i: 2 | 0.5000     | 6.712    | 8        | 60   | 0.216      |
| i: 3 | 1.0000     | 12.673   | 14       | 60   | 0.133      |
| i: 4 | 2.5000     | 26.845   | 31       | 60   | 0.280      |
| i: 5 | 5.0000     | 41.679   | 42       | 60   | 0.025      |
| i: 6 | 10.0000    | 54.406   | 51       | 60   | -0.671     |

Chi-square = 3.91      DF = 5      P-value = 0.5620

Benchmark Dose Computation

|                    |            |
|--------------------|------------|
| Specified effect = | 0.83       |
| Risk Type =        | Extra risk |
| Confidence level = | 0.95       |
| BMD =              | 7.46828    |
| BMDL =             | 6.45083    |

```

1 MOHAPATRA_MT_BEAC.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS_PAH
5 RPS\MODELING\MOHAPATRA_MT_BEAC.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS_PAH RPS\MODELING\MOHAPATRA_MT_BEAC.plt
8 Fri Feb 09 10:49:12 2007
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16
$$P[\text{response}] = \text{background} + (1-\text{background}) * [1 - \text{EXP}(-\beta_1 * \text{dose}^1 - \beta_2 * \text{dose}^2 - \beta_3 * \text{dose}^3 - \beta_4 * \text{dose}^4)]$$

17
18 The parameter betas are restricted to be positive
19
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 6
26 Total number of records with missing values = 0
27 Total number of parameters in model = 5
28 Total number of specified parameters = 0
29 Degree of polynomial = 4
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 0.0946116
40 Beta(1) = 0.082434
41 Beta(2) = 0
42 Beta(3) = 0
43 Beta(4) = 0
44
45
46 Asymptotic Correlation Matrix of Parameter Estimates
47
48 (*** The model parameter(s) -Beta(2) -Beta(3) -Beta(4)
49 have been estimated at a boundary point, or have been
50 specified by the user,
51 and do not appear in the correlation matrix)
52
53 Background Beta(1)
54
55 Background 1 -0.68
56
57 Beta(1) -0.68 1
58
59
60

```

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57

Parameter Estimates

| Variable   | Estimate  | Std. Err. |
|------------|-----------|-----------|
| Background | 0.0246825 | 0.106613  |
| Beta(1)    | 0.109348  | 0.0321778 |
| Beta(2)    | 0         | NA        |
| Beta(3)    | 0         | NA        |
| Beta(4)    | 0         | NA        |

NA - Indicates that this parameter has hit a bound implied by some inequality constraint and thus has no standard error.

Analysis of Deviance Table

| Model         | Log(likelihood) | Deviance | Test DF | P-value |
|---------------|-----------------|----------|---------|---------|
| Full model    | -101.226        |          |         |         |
| Fitted model  | -104.24         | 6.02698  | 4       | 0.1971  |
| Reduced model | -126.655        | 50.8576  | 5       | <.0001  |
| AIC:          | 212.479         |          |         |         |

Goodness of Fit

| Dose | Est._Prob. | Expected | Observed | Size | Chi^2 Res. |
|------|------------|----------|----------|------|------------|
| i: 1 | 0.0000     | 0.0247   | 0.889    | 0    | -1.025     |
| i: 2 | 0.5000     | 0.0766   | 2.757    | 4    | 0.488      |
| i: 3 | 1.0000     | 0.1257   | 4.525    | 6    | 0.373      |
| i: 4 | 2.5000     | 0.2580   | 9.287    | 13   | 0.539      |
| i: 5 | 5.0000     | 0.4355   | 15.676   | 15   | -0.076     |
| i: 6 | 10.0000    | 0.6732   | 24.236   | 21   | -0.409     |

Chi-square = 5.44    DF = 4    P-value = 0.2448

Benchmark Dose Computation

|                    |            |
|--------------------|------------|
| Specified effect = | 0.86       |
| Risk Type =        | Extra risk |
| Confidence level = | 0.95       |
| BMD =              | 17.9803    |
| BMDL =             | 12.7064    |

```

1 PIENTA_MT_BAA.OUT.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\PIENTA_MT_BAA.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\PIENTA_MT_BAA.plt
8
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(
17 -beta1*dose^1-beta2*dose^2-beta3*dose^3-beta4*dose^4)]
18
19 The parameter betas are restricted to be positive
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 6
26 Total number of records with missing values = 0
27 Total number of parameters in model = 5
28 Total number of specified parameters = 0
29 Degree of polynomial = 4
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 0.00472474
40 Beta(1) = 0
41 Beta(2) = 0
42 Beta(3) = 2.31177e-005
43 Beta(4) = 0
44
45
46 Asymptotic Correlation Matrix of Parameter Estimates
47
48 (*** The model parameter(s) -Beta(1) -Beta(2) -Beta(3)
49 have been estimated at a boundary point, or have been
50 specified by the user,
51 and do not appear in the correlation matrix)
52
53 Background Beta(4)
54
55 Background 1 -0.43
56
57 Beta(4) -0.43 1
58
59
60

```

1 Parameter Estimates

2

| 3 Variable   | Estimate     | Std. Err.   |
|--------------|--------------|-------------|
| 4 Background | 0.00480466   | 0.0290234   |
| 5 Beta(1)    | 0            | NA          |
| 6 Beta(2)    | 0            | NA          |
| 7 Beta(3)    | 0            | NA          |
| 8 Beta(4)    | 2.25394e-006 | 6.9765e-006 |

9

10 NA - Indicates that this parameter has hit a bound  
 11 implied by some inequality constraint and thus  
 12 has no standard error.

13

14

15

16 Analysis of Deviance Table

| 17 Model         | Log(likelihood) | Deviance | Test DF | P-value |
|------------------|-----------------|----------|---------|---------|
| 18 Full model    | -67.8785        |          |         |         |
| 19 Fitted model  | -69.9491        | 4.14115  | 4       | 0.3872  |
| 20 Reduced model | -74.327         | 12.8971  | 5       | 0.02436 |

21

22

23 AIC: 143.898

24

25

26 Goodness of Fit

| 27 Dose              | Est._Prob. | Expected | Observed | Size             | Chi^2 Res. |
|----------------------|------------|----------|----------|------------------|------------|
| 28 -----             |            |          |          |                  |            |
| 29 i: 1              |            |          |          |                  |            |
| 30 0.0000            | 0.0048     | 1.100    | 0        | 229              | -1.005     |
| 31 i: 2              |            |          |          |                  |            |
| 32 0.1000            | 0.0048     | 1.081    | 1        | 225              | -0.075     |
| 33 i: 3              |            |          |          |                  |            |
| 34 0.5000            | 0.0048     | 1.211    | 2        | 252              | 0.655      |
| 35 i: 4              |            |          |          |                  |            |
| 36 1.0000            | 0.0048     | 0.928    | 2        | 193              | 1.161      |
| 37 i: 5              |            |          |          |                  |            |
| 38 5.0000            | 0.0062     | 1.936    | 1        | 312              | -0.487     |
| 39 i: 6              |            |          |          |                  |            |
| 40 10.0000           | 0.0270     | 6.746    | 7        | 250              | 0.039      |
| 41                   |            |          |          |                  |            |
| 42                   |            |          |          |                  |            |
| 43 Chi-square = 3.34 |            | DF = 4   |          | P-value = 0.5028 |            |

44

45

46 Benchmark Dose Computation

47

48 Specified effect = 0.01

49

50 Risk Type = Extra risk

51

52 Confidence level = 0.95

53

54 BMD = 8.17165

55

56 \*\*\*\* WARNING: Completion code = -2. Optimum not found. Trying new starting  
 57 point\*\*\*\*

58

59 BMDL = 4.47767

60

```

1 PIENTA_MT_BAP.OUT.txt
2 =====
3 Multistage Model. $Revision: 2.1 $ $Date: 2000/08/21 03:38:21 $
4 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH
5 RPS\MODELING\PIENTA_MT_BAP.(d)
6 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY
7 DOCUMENTS\PAH RPS\MODELING\PIENTA_MT_BAP.plt
8 Mon Jun 27 16:28:28 2005
9 =====
10
11 BMDS MODEL RUN
12 ~~~~~
13
14 The form of the probability function is:
15
16 P[response] = background + (1-background)*[1-EXP(
17 -beta1*dose^1-beta2*dose^2-beta3*dose^3-beta4*dose^4)]
18
19 The parameter betas are restricted to be positive
20
21
22 Dependent variable = COLUMN2
23 Independent variable = COLUMN1
24
25 Total number of observations = 5
26 Total number of records with missing values = 0
27 Total number of parameters in model = 5
28 Total number of specified parameters = 0
29 Degree of polynomial = 4
30
31
32 Maximum number of iterations = 250
33 Relative Function Convergence has been set to: 1e-008
34 Parameter Convergence has been set to: 1e-008
35
36
37
38 Default Initial Parameter Values
39 Background = 0.00129459
40 Beta(1) = 0.00056154
41 Beta(2) = 0
42 Beta(3) = 0
43 Beta(4) = 0
44
45
46 Asymptotic Correlation Matrix of Parameter Estimates
47
48 (*** The model parameter(s) -Beta(2) -Beta(3) -Beta(4)
49 have been estimated at a boundary point, or have been
50 specified by the user,
51 and do not appear in the correlation matrix)
52
53 Background Beta(1)
54
55 Background 1 -0.72
56
57 Beta(1) -0.72 1
58
59
60

```

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59

Parameter Estimates

| Variable   | Estimate    | Std. Err.  |
|------------|-------------|------------|
| Background | 0.000529694 | 0.0310484  |
| Beta(1)    | 0.000662444 | 0.00321227 |
| Beta(2)    | 0           | NA         |
| Beta(3)    | 0           | NA         |
| Beta(4)    | 0           | NA         |

NA - Indicates that this parameter has hit a bound implied by some inequality constraint and thus has no standard error.

Analysis of Deviance Table

| Model         | Log(likelihood) | Deviance | Test DF | P-value |
|---------------|-----------------|----------|---------|---------|
| Full model    | -64.5099        |          |         |         |
| Fitted model  | -65.0987        | 1.17762  | 3       | 0.7584  |
| Reduced model | -68.985         | 8.95024  | 4       | 0.06236 |

AIC: 134.197

Goodness of Fit

| Dose | Est._Prob. | Expected | Observed | Size | Chi^2 Res. |        |
|------|------------|----------|----------|------|------------|--------|
| i: 1 | 0.0000     | 0.0005   | 0.267    | 0    | 504        | -1.001 |
| i: 2 | 1.0000     | 0.0012   | 0.468    | 1    | 393        | 1.137  |
| i: 3 | 5.0000     | 0.0038   | 1.557    | 2    | 406        | 0.286  |
| i: 4 | 10.0000    | 0.0071   | 3.094    | 3    | 434        | -0.031 |
| i: 5 | 20.0000    | 0.0137   | 5.611    | 5    | 410        | -0.110 |

Chi-square = 1.07    DF = 3    P-value = 0.7847

Benchmark Dose Computation

Specified effect = 0.01  
Risk Type = Extra risk  
Confidence level = 0.95  
BMD = 15.1716  
BMDL = 8.76437

PIENTA\_MT\_DBAHA.OUT.txt

=====  
Multistage Model. \$Revision: 2.1 \$ \$Date: 2000/08/21 03:38:21 \$  
Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH  
RPS\MODELING\PIENTA\_MT\_DBAHA.(d)

1 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY  
2 DOCUMENTS\PAH RPS\MODELING\PIENTA\_MT\_DBAHA.plt  
3 Mon Jun 27 16:35:08 2005

4 =====

5  
6 BMDS MODEL RUN

7 ~~~~~  
8  
9 The form of the probability function is:  
10  
11  $P[\text{response}] = \text{background} + (1 - \text{background}) * [1 - \text{EXP}(-\text{beta1} * \text{dose}^1 - \text{beta2} * \text{dose}^2)]$   
12

13  
14 The parameter betas are restricted to be positive

15  
16  
17 Dependent variable = COLUMN2  
18 Independent variable = COLUMN1

19  
20 Total number of observations = 4  
21 Total number of records with missing values = 0  
22 Total number of parameters in model = 3  
23 Total number of specified parameters = 0  
24 Degree of polynomial = 2

25  
26  
27 Maximum number of iterations = 250  
28 Relative Function Convergence has been set to: 1e-008  
29 Parameter Convergence has been set to: 1e-008

30  
31  
32  
33 Default Initial Parameter Values

34 Background = 0.000660992  
35 Beta(1) = 0.020798  
36 Beta(2) = 0

37  
38  
39 Asymptotic Correlation Matrix of Parameter Estimates

40  
41 ( \*\*\* The model parameter(s) -Background -Beta(2)  
42 have been estimated at a boundary point, or have been  
43 specified by the user,  
44 and do not appear in the correlation matrix )

45  
46 Beta(1)  
47  
48 Beta(1) 1

49  
50  
51  
52 Parameter Estimates

| Variable   | Estimate  | Std. Err. |
|------------|-----------|-----------|
| Background | 0         | NA        |
| Beta(1)    | 0.0227021 | 0.0618036 |
| Beta(2)    | 0         | NA        |

53  
54  
55  
56  
57  
58  
59 NA - Indicates that this parameter has hit a bound  
60 implied by some inequality constraint and thus

1 has no standard error.

2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44

Analysis of Deviance Table

| Model         | Log(likelihood) | Deviance | Test DF | P-value |
|---------------|-----------------|----------|---------|---------|
| Full model    | -40.1618        |          |         |         |
| Fitted model  | -41.0551        | 1.78665  | 3       | 0.6178  |
| Reduced model | -45.7301        | 11.1367  | 3       | 0.01101 |

AIC: 84.1102

Goodness of Fit

| Dose | Est._Prob. | Expected | Observed | Size | Chi^2 Res. |
|------|------------|----------|----------|------|------------|
| i: 1 | 0.0000     | 0.0000   | 0        | 229  | 0.000      |
| i: 2 | 0.1000     | 0.0023   | 0        | 219  | -1.002     |
| i: 3 | 0.5000     | 0.0113   | 4        | 233  | 0.527      |
| i: 4 | 1.0000     | 0.0224   | 4        | 217  | -0.183     |

Chi-square = 1.38    DF = 3    P-value = 0.7105

Benchmark Dose Computation

Specified effect = 0.01  
Risk Type = Extra risk  
Confidence level = 0.95  
BMD = 0.442705  
BMDL = 0.260515

1 **D.8. IN VITRO DNA DAMAGE**

2 JOHNSEN\_DNA\_DAM\_BJAC.OUT.txt

3 =====  
4 Polynomial Model. Revision: 2.2 Date: 9/12/2002  
5 Input Data File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH  
6 RPS\MODELING\JOHNSEN\_DNA\_DAM\_BAP.(d)  
7 Gnuplot Plotting File: C:\DOCUMENTS AND SETTINGS\HCLYNCH\MY DOCUMENTS\PAH  
8 RPS\MODELING\JOHNSEN\_DNA\_DAM\_BAP.plt  
9

Mon Jul 04 21:51:27 2005

10 =====  
11  
12 BMDS MODEL RUN  
13 ~~~~~

14  
15 The form of the response function is:

16  $Y[\text{dose}] = \text{beta}_0 + \text{beta}_1 \cdot \text{dose} + \text{beta}_2 \cdot \text{dose}^2 + \dots$

17  
18  
19  
20 Dependent variable = MEAN  
21 Independent variable = COLUMN1  
22 rho is set to 0  
23 Signs of the polynomial coefficients are not restricted  
24 A constant variance model is fit

25  
26 Total number of dose groups = 3  
27 Total number of records with missing values = 0  
28 Maximum number of iterations = 250  
29 Relative Function Convergence has been set to: 1e-008  
30 Parameter Convergence has been set to: 1e-008

31  
32  
33  
34 Default Initial Parameter Values  
35 alpha = 5.88667  
36 rho = 0 Specified  
37 beta\_0 = 4.94396  
38 beta\_1 = 0.150549

39  
40  
41  
42 Parameter Estimates

43  
44  
45 95.0% Wald Confidence Interval

| Variable | Estimate | Std. Err. | Lower Conf. Limit | Upper Conf. Limit |
|----------|----------|-----------|-------------------|-------------------|
| alpha    | 4.14606  | 1.95447   | 0.315366          | 7.97675           |
| beta_0   | 4.94396  | 0.875754  | 3.22751           | 6.6604            |
| beta_1   | 0.150549 | 0.0503107 | 0.0519422         | 0.249157          |

49

50  
51 Asymptotic Correlation Matrix of Parameter Estimates

52  
53

|        | alpha    | beta_0   | beta_1   |
|--------|----------|----------|----------|
| alpha  | 1        | 7.6e-015 | 1.7e-015 |
| beta_0 | 7.6e-015 | 1        | -0.63    |
| beta_1 | 1.7e-015 | -0.63    | 1        |

57

58  
59 Table of Data and Estimated Values of Interest

60  
61

| Dose | N | Obs Mean | Obs Std Dev | Est Mean | Est Std Dev | Chi^2   |
|------|---|----------|-------------|----------|-------------|---------|
| 0    | 3 | 4.4      | 1.3         | 4.94     | 2.04        | -0.463  |
| 3    | 3 | 6        | 2.1         | 5.4      | 2.04        | 0.514   |
| 30   | 3 | 9.4      | 3.4         | 9.46     | 2.04        | -0.0514 |

63  
64  
65  
66  
67  
68  
69

70  
71 Model Descriptions for likelihoods calculated

72  
73  
74 Model A1:  $Y_{ij} = \mu(i) + e(ij)$

```

1 Var{e(ij)} = Sigma^2
2
3 Model A2: Yij = Mu(i) + e(ij)
4 Var{e(ij)} = Sigma(i)^2
5
6 Model R: Yi = Mu + e(i)
7 Var{e(i)} = Sigma^2
8
9
10 Likelihoods of Interest
11
12 Model Log(likelihood) DF AIC
13 A1 -10.652512 4 29.305023
14 A2 -9.359638 6 30.719276
15 fitted -10.899709 2 25.799418
16 R -14.037484 2 32.074967
17
18 Test 1: Does response and/or variances differ among dose
19 levels
20 (A2 vs. R)
21 Test 2: Are Variances Homogeneous (A1 vs A2)
22 Test 3: Does the Model for the Mean Fit (A1 vs. fitted)
23
24 Tests of Interest
25
26 Test -2*log(Likelihood Ratio) Test df p-value
27
28 Test 1 9.35569 4 0.009299
29 Test 2 2.58575 2 0.2745
30 Test 3 0.494395 1 0.482
31
32 The p-value for Test 1 is less than .05. There appears
33 to be a
34 difference between response and/or variances among the
35 dose levels.
36 It seems appropriate to model the data
37
38 The p-value for Test 2 is greater than .05. A
39 homogeneous variance
40 model appears to be appropriate here
41
42
43 The p-value for Test 3 is greater than .05. The model
44 chosen appears
45 to adequately describe the data
46
47
48
49 Benchmark Dose Computation
50 Specified effect = 7.6
51
52 Risk Type = Point risk
53
54 Confidence level = 0.95
55
56 BMD = 17.6423
57
58
59 BMDL = 9.58925
60

```

1  
2  
3

**APPENDIX E. CALCULATION OF RPFs**

**Table E-1. Dermal bioassays: RPF calculations for incidence data**

| Record number                           | Reference                 | Tumor type(s)                          | Sex | PAH   | Relative potency calculation |        |                                    |                     |                  |                |                      |      |                                                                                  |
|-----------------------------------------|---------------------------|----------------------------------------|-----|-------|------------------------------|--------|------------------------------------|---------------------|------------------|----------------|----------------------|------|----------------------------------------------------------------------------------|
|                                         |                           |                                        |     |       | BMR                          | BMD    | Point estimate extra risk response | Point estimate dose | Dose units       | Converted dose | Converted dose units | RPF  | Comments                                                                         |
| <i>Complete carcinogenicity studies</i> |                           |                                        |     |       |                              |        |                                    |                     |                  |                |                      |      |                                                                                  |
| 600                                     | Habs et al., 1980         | Sum of Papilloma, carcinoma, sarcoma   | F   | BaP   |                              |        | 0.24                               | 1.7                 | µg/animal        |                |                      | 1    | No model fit; lowest statistically significant point used                        |
|                                         |                           |                                        | F   | BbF   | 0.24                         | 6.05   |                                    |                     | µg/animal        |                |                      | 0.28 |                                                                                  |
| 13640                                   | Cavalieri et al., 1983    | Papilloma, adenoma, carcinoma          | F   | BaP   | 0.1                          | 5.3    |                                    |                     | nmol             | 0.001          | mg                   | 1    |                                                                                  |
|                                         |                           |                                        | F   | CPcdP | 0.1                          | 47     |                                    |                     | nmol             | 0.011          | mg                   | 0.13 |                                                                                  |
| 620                                     | Hoffmann and Wynder, 1966 | Papilloma                              | F   | BaP   | 0.1                          | 0.0031 |                                    |                     | %                |                |                      | 1    |                                                                                  |
|                                         |                           |                                        | F   | DBaEP | 0.1                          | 0.0094 |                                    |                     | %                |                |                      | 0.33 | Toxicity resulted in significant mortality unrelated to tumor induction          |
|                                         |                           |                                        | F   | DBaIP | 0.1                          | 0.0042 |                                    |                     | %                |                |                      | 0.74 |                                                                                  |
|                                         |                           |                                        | F   | DBaEF | 0.1                          | 0.0028 |                                    |                     | %                |                |                      | 1.1  |                                                                                  |
| 17660                                   | Cavalieri et al., 1977    | Papilloma, kerato-acanthoma, carcinoma | F   | BaP   |                              |        | 0.79                               | 0.396               | µmol/application | 0.100          | mg/application       | 1    |                                                                                  |
|                                         |                           |                                        | F   | AA    |                              |        | 0.47                               | 0.396               | µmol/application | 0.109          | mg/application       | 0.55 |                                                                                  |
| <i>Initiation studies</i>               |                           |                                        |     |       |                              |        |                                    |                     |                  |                |                      |      |                                                                                  |
| 630                                     | LaVoie et al., 1982       | Primarily squamous cell papilloma      | F   | BaP   |                              |        | 0.85                               | 30                  | µg/animal        |                |                      | 1    |                                                                                  |
|                                         |                           |                                        | F   | BbF   |                              |        | 0.8                                | 100                 | µg/animal        |                |                      | 0.28 | No model fit; point estimate using incidence/dose point closest to BaP incidence |
|                                         |                           |                                        | F   | BjF   |                              |        | 0.95                               | 1,000               | µg/animal        |                |                      | 0.03 | No model fit; point estimate using incidence/dose point closest to BaP incidence |

**Table E-1. Dermal bioassays: RPF calculations for incidence data**

| Record number | Reference                 | Tumor type(s) | Sex | PAH    | Relative potency calculation |       |                                    |                     |            |                |                      |      |                                                                                                               |
|---------------|---------------------------|---------------|-----|--------|------------------------------|-------|------------------------------------|---------------------|------------|----------------|----------------------|------|---------------------------------------------------------------------------------------------------------------|
|               |                           |               |     |        | BMR                          | BMD   | Point estimate extra risk response | Point estimate dose | Dose units | Converted dose | Converted dose units | RPF  | Comments                                                                                                      |
|               |                           |               | F   | BkF    | 0.85                         | 1,163 |                                    |                     | µg/animal  |                |                      | 0.03 |                                                                                                               |
| 18570         | Hecht et al., 1974        | Unspecified   | F   | BaP    |                              |       | 0.3                                | 0.05                | mg/animal  |                |                      | 1    |                                                                                                               |
|               |                           |               | F   | CH     |                              |       | 0.58                               | 1                   | mg/animal  |                |                      | 0.10 |                                                                                                               |
| 21420         | Slaga et al., 1980        | Papilloma     | F   | BaP    |                              |       | 0.64                               | 200                 | nmol       | 0.050          | mg                   | 1    |                                                                                                               |
|               |                           |               | F   | CH     |                              |       | 0.71                               | 2,000               | nmol       | 0.457          | mg                   | 0.12 | Not clear if BaP administered simultaneously; control groups pooled for analysis                              |
|               |                           |               | F   | DBahA  |                              |       | 0.45                               | 100                 | nmol       | 0.028          | mg                   | 1.27 |                                                                                                               |
| 15640         | Raveh et al., 1982        | Papilloma     | F   | BaP    | 0.1                          | 2.2   |                                    |                     | µg         |                |                      | 1    |                                                                                                               |
|               |                           |               | F   | CPcdP  | 0.1                          | 30    |                                    |                     | µg         |                |                      | 0.07 |                                                                                                               |
| 620           | Hoffmann and Wynder, 1966 | Papilloma     | F   | BaP    |                              |       | 0.79                               | 0.25                | mg/animal  |                |                      | 1    |                                                                                                               |
|               |                           |               | F   | DBaeF  |                              |       | 0.57                               | 0.25                | mg/animal  |                |                      | 0.73 |                                                                                                               |
|               |                           |               | F   | DBaeP  |                              |       | 0.33                               | 0.25                | mg/animal  |                |                      | 0.41 |                                                                                                               |
|               |                           |               | F   | DBahP  |                              |       | 0.7                                | 0.25                | mg/animal  |                |                      | 0.90 |                                                                                                               |
|               |                           |               | F   | DBaiP  |                              |       | 0.36                               | 0.25                | mg/animal  |                |                      | 0.45 |                                                                                                               |
|               |                           |               | F   | N23eP  |                              |       | 0.25                               | 0.25                | mg/animal  |                |                      | 0.32 |                                                                                                               |
| 13650         | Cavalieri et al., 1981b   | Papilloma     | F   | BaP    |                              |       | 0.33                               | 0.2                 | µmol       | 0.050          | mg                   | 1    |                                                                                                               |
|               |                           |               | F   | CPcdP  |                              |       | 0.23                               | 0.6                 | µmol       | 0.136          | mg                   | 0.26 | Mid dose borderline significant, high dose not, trend not; no model fit; RPF uses mid dose for point estimate |
| 15700         | Rice et al., 1988         | Unspecified   | F   | BaP    |                              |       | 0.88                               | 0.1                 | µmol       | 0.025          | mg                   | 1    |                                                                                                               |
|               |                           |               | F   | CH     |                              |       | 0.89                               | 0.5                 | µmol       | 0.114          | mg                   | 0.22 | No model fit; point estimate using point closest to BaP incidence                                             |
|               |                           |               | F   | CPdefC | 0.88                         | 0.22  |                                    |                     | µmol       | 0.053          | mg                   | 0.47 |                                                                                                               |
|               |                           |               | F   | BbcAC  |                              |       | 0.89                               | 2                   | µmol       | 0.481          | mg                   | 0.05 | No model fit; point estimate using point closest to BaP incidence                                             |

**Table E-1. Dermal bioassays: RPF calculations for incidence data**

| Record number | Reference           | Tumor type(s) | Sex | PAH  | Relative potency calculation |     |                                    |                     |            |                |                      |      |                                                                   |
|---------------|---------------------|---------------|-----|------|------------------------------|-----|------------------------------------|---------------------|------------|----------------|----------------------|------|-------------------------------------------------------------------|
|               |                     |               |     |      | BMR                          | BMD | Point estimate extra risk response | Point estimate dose | Dose units | Converted dose | Converted dose units | RPF  | Comments                                                          |
| 24800         | Nesnow et al., 1984 | Papilloma     | M   | BaP  |                              |     | 0.67                               | 200                 | nmol       | 0.050          | mg                   | 1    |                                                                   |
|               |                     |               | M   | BeAC |                              |     | 0.60                               | 250                 | nmol       | 0.063          | mg                   | 0.71 | No model fit; point estimate using point closest to BaP incidence |
|               |                     |               | M   | BIAC | 0.67                         | 50  |                                    |                     | nmol       | 0.013          | mg                   | 4.00 | Three high doses dropped due to plateau                           |
|               |                     |               | F   | BaP  |                              |     | 0.51                               | 200                 | nmol       | 0.050          | mg                   | 1    |                                                                   |
|               |                     |               | F   | BeAC | 0.51                         | 228 |                                    |                     | nmol       | 0.058          | mg                   | 0.88 | Two high doses dropped to achieve model fit                       |
|               |                     |               | F   | BIAC | 0.51                         | 30  |                                    |                     | nmol       | 0.008          | mg                   | 6.67 | Three high doses dropped to achieve model fit                     |

1  
2

**Table E-2. Dermal bioassays: RPF calculations for multiplicity data**

| Record number                           | Reference               | Tumor type(s)                     | Sex | PAH           | Relative potency calculation |                     |            |                |                      |       | Comments                                |
|-----------------------------------------|-------------------------|-----------------------------------|-----|---------------|------------------------------|---------------------|------------|----------------|----------------------|-------|-----------------------------------------|
|                                         |                         |                                   |     |               | Point estimate response      | Point estimate dose | Dose units | Converted dose | Converted dose units | RPF   |                                         |
| <i>Complete carcinogenicity studies</i> |                         |                                   |     |               |                              |                     |            |                |                      |       |                                         |
| 13640                                   | Cavalieri et al., 1983  | Papilloma, adenoma, carcinoma     | F   | BaP           | 1.5                          | 20                  | nmol       | 0.0050         | mg                   | 1     | Variance not reported                   |
|                                         |                         |                                   | F   | CPcdP         | 2.5                          | 200                 | nmol       | 0.045          | mg                   | 0.18  | Variance not reported                   |
| 13650                                   | Cavalieri et al., 1981b | Primarily squamous cell carcinoma | US  | BaP           | 1.5                          | 0.2                 | µmol       | 0.050          | mg                   | 1     |                                         |
|                                         |                         |                                   | US  | CPcdP         | 0.80                         | 0.2                 | µmol       | 0.045          | mg                   | 0.59  | Variance not reported                   |
| <i>Initiation studies</i>               |                         |                                   |     |               |                              |                     |            |                |                      |       |                                         |
| 630                                     | LaVoie et al., 1982     | Primarily squamous cell papilloma | F   | BaP           | 4.9                          | 30                  | µg         |                |                      | 1     |                                         |
|                                         |                         |                                   | F   | BbF           | 7.1                          | 100                 | µg         |                |                      | 0.43  | Variance not reported                   |
|                                         |                         |                                   | F   | BjF           | 7.2                          | 1,000               | µg         |                |                      | 0.044 | Variance not reported                   |
|                                         |                         |                                   | F   | BkF           | 2.8                          | 1,000               | µg         |                |                      | 0.017 | Variance not reported                   |
| 18570                                   | Hecht et al., 1974      | Unspecified                       | F   | BaP           | 0.5                          | 0.05                | mg         |                |                      | 1     |                                         |
|                                         |                         |                                   | F   | CH            | 1.0                          | 1                   | mg         |                |                      | 0.10  |                                         |
| 21420                                   | Slaga et al., 1980      | Papilloma                         | F   | BaP           | 2.1                          | 200                 | nmol       | 0.050          | mg                   | 1     |                                         |
|                                         |                         |                                   | F   | CH            | 1.5                          | 2,000               | nmol       | 0.46           | mg                   | 0.078 |                                         |
|                                         |                         |                                   | F   | DBahA         | 1.3                          | 100                 | nmol       | 0.028          | mg                   | 1.1   |                                         |
| 15640                                   | Raveh et al., 1982      | Papilloma                         | F   | BaP           | 1.1                          | 10                  | µg         |                |                      | 1     | Variance not reported                   |
|                                         |                         |                                   | F   | CPcdP         | 0.7                          | 200                 | µg         |                |                      | 0.032 | Variance not reported                   |
| 13650                                   | Cavalieri et al., 1981  | Papilloma                         | F   | BaP           | 1.1                          | 0.2                 | µmol       | 0.050          | mg                   | 1     |                                         |
|                                         |                         |                                   | F   | CPcdP         | 0.17                         | 0.6                 | µmol       | 0.14           | mg                   | 0.060 | Variance not reported                   |
| 21410                                   | Slaga et al., 1978      | Papilloma                         | F   | BaP           | 5.2                          | 0.2                 | µmol       | 0.050          | mg                   | 1     |                                         |
|                                         |                         |                                   | F   | BaA           | 1.1                          | 2                   | µmol       | 0.46           | mg                   | 0.023 |                                         |
| 16310                                   | Weyand et al., 1992     | Unspecified                       | US  | BaP           | 4.0                          | 0.01                | µmol       | 0.0025         | mg                   | 1     |                                         |
|                                         |                         |                                   | US  | BjF           | 4.0                          | 1                   | µmol       | 0.252          | mg                   | 0.010 | Variance not reported                   |
| 10200                                   | El-Bayoumy et al., 1982 | Primarily squamous cell papilloma | F   | BaP           | 7.0                          | 0.05                | mg         |                |                      | 1     |                                         |
|                                         |                         |                                   | F   | CH            | 7.6                          | 1                   | mg         |                |                      | 0.054 |                                         |
| 24300                                   | Rice et al., 1985       | Unspecified                       | F   | BaP           | 7.9                          | 0.3                 | mg         |                |                      | 1     |                                         |
|                                         |                         |                                   | F   | CH            | 4.9                          | 1                   | mg         |                |                      | 0.18  |                                         |
|                                         |                         |                                   | F   | CPdefC        | 5.5                          | 1                   | mg         |                |                      | 0.21  |                                         |
| 13660                                   | Cavalieri et al., 1991  | Primarily papilloma               | F   | BaP Expt I    | 5.2                          | 300                 | nmol       | 0.0757         | mg                   | 1     | 16 Wk experiment; variance not reported |
|                                         |                         |                                   | F   | DBalP Expt I  | 6.8                          | 33.3                | nmol       | 0.010          | mg                   | 9.7   |                                         |
| 13660                                   | Cavalieri et al., 1991  | Primarily papilloma               | F   | BaP Expt II   | 3.4                          | 100                 | nmol       | 0.0252         | mg                   | 1     | 27 Wk experiment; variance not reported |
|                                         |                         |                                   | F   | DBalP Expt II | 7.0                          | 4                   | nmol       | 0.0012         | mg                   | 42    |                                         |
| 24800                                   | Nesnow et al., 1984     | Papilloma                         | M   | BaP           | 1.4                          | 200                 | nmol       | 0.050          | mg                   | 1     | Variance not reported                   |
|                                         |                         |                                   | M   | BeAC          | 1.3                          | 250                 | nmol       | 0.063          | mg                   | 0.74  | Variance not reported                   |
|                                         |                         |                                   | M   | BIAC          | 1.4                          | 50                  | nmol       | 0.013          | mg                   | 4.0   | Variance not reported                   |
|                                         |                         |                                   | F   | BaP           | 1.5                          | 200                 | nmol       | 0.050          | mg                   | 1     | Variance not reported                   |
|                                         |                         |                                   | F   | BeAC          | 1.1                          | 250                 | nmol       | 0.063          | mg                   | 0.58  | Variance not reported                   |
|                                         |                         |                                   | F   | BIAC          | 1.1                          | 50                  | nmol       | 0.013          | mg                   | 2.9   | Variance not reported                   |

**Table E-3. Intraperitoneal bioassays: RPF calculations for incidence data**

| Record number | Reference           | Target organ  | Tumor type(s)           | Sex | PAH | Relative potency calculation |     |                                    |                     |            |                |                      |      |                                         |
|---------------|---------------------|---------------|-------------------------|-----|-----|------------------------------|-----|------------------------------------|---------------------|------------|----------------|----------------------|------|-----------------------------------------|
|               |                     |               |                         |     |     | BMR                          | BMD | Point estimate extra risk response | Point estimate dose | Dose units | Converted dose | Converted dose units | RPF  | Comments                                |
| 17560         | Busby et al., 1989  | Lung          | Adenoma, adenocarcinoma | F   | BaP |                              |     | 0.68                               | 59.5                | µg         |                |                      | 1    |                                         |
|               |                     |               |                         |     | FA  |                              |     | 0.26                               | 257.6               | µg         |                |                      | 0.09 |                                         |
| 640           | LaVoie et al., 1987 | Lung          | Adenoma                 | M   | BaP |                              |     | 0.82                               | 1.1                 | µmol/mouse | 0.28           | mg/mouse             | 1    |                                         |
|               |                     |               |                         |     | BjF |                              |     | 0.52                               | 1.1                 | µmol/mouse | 0.28           | mg/mouse             | 0.64 | Do not use: use liver or lung RPF below |
|               |                     |               |                         | F   | BaP |                              |     | 0.64                               | 1.1                 | µmol/mouse | 0.28           | mg/mouse             | 1    |                                         |
|               |                     |               |                         |     | BjF |                              |     | 0.22                               | 1.1                 | µmol/mouse | 0.28           | mg/mouse             | 0.35 | Do not use: use liver or lung RPF below |
|               |                     | Liver         | Adenoma, hepatoma       | M   | BaP |                              |     | 0.75                               | 1.1                 | µmol/mouse | 0.28           | mg/mouse             | 1    |                                         |
|               |                     |               |                         |     | BbF |                              |     | 0.5                                | 0.5                 | µmol/mouse | 0.13           | mg/mouse             | 1.50 | Do not use: use liver or lung RPF below |
|               |                     |               |                         |     | BjF |                              |     | 0.49                               | 1.1                 | µmol/mouse | 0.28           | mg/mouse             | 0.66 | Do not use: use liver or lung RPF below |
|               |                     | Liver or lung | Adenoma, hepatoma       | M   | BaP |                              |     | 0.75                               | 1.1                 | µmol/mouse | 0.28           | mg/mouse             | 1    |                                         |
|               |                     |               |                         |     | BbF |                              |     | 0.51                               | 0.5                 | µmol/mouse | 0.13           | mg/mouse             | 1.50 |                                         |
|               |                     |               |                         |     | BjF |                              |     | 0.8                                | 1.1                 | µmol/mouse | 0.28           | mg/mouse             | 1.10 |                                         |
|               |                     |               |                         | F   | BaP |                              |     | 0.64                               | 1.1                 | µmol/mouse | 0.28           | mg/mouse             | 1    |                                         |
|               |                     |               |                         |     | BjF |                              |     | 0.22                               | 1.1                 | µmol/mouse | 0.28           | mg/mouse             | 0.35 |                                         |
| 7510          | LaVoie et al., 1994 | Lung          | Total                   | M   | BaP |                              |     | 0.7                                | 1.1                 | µmol/mouse | 0.28           | mg/mouse             | 1    |                                         |
|               |                     |               |                         |     | FA  | 0.7                          | 22  |                                    |                     | µmol/mouse | 4.45           | mg/mouse             | 0.06 | Do not use: male liver RPF is higher    |

**Table E-3. Intraperitoneal bioassays: RPF calculations for incidence data**

| Record number | Reference             | Target organ | Tumor type(s)            | Sex | PAH   | Relative potency calculation |       |                                    |                     |            |                |                      |      |                                                             |
|---------------|-----------------------|--------------|--------------------------|-----|-------|------------------------------|-------|------------------------------------|---------------------|------------|----------------|----------------------|------|-------------------------------------------------------------|
|               |                       |              |                          |     |       | BMR                          | BMD   | Point estimate extra risk response | Point estimate dose | Dose units | Converted dose | Converted dose units | RPF  | Comments                                                    |
|               |                       |              |                          | F   | BaP   |                              |       | 0.83                               | 1.1                 | μmol/mouse | 0.28           | mg/mouse             | 1    |                                                             |
|               |                       |              |                          |     | FA    | 0.83                         | 17    |                                    |                     | μmol/mouse | 3.44           | mg/mouse             | 0.08 |                                                             |
|               |                       | Liver        | Foci, adenoma, carcinoma | M   | BaP   |                              |       | 0.81                               | 1.1                 | μmol/mouse | 0.28           | mg/mouse             | 1    |                                                             |
|               |                       |              |                          |     | FA    | 0.81                         | 6.4   |                                    |                     | μmol/mouse | 1.29           | mg/mouse             | 0.21 |                                                             |
| 24590         | Nesnow et al., 1998   | Lung         | NS                       | M   | BaP   | 0.1                          | 8.35  |                                    |                     | mg/kg      |                |                      | 1    |                                                             |
|               |                       |              |                          |     | BbF   | 0.1                          | 5.68  |                                    |                     | mg/kg      |                |                      | 1.47 |                                                             |
|               |                       |              |                          |     | CPcdP | 0.1                          | 8.65  |                                    |                     | mg/kg      |                |                      | 0.97 |                                                             |
|               |                       |              |                          |     | DBahA | 0.1                          | 0.23  |                                    |                     | mg/kg      |                |                      | 36   |                                                             |
|               |                       |              |                          |     | DBalP | 0.1                          | 0.29  |                                    |                     | mg/kg      |                |                      | 29   |                                                             |
| 24801         | Weyand et al., 2004   | Lung         | Adenoma                  | F   | BaP   |                              |       | 0.81                               | 100                 | mg/kg bw   |                |                      | 1    |                                                             |
|               |                       |              |                          |     | BcFE  |                              |       | 0.85                               | 100                 | mg/kg bw   |                |                      | 1.05 |                                                             |
| 22510         | Wislocki et al., 1986 | Liver        | Adenoma, carcinoma       | M   | BaP   |                              |       | 0.44                               | 560                 | nmol       | 0.14           | mg                   | 1    |                                                             |
|               |                       |              |                          |     | CH    | 0.44                         | 3,339 |                                    |                     | nmol       | 0.76           | mg                   | 0.19 | Using pooled controls                                       |
|               |                       |              |                          |     | BaA   |                              |       | 0.77                               | 2,800               | nmol       | 0.64           | mg                   | 0.39 |                                                             |
|               |                       | Lung         | Unspecified              | M   | BaP   |                              |       | 0.3                                | 560                 | nmol       | 0.14           | mg                   | 1    |                                                             |
|               |                       |              |                          |     | CH    | 0.3                          | 5,601 |                                    |                     | nmol       | 1.28           | mg                   | 0.11 | Do not use: male liver RPF is higher; using pooled controls |
|               |                       |              |                          | F   | BaP   |                              |       | 0.46                               | 560                 | nmol       | 0.14           | mg                   | 1    |                                                             |
|               |                       |              |                          |     | BaA   |                              |       | 0.16                               | 2,800               | nmol       | 0.64           | mg                   | 0.08 |                                                             |

1  
2  
3

**Table E-4. Intraperitoneal bioassays: RPF calculations for multiplicity data**

| Record number | Reference             | Target organ(s) | Tumor type(s)            | Sex | PAH   | RPF Calculation |       |                         |                     |            |                |                      | Comments |                                                                                              |
|---------------|-----------------------|-----------------|--------------------------|-----|-------|-----------------|-------|-------------------------|---------------------|------------|----------------|----------------------|----------|----------------------------------------------------------------------------------------------|
|               |                       |                 |                          |     |       | BMR             | BMD   | Point estimate response | Point estimate dose | Dose units | Converted dose | Converted dose units |          | RPF                                                                                          |
| 17560         | Busby et al., 1989    | Lung            | Adenoma, adenocarcinoma  | F   | BaP   |                 |       | 1.11                    | 59.5                | µg         |                |                      | 1        |                                                                                              |
|               |                       |                 |                          |     | FA    |                 |       | 0.33                    | 257.6               | µg         |                |                      | 0.069    |                                                                                              |
| 7510          | LaVoie et al., 1994   | Lung            | Total                    | M   | BaP   |                 |       | 4.13                    | 1.1                 | µmol       | 0.28           | mg                   | 1        |                                                                                              |
|               |                       |                 |                          |     | FA    |                 |       | 0.95                    | 17.30               | µmol       | 3.50           | mg                   | 0.018    | Do not use: male liver RPF is higher                                                         |
|               |                       |                 |                          | F   | BaP   |                 |       | 3.40                    | 1.1                 | µmol       | 0.28           | mg                   | 1        |                                                                                              |
|               |                       |                 |                          |     | FA    |                 |       | 2.30                    | 17.30               | µmol       | 3.50           | mg                   | 0.054    |                                                                                              |
|               |                       | Liver           | Foci, adenoma, carcinoma | M   | BaP   |                 |       | 4.12                    | 1.1                 | µmol       | 0.28           | mg                   | 1        |                                                                                              |
|               |                       |                 |                          |     | FA    |                 |       | 1.45                    | 3.46                | µmol       | 0.700          | mg                   | 0.14     |                                                                                              |
| 22510         | Wislocki et al., 1986 | Liver           | Adenoma, carcinoma       | M   | BaP   |                 |       | 1.36                    | 560                 | nmol       | 0.141          | mg                   | 1        |                                                                                              |
|               |                       |                 |                          |     | CH    |                 |       | 0.93                    | 2,800               | nmol       | 0.639          | mg                   | 0.15     | Using pooled controls                                                                        |
|               |                       |                 |                          |     | BaA   |                 |       | 2.28                    | 2,800               | nmol       | 0.639          | mg                   | 0.37     |                                                                                              |
| 13610         | Busby et al., 1984    | Lung            | Adenoma, carcinoma       | M   | BaP   |                 |       | 4.28                    | 0.28                | mg         |                |                      | 1        | No model fit                                                                                 |
|               |                       |                 |                          |     | FA    | 4.28            | 9.99  |                         |                     | mg         |                |                      | 0.028    |                                                                                              |
|               |                       |                 |                          | F   | BaP   |                 |       | 3.56                    | 0.28                | mg         |                |                      | 1        | No model fit                                                                                 |
|               |                       |                 |                          |     | FA    | 3.56            | 32.28 |                         |                     | mg         |                |                      | 0.0086   |                                                                                              |
| 24590         | Nesnow et al., 1998b  | Lung            | Not specified            | M   | BaP   |                 |       | 3.85                    | 50                  | mg/kg      |                |                      | 1        | No model fit                                                                                 |
|               |                       |                 |                          |     | BbF   | 3.85            | 123   |                         |                     | mg/kg      |                |                      | 0.41     | BMR = BaP response                                                                           |
|               |                       |                 |                          |     | CPcdP |                 |       | 4.15                    | 50                  | mg/kg      |                |                      | 1.1      | No model fit                                                                                 |
|               |                       |                 |                          |     | DBahA | 3.85            | 3.57  |                         |                     | mg/kg      |                |                      | 14       | BMR = BaP response                                                                           |
|               |                       |                 |                          |     | DBalP |                 |       | 3.66                    | 1.5                 | mg/kg      |                |                      | 32       | No model fit<br>These data from Record 8180 Prahalad 1987 but use BaP data from Record 24590 |

**Table E-4. Intraperitoneal bioassays: RPF calculations for multiplicity data**

| Record number | Reference           | Target organ(s) | Tumor type(s) | Sex | PAH  | RPF Calculation |     |                         |                     |            |                |                      |      |              |
|---------------|---------------------|-----------------|---------------|-----|------|-----------------|-----|-------------------------|---------------------|------------|----------------|----------------------|------|--------------|
|               |                     |                 |               |     |      | BMR             | BMD | Point estimate response | Point estimate dose | Dose units | Converted dose | Converted dose units | RPF  | Comments     |
| 11190         | Mass et al., 1993   | Lung            | Not specified | M   | BaP  |                 |     | 5.05                    | 100                 | mg/kg      |                |                      | 1    | No model fit |
|               |                     |                 |               |     | BjAC |                 |     | 59.45                   | 20                  | mg/kg      |                |                      | 59   | No model fit |
| 24801         | Weyand et al., 2004 | Lung            | Adenoma       | F   | BaP  |                 |     | 6.1                     | 100                 | mg/kg bw   |                |                      | 1    |              |
|               |                     |                 |               |     | BcFE |                 |     | 3.4                     | 100                 | mg/kg bw   |                |                      | 0.56 |              |

1

**Table E-5. Lung implantation bioassays: RPF calculations (incidence data)**

| Record number | Reference                   | Target organ(s) | Tumor type(s)           | PAH   | Relative potency calculation |       |                                    |                     |            |        |             |
|---------------|-----------------------------|-----------------|-------------------------|-------|------------------------------|-------|------------------------------------|---------------------|------------|--------|-------------|
|               |                             |                 |                         |       | BMR                          | BMD   | Point estimate extra risk response | Point estimate dose | Dose units | RPF    | Comments    |
| 17940         | Deutsch-Wenzel et al., 1983 | Lung            | Sum carcinoma + sarcoma | BaP   | 0.1                          | 0.032 |                                    |                     | mg         | 1      |             |
|               |                             |                 |                         | AA    | 0.1                          | 0.14  |                                    |                     | mg         | 0.24   |             |
|               |                             |                 |                         | BbF   | 0.1                          | 0.33  |                                    |                     | mg         | 0.10   |             |
|               |                             |                 |                         | BghiP | 0.1                          | 3.5   |                                    |                     | mg         | 0.0092 |             |
|               |                             |                 |                         | BjF   | 0.1                          | 1.0   |                                    |                     | mg         | 0.032  |             |
|               |                             |                 |                         | BkF   | 0.1                          | 1.1   |                                    |                     | mg         | 0.031  |             |
|               |                             |                 |                         | IP    | 0.1                          | 0.44  |                                    |                     | mg         | 0.074  |             |
| 22000         | Wenzel-Hartung et al., 1990 | Lung            | Carcinoma               | BaP   | 0.1                          | 0.033 |                                    |                     | mg/ animal | 1      |             |
|               |                             |                 |                         | CH    | 0.1                          | 0.85  |                                    |                     | mg/ animal | 0.038  |             |
|               |                             |                 |                         | BaP   | 0.57                         | 0.20  |                                    |                     | mg/ animal | 1      |             |
|               |                             |                 |                         | DBahA |                              |       | 0.57                               | 0.1                 | mg/ animal | 2.0    | Single dose |

2

**Table E-6. Oral bioassays: RPF calculations (incidence and multiplicity data)**

| Record number | Reference           | Target organ | Tumor and data type  | PAH  | Relative potency calculation |     |                                    |                     |              |      |              |
|---------------|---------------------|--------------|----------------------|------|------------------------------|-----|------------------------------------|---------------------|--------------|------|--------------|
|               |                     |              |                      |      | BMR                          | BMD | Point estimate extra risk response | Point estimate dose | Dose units   | RPF  | Comments     |
| 24801         | Weyand et al., 2004 | Lung         | Adenoma incidence    | BaP  |                              |     | 0.7                                | 230                 | µg/mouse/day | 1    |              |
|               |                     |              |                      | BcFE | 0.7                          | 42  |                                    |                     | µg/mouse/day | 5.48 |              |
| 24801         | Weyand et al., 2004 | Lung         | Adenoma multiplicity | BaP  |                              |     | 1.09                               | 230                 | µg/mouse/day | 1    |              |
|               |                     |              |                      | BcFE |                              |     | 45.69                              | 197                 | µg/mouse/day | 48.9 | No model fit |

1

**Table E-7. In vivo DNA adducts: RPF calculations**

| Record number | Reference                 | Target organ(s)/route                                                  | PAH   | Relative potency calculation |                 |                         |                     |                    |                |                      |       |                                                                                           |
|---------------|---------------------------|------------------------------------------------------------------------|-------|------------------------------|-----------------|-------------------------|---------------------|--------------------|----------------|----------------------|-------|-------------------------------------------------------------------------------------------|
|               |                           |                                                                        |       | AUC                          | AUC versus dose | Point estimate response | Point estimate dose | Dose units         | Converted dose | Converted dose units | RPF   | Comments                                                                                  |
| 6210          | Arif et al., 1997         | Sum of adducts in mammary gland, lung, heart, pancreas, bladder, liver | BaP   |                              |                 | 325                     | 0.25                | µmol/mammary gland | 0.063          | mg/mammary gland     | 1     |                                                                                           |
|               |                           |                                                                        | DBaP  |                              |                 | 2,245                   | 0.25                | µmol/mammary gland | 0.076          | mg/mammary gland     | 5.8   |                                                                                           |
| 17630         | Cavalieri et al., 1981a   | Skin 4-hr                                                              | BaP   |                              |                 | 16                      | 0.2                 | µmol/animal        | 0.050          | mg/animal            | 1     | Higher of two values measured at 4 hrs                                                    |
|               |                           |                                                                        | ACEP  |                              |                 | 2.2                     | 0.2                 | µmol/animal        | 0.046          | mg/animal            | 0.15  | Higher of two values measured at 4 hrs                                                    |
|               |                           |                                                                        | CPcdP |                              |                 | 8.8                     | 0.2                 | µmol/animal        | 0.045          | mg/animal            | 0.61  | Higher of two values measured at 24 hrs                                                   |
| 18810         | Hughes and Phillips, 1990 | Sum of skin and lung                                                   | BaP   |                              |                 | 9                       | 1                   | µmol               | 0.25           | mg                   | 1     | RPFs based on peaks; digitizing not possible; peaks reached at different times postdosing |
|               |                           |                                                                        | DBaeP |                              |                 | Cannot determine        | 1                   | µmol               |                |                      | NA    |                                                                                           |
|               |                           |                                                                        | DBahP |                              |                 | 3.2                     | 1                   | µmol               | 0.30           | mg                   | 0.30  |                                                                                           |
|               |                           |                                                                        | DBaiP |                              |                 | 0.85                    | 1                   | µmol               | 0.30           | mg                   | 0.079 |                                                                                           |
|               |                           |                                                                        | DBalP |                              |                 | 65                      | 1                   | µmol               | 0.30           | mg                   | 6.0   |                                                                                           |
| 11190         | Mass et al., 1993         | Lung                                                                   | BaP   |                              | 470             |                         |                     | mg/kg              |                |                      | 1     |                                                                                           |
|               |                           |                                                                        | BjAC  |                              | 464             |                         |                     | mg/kg              |                |                      | 0.99  | Ratio of slopes of AUC versus dose; BjAC plot shows curvature                             |
| 8010          | Nesnow et al., 1993b      | Total of lung, liver, and peripheral blood lymphocytes                 | BaP   | 52,084                       |                 |                         | 100                 | mg/kg              |                |                      | 1     |                                                                                           |
|               |                           |                                                                        | BbF   | 11,314                       |                 |                         | 100                 | mg/kg              |                |                      | 0.22  | Ratio of (sum of AUCs)/dose                                                               |

**Table E-7. In vivo DNA adducts: RPF calculations**

| Record number | Reference              | Target organ(s)/route                               | PAH   | Relative potency calculation |                 |                         |                     |             |                |                      |       |                                                           |  |
|---------------|------------------------|-----------------------------------------------------|-------|------------------------------|-----------------|-------------------------|---------------------|-------------|----------------|----------------------|-------|-----------------------------------------------------------|--|
|               |                        |                                                     |       | AUC                          | AUC versus dose | Point estimate response | Point estimate dose | Dose units  | Converted dose | Converted dose units | RPF   | Comments                                                  |  |
| 24590         | Nesnow et al., 1998b   | Lung                                                | BaP   |                              | 113             |                         |                     | mg/kg       |                |                      | 1     | Ratio of slopes of AUC versus dose as reported by authors |  |
|               |                        |                                                     | BbF   |                              | 38              |                         |                     | mg/kg       |                |                      | 0.33  |                                                           |  |
|               |                        |                                                     | CPcdP |                              | 148             |                         |                     | mg/kg       |                |                      | 1.3   |                                                           |  |
|               |                        |                                                     | DBahA |                              | 219             |                         |                     | mg/kg       |                |                      | 1.9   |                                                           |  |
|               |                        |                                                     | DBaP  |                              | 1,390           |                         |                     | mg/kg       |                |                      | 12    |                                                           |  |
| 22810         | Phillips et al., 1979  | Skin                                                | BaP   |                              |                 | 27                      | 1                   | µmol/animal | 0.25           | mg/animal            | 1     | Ratio of peak levels; peaks reached at different times    |  |
|               |                        |                                                     | DBacA |                              |                 | 10                      | 1                   | µmol/animal | 0.28           | mg/animal            | 0.34  |                                                           |  |
|               |                        |                                                     | DBahA |                              |                 | 15                      | 1                   | µmol/animal | 0.28           | mg/animal            | 0.50  |                                                           |  |
| 24790         | Kligerman et al., 2002 | Mouse peripheral blood lymphocytes/ intraperitoneal | BaP   |                              |                 | 4,186                   | 100                 | mg/kg       |                |                      | 1     | Ratio of single measure on d 7 postdosing                 |  |
|               |                        |                                                     | BaA   |                              |                 | 93                      | 100                 | mg/kg       |                |                      | 0.022 |                                                           |  |
|               |                        |                                                     | BbF   |                              |                 | 516                     | 100                 | mg/kg       |                |                      | 0.12  |                                                           |  |
|               |                        |                                                     | CH    |                              |                 | 81                      | 100                 | mg/kg       |                |                      | 0.019 |                                                           |  |
|               |                        | Mouse peripheral blood lymphocytes/ gavage          | BaP   |                              |                 | 143                     | 100                 | mg/kg       |                |                      | 1     |                                                           |  |
|               |                        |                                                     | BaA   |                              |                 | 32                      | 100                 | mg/kg       |                |                      | 0.22  |                                                           |  |
|               |                        |                                                     | BbF   |                              |                 | 39                      | 100                 | mg/kg       |                |                      | 0.27  |                                                           |  |
|               |                        |                                                     | CH    |                              |                 | 37                      | 100                 | mg/kg       |                |                      | 0.26  |                                                           |  |
|               |                        | Rat peripheral blood lymphocytes/ intraperitoneal   | BaP   |                              |                 | 755                     | 100                 | mg/kg       |                |                      | 1     |                                                           |  |
|               |                        |                                                     | BaA   |                              |                 | 38                      | 100                 | mg/kg       |                |                      | 0.05  |                                                           |  |
|               |                        |                                                     | BbF   |                              |                 | 63                      | 100                 | mg/kg       |                |                      | 0.083 |                                                           |  |
|               |                        |                                                     | CH    |                              |                 | 24                      | 100                 | mg/kg       |                |                      | 0.032 |                                                           |  |
|               |                        | Rat peripheral blood lymphocytes/ gavage            | BaP   |                              |                 | 177                     | 100                 | mg/kg       |                |                      | 1     |                                                           |  |
|               |                        |                                                     | BaA   |                              |                 | 20                      | 100                 | mg/kg       |                |                      | 0.11  |                                                           |  |
|               |                        |                                                     | BbF   |                              |                 | 17                      | 100                 | mg/kg       |                |                      | 0.1   |                                                           |  |
|               |                        |                                                     | CH    |                              |                 | 10                      | 100                 | mg/kg       |                |                      | 0.056 |                                                           |  |

**Table E-7. In vivo DNA adducts: RPF calculations**

| Record number | Reference           | Target organ(s)/route                       | PAH  | Relative potency calculation |                 |                         |                     |            |                |                      |     |          |  |
|---------------|---------------------|---------------------------------------------|------|------------------------------|-----------------|-------------------------|---------------------|------------|----------------|----------------------|-----|----------|--|
|               |                     |                                             |      | AUC                          | AUC versus dose | Point estimate response | Point estimate dose | Dose units | Converted dose | Converted dose units | RPF | Comments |  |
| 24801         | Weyand et al., 2004 | Sum of adducts in lung and forestomach/diet | BaP  |                              |                 | 0.117                   | 230                 | mg/kg food |                |                      |     | 1        |  |
|               |                     |                                             | BcFE |                              |                 | 0.191                   | 197                 | mg/kg food |                |                      |     | 1.9      |  |
|               |                     | Lung/ intraperitoneal                       | BaP  |                              |                 | 0.776                   | 100                 | mg/kg bw   |                |                      |     | 1        |  |
|               |                     |                                             | BcFE |                              |                 | 0.333                   | 100                 | mg/kg bw   |                |                      |     | 0.43     |  |

1  
2

**Table E-8. In vivo clastogenicity or sister chromatid exchange: RPF calculation**

| Record number | Reference                     | Route           | Endpoint                                   | Data type: quantal or continuous | PAH  | Relative potency calculation |     |                         |                     |            |       | Comments                                            |
|---------------|-------------------------------|-----------------|--------------------------------------------|----------------------------------|------|------------------------------|-----|-------------------------|---------------------|------------|-------|-----------------------------------------------------|
|               |                               |                 |                                            |                                  |      | BMR                          | BMD | Point estimate response | Point estimate dose | Dose units | RPF   |                                                     |
| 24740         | Allen et al., 1999            | Intraperitoneal | MN-PCEs in bone marrow (A/J mouse)         | Q                                | BaP  |                              |     | 0.0086                  | 200                 | mg/kg      | 1     |                                                     |
|               |                               |                 |                                            |                                  | DBaP |                              |     | 0.0013                  | 1.5                 | mg/kg      | 20    | Model won't predict BaP BMR; RPF based on peak      |
|               |                               | Intraperitoneal | MN-PCEs in peripheral blood (A/J mouse)    | Q                                | BaP  |                              |     | 0.0067                  | 200                 | mg/kg      | 1     |                                                     |
|               |                               |                 |                                            |                                  | DBaP |                              |     | 0.0015                  | 6                   | mg/kg      | 7.5   | Model won't predict BaP BMR; RPF based on peak      |
|               |                               | Intraperitoneal | MN-PCEs in bone marrow (p53 wt mouse)      | Q                                | BaP  |                              |     | 0.0019                  | 200                 | mg/kg      | 1     |                                                     |
|               |                               |                 |                                            |                                  | DBaP |                              |     | 0.0042                  | 12                  | mg/kg      | 37    | Model won't predict BaP BMR; RPF based on peak      |
|               |                               | Intraperitoneal | MN-PCEs in peripheral blood (p53 wt mouse) | Q                                | BaP  |                              |     | 0.0022                  | 200                 | mg/kg      | 1     |                                                     |
|               |                               |                 |                                            |                                  | DBaP |                              |     | 0.0011                  | 18                  | mg/kg      | 5.6   | BMD doesn't reflect selected BMR; RPF based on peak |
| 14270         | He and Baker, 1991            | Dermal          | Micronuclei                                | Q                                | BaP  |                              |     | 0.064                   | 50                  | µg/animal  | 1     | No model fit; RPF based on peak                     |
|               |                               |                 |                                            |                                  | CH   |                              |     | 0.05                    | 500                 | µg/animal  | 0.078 | No model fit; RPF based on peak                     |
| 17190         | Bayer, 1978                   | Intraperitoneal | Sister chromatid exchanges                 | C                                | BaP  |                              |     | 4.2                     | 100                 | mg/kg      | 1     | No model fit; RPF based on peak                     |
|               |                               |                 |                                            |                                  | PH   |                              |     | 0.9                     | 100                 | mg/kg      | 0.21  | No model fit; RPF based on peak                     |
| 20950         | Roszinsky-Kocher et al., 1979 | Intraperitoneal | Sister chromatid exchanges                 | C                                | BaP  |                              |     | 6.7                     | 900                 | mg/kg      | 1     |                                                     |
|               |                               |                 |                                            |                                  | DBaH |                              |     | 1                       | 900                 | mg/kg      | 0.15  |                                                     |
|               |                               |                 |                                            |                                  | CH   |                              |     | 1.2                     | 900                 | mg/kg      | 0.18  |                                                     |
|               |                               |                 |                                            |                                  | PH   |                              |     | 1.6                     | 900                 | mg/kg      | 0.24  |                                                     |
|               |                               |                 |                                            |                                  | BeP  |                              |     | 1.6                     | 900                 | mg/kg      | 0.24  |                                                     |
|               |                               |                 |                                            |                                  | BbF  |                              |     | 1.7                     | 900                 | mg/kg      | 0.25  |                                                     |

**Table E-8. In vivo clastogenicity or sister chromatid exchange: RPF calculation**

| Record number | Reference              | Route           | Endpoint                   | Data type: quantal or continuous | PAH  | Relative potency calculation |     |                         |                     |            |      |                                                              |
|---------------|------------------------|-----------------|----------------------------|----------------------------------|------|------------------------------|-----|-------------------------|---------------------|------------|------|--------------------------------------------------------------|
|               |                        |                 |                            |                                  |      | BMR                          | BMD | Point estimate response | Point estimate dose | Dose units | RPF  | Comments                                                     |
|               |                        |                 |                            |                                  | BaA  |                              |     | 2.2                     | 900                 | mg/kg      | 0.33 |                                                              |
| 24720         | Kligerman et al., 1986 | Gavage          | Sister chromatid exchanges | C                                | BaP  |                              |     | 8                       | 63                  | mg/kg      | 1    | No SD for control                                            |
|               |                        |                 |                            |                                  | BIAC |                              |     | 16                      | 126                 | mg/kg      | 1.1  | No SD for control; RPF based on lowest dose approaching peak |
| 24790         | Kligerman et al., 2002 | Intraperitoneal | Sister chromatid exchanges | C                                | BaP  |                              |     | 12.42                   | 100                 | mg/kg      | 1    |                                                              |
|               |                        |                 |                            |                                  | BaA  |                              |     | 6.01                    | 100                 | mg/kg      | 0.48 |                                                              |
|               |                        |                 |                            |                                  | BbF  |                              |     | 13.46                   | 100                 | mg/kg      | 1.1  |                                                              |
|               |                        |                 |                            |                                  | CH   |                              |     | 3.17                    | 100                 | mg/kg      | 0.26 |                                                              |
|               |                        | Gavage          | Sister chromatid exchanges | C                                | BaP  |                              |     | 6.79                    | 100                 | mg/kg      | 1    |                                                              |
|               |                        |                 |                            |                                  | BaA  |                              |     | 2.26                    | 100                 | mg/kg      | 0.33 |                                                              |
|               |                        | Gavage          | Micronuclei                | Q                                | BaP  |                              |     | 0.0025                  | 100                 | mg/kg      | 1    |                                                              |
|               |                        |                 |                            |                                  | BbF  |                              |     | 0.0017                  | 100                 | mg/kg      | 0.68 |                                                              |

1  
2  
3

**Table E-9. In vitro bacterial mutagenicity: RPF calculations**

| Record number | Reference               | PAH   | Data type: quantal or continuous | Relative potency calculation |     |       |                         |                     |            |                |                      |       | Comments                                                                                                                                                   |
|---------------|-------------------------|-------|----------------------------------|------------------------------|-----|-------|-------------------------|---------------------|------------|----------------|----------------------|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
|               |                         |       |                                  | BMR                          | BMD | Slope | Point estimate response | Point estimate dose | Dose units | Converted dose | Converted dose units | RPF   |                                                                                                                                                            |
| 17030         | Andrews et al., 1978    | BaP   | C                                |                              |     |       | 1,531                   | 250                 | µg         |                |                      | 1     |                                                                                                                                                            |
|               |                         | DBacA | C                                |                              |     |       | 2,807                   | 10                  | µg         |                |                      | 46    |                                                                                                                                                            |
|               |                         | DBajA | C                                |                              |     |       | 693                     | 10                  | µg         |                |                      | 11    |                                                                                                                                                            |
|               |                         | DBahA | C                                |                              |     |       | 467                     | 25                  | µg         |                |                      | 3     |                                                                                                                                                            |
|               |                         | AA    | C                                |                              |     |       | 1,645                   | 250                 | µg         |                |                      | 1.1   |                                                                                                                                                            |
|               |                         | BghiP | C                                |                              |     |       | 642                     | 100                 | µg         |                |                      | 1     |                                                                                                                                                            |
|               |                         | BeP   | C                                |                              |     |       | 492                     | 1,000               | µg         |                |                      | 0.08  |                                                                                                                                                            |
| 23830         | Baker et al., 1980      | BaP   | C                                |                              |     |       | 1,144                   | 2.5                 | µg/plate   |                |                      | 1     |                                                                                                                                                            |
|               |                         | DBaiP | C                                |                              |     |       | 603                     | 5                   | µg/plate   |                |                      | 0.26  |                                                                                                                                                            |
|               |                         | BaA   | C                                |                              |     |       | 813                     | 10                  | µg/plate   |                |                      | 0.18  |                                                                                                                                                            |
|               |                         | DBacA | C                                |                              |     |       | 1,604                   | 2.5                 | µg/plate   |                |                      | 1.4   |                                                                                                                                                            |
|               |                         | DBahA | C                                |                              |     |       | 1,197                   | 5                   | µg/plate   |                |                      | 0.52  |                                                                                                                                                            |
| 23660         | Bartsch et al., 1980    | BaP   | C                                |                              |     |       | 29,000                  | 0.027               | µmol/plate | 0.007          | mg/plate             | 1     |                                                                                                                                                            |
|               |                         | BaA   | C                                |                              |     |       | 6,000                   | 0.067               | µmol/plate | 0.015          | mg/plate             | 0.092 |                                                                                                                                                            |
| 17380         | Bos et al., 1988        | BaP   | C                                |                              |     |       | 739                     | 7.5                 | µg/plate   |                |                      | 1     | RPF based on peak response; BaP response well above range for other data sets; model fit required dropping high doses but not appropriate given BMR target |
|               |                         | PH    | C                                |                              |     |       | 155                     | 25                  | µg/plate   |                |                      | 0.063 |                                                                                                                                                            |
|               |                         | Pyr   | C                                |                              |     |       | 193                     | 25                  | µg/plate   |                |                      | 0.078 |                                                                                                                                                            |
| 17590         | Carver et al., 1986     | BaP   | C                                |                              |     |       | 895                     | 50                  | µg/plate   |                |                      | 1     | Continuous data, no SD; RPF based on peak or lowest dose approaching peak                                                                                  |
|               |                         | BaA   | C                                |                              |     |       | 1,123                   | 50                  | µg/plate   |                |                      | 1.3   |                                                                                                                                                            |
|               |                         | BghiF | C                                |                              |     |       | 845                     | 50                  | µg/plate   |                |                      | 0.94  |                                                                                                                                                            |
|               |                         | Pery  | C                                |                              |     |       | 853                     | 10                  | µg/plate   |                |                      | 4.8   | Uses S9 level with max BaP response; max Pery response at a different S9                                                                                   |
| 17630         | Cavalieri et al., 1981a | BaP   | Q                                |                              |     |       | 0.00126                 | 60                  | µM         | 15.1           | mg/L                 | 1     | RPF based on peak; no model fit                                                                                                                            |
|               |                         | CPcdP | Q                                |                              |     |       | 0.0013                  | 40                  | µM         | 9.1            | mg/L                 | 1.7   | RPF based on peak; no model fit                                                                                                                            |

**Table E-9. In vitro bacterial mutagenicity: RPF calculations**

| Record number | Reference                 | PAH   | Data type: quantal or continuous | Relative potency calculation |     |       |                         |                     |                 |                |                      |       | RPF                                                                                                                | Comments |
|---------------|---------------------------|-------|----------------------------------|------------------------------|-----|-------|-------------------------|---------------------|-----------------|----------------|----------------------|-------|--------------------------------------------------------------------------------------------------------------------|----------|
|               |                           |       |                                  | BMR                          | BMD | Slope | Point estimate response | Point estimate dose | Dose units      | Converted dose | Converted dose units |       |                                                                                                                    |          |
|               |                           | ACEP  | Q                                |                              |     |       | 0.0005                  | 120                 | µM              | 27.4           | mg/L                 | 0.22  | RPF based on peak; BMD doesn't coincide with selected BMR                                                          |          |
| 9620          | Chang et al., 2002        | BaP   | C                                |                              |     |       | 2,217                   | 5                   | µg/plate        |                |                      | 1     | Continuous data, no SD; RPF based on peak or lowest dose approaching peak                                          |          |
|               |                           | BghiF | C                                |                              |     |       | 1,304                   | 5                   | µg/plate        |                |                      | 0.59  |                                                                                                                    |          |
|               |                           | BcPH  | C                                |                              |     |       | 717                     | 10                  | µg/plate        |                |                      | 0.16  |                                                                                                                    |          |
| 24030         | De Flora et al., 1984     | BaP   | NA                               |                              |     | 185   |                         |                     | revertants/nmol | 733,196        | revertants/mg        | 1     | RPFs based on potency estimates as reported by authors                                                             |          |
|               |                           | BaA   | NA                               |                              |     | 12    |                         |                     | revertants/nmol | 52,565         | revertants/mg        | 0.072 |                                                                                                                    |          |
|               |                           | BeP   | NA                               |                              |     | 1.6   |                         |                     | revertants/nmol | 6,341          | revertants/mg        | 0.009 |                                                                                                                    |          |
|               |                           | Pery  | NA                               |                              |     | 21    |                         |                     | revertants/nmol | 83,229         | revertants/mg        | 0.11  |                                                                                                                    |          |
| 18050         | Eisenstadt and Gold, 1978 | BaP   | C                                |                              |     |       | 1,705                   | 2                   | µg              |                |                      | 1     | Uses S9 level with max BaP response; CPcdP max at much lower S9                                                    |          |
|               |                           | CPcdP | C                                |                              |     |       | 134                     | 1                   | µg              |                |                      | 0.16  |                                                                                                                    |          |
| 18180         | Florin et al., 1980       | BaP   | C                                |                              |     |       | 255                     | 0.003               | µmol/plate      | 0.001          | mg/plate             | 1     | TA100                                                                                                              |          |
|               |                           | BaA   | C                                |                              |     |       | 326                     | 0.1                 | µmol/plate      | 0.023          | mg/plate             | 0.042 |                                                                                                                    |          |
|               |                           | CH    | C                                |                              |     |       | 196                     | 0.005               | µmol/plate      | 0.001          | mg/plate             | 0.51  |                                                                                                                    |          |
|               |                           | BaP   | C                                |                              |     |       | 235                     | 0.003               | µmol/plate      | 0.001          | mg/plate             | 1     | TA 98                                                                                                              |          |
|               |                           | CO    | C                                |                              |     |       | 82                      | 0.07                | µmol/plate      | 0.021          | mg/plate             | 0.013 |                                                                                                                    |          |
|               |                           | Pery  | C                                |                              |     |       | 91                      | 0.025               | µmol/plate      | 0.006          | mg/plate             | 0.046 |                                                                                                                    |          |
| 24080         | Gibson et al., 1978       | BaP   | C                                |                              |     |       | 35                      | 300                 | µg/plate        |                |                      | 1     | Continuous data, no SD; RPF based on peak or lowest dose approaching peak; metabolic activation by gamma radiation |          |
|               |                           | BaA   | C                                |                              |     |       | 6.4                     | 250                 | µg/plate        |                |                      | 0.22  |                                                                                                                    |          |
|               |                           | BghiP | C                                |                              |     |       | 4.2                     | 400                 | µg/plate        |                |                      | 0.090 |                                                                                                                    |          |
|               |                           | CH    | C                                |                              |     |       | 6.1                     | 500                 | µg/plate        |                |                      | 0.1   | Lowest dose approaching peak                                                                                       |          |
|               |                           | FE    | C                                |                              |     |       | 2.2                     | 360                 | µg/plate        |                |                      | 0.052 |                                                                                                                    |          |
|               |                           | Pyr   | C                                |                              |     |       | 28                      | 160                 | µg/plate        |                |                      | 1.5   |                                                                                                                    |          |

**Table E-9. In vitro bacterial mutagenicity: RPF calculations**

| Record number | Reference                 | PAH   | Data type: quantal or continuous | Relative potency calculation |     |       |                         |                     |                 |                |                      |       | Comments                                               |
|---------------|---------------------------|-------|----------------------------------|------------------------------|-----|-------|-------------------------|---------------------|-----------------|----------------|----------------------|-------|--------------------------------------------------------|
|               |                           |       |                                  | BMR                          | BMD | Slope | Point estimate response | Point estimate dose | Dose units      | Converted dose | Converted dose units | RPF   |                                                        |
| 14080         | Gold and Eisenstadt, 1980 | BaP   | C                                |                              |     |       | 1,103                   | 4                   | nmol            | 0.001          | mg                   | 1     |                                                        |
|               |                           | CPcdP | C                                |                              |     |       | 281                     | 4                   | nmol            | 0.001          | mg                   | 0.28  |                                                        |
| 18650         | Hermann, 1981             | BaP   | NA                               |                              |     | 100   |                         |                     | revertants/nmol | 396,322        | revertants/mg        | 1     | RPFs based on potency estimates as reported by authors |
|               |                           | AA    | NA                               |                              |     | 62    |                         |                     | revertants/nmol | 224,394        | revertants/mg        | 0.57  |                                                        |
|               |                           | BaA   | NA                               |                              |     | 4     |                         |                     | revertants/nmol | 17,522         | revertants/mg        | 0.044 |                                                        |
|               |                           | BbA   | NA                               |                              |     | 8     |                         |                     | revertants/nmol | 35,043         | revertants/mg        | 0.088 |                                                        |
|               |                           | BbF   | NA                               |                              |     | 15    |                         |                     | revertants/nmol | 59,448         | revertants/mg        | 0.15  |                                                        |
|               |                           | BeP   | NA                               |                              |     | 15    |                         |                     | revertants/nmol | 59,449         | revertants/mg        | 0.15  |                                                        |
|               |                           | CH    | NA                               |                              |     | 2     |                         |                     | revertants/nmol | 8,761          | revertants/mg        | 0.022 |                                                        |
|               |                           | CO    | NA                               |                              |     | 60    |                         |                     | revertants/nmol | 199,761        | revertants/mg        | 0.50  |                                                        |
|               |                           | DBacA | NA                               |                              |     | 42    |                         |                     | revertants/nmol | 150,888        | revertants/mg        | 0.38  |                                                        |
|               |                           | DBahA | NA                               |                              |     | 8     |                         |                     | revertants/nmol | 28,743         | revertants/mg        | 0.073 |                                                        |
|               |                           | DBaiP | NA                               |                              |     | 38    |                         |                     | revertants/nmol | 125,661        | revertants/mg        | 0.32  |                                                        |
|               |                           | DBalP | NA                               |                              |     | 21    |                         |                     | revertants/nmol | 69,451         | revertants/mg        | 0.18  |                                                        |
|               |                           | FA    | NA                               |                              |     | 3     |                         |                     | revertants/nmol | 14,832         | revertants/mg        | 0.037 |                                                        |
|               |                           | Pery  | NA                               |                              |     | 31    |                         |                     | revertants/nmol | 122,862        | revertants/mg        | 0.31  |                                                        |
|               |                           | Tphen | NA                               |                              |     | 13    |                         |                     | revertants/nmol | 56,944         | revertants/mg        | 0.14  |                                                        |
| 10670         | Johnsen et al., 1997      | BaP   | C                                |                              |     |       | 128                     | 10                  | µg/plate        |                |                      | 1     |                                                        |
|               |                           | BjAC  | C                                |                              |     |       | 192                     | 10                  | µg/plate        |                |                      | 1.5   | RPF based on peak; no model fit                        |
|               |                           | BIAC  | C                                |                              |     |       | 204                     | 10                  | µg/plate        |                |                      | 1.6   | RPF based on peak; no model fit                        |
| 19000         | Kaden et al., 1979        | BaP   | NA                               |                              |     |       |                         |                     |                 |                |                      | 1     | RPFs as reported by authors                            |
|               |                           | AA    | NA                               |                              |     |       |                         |                     |                 |                |                      | 0.08  |                                                        |
|               |                           | AN    | NA                               |                              |     |       |                         |                     |                 |                |                      | 0.01  |                                                        |
|               |                           | ANL   | NA                               |                              |     |       |                         |                     |                 |                |                      | 0.07  |                                                        |
|               |                           | BaA   | NA                               |                              |     |       |                         |                     |                 |                |                      | 0.14  |                                                        |
|               |                           | BbFE  | NA                               |                              |     |       |                         |                     |                 |                |                      | 0.08  |                                                        |
|               |                           | BeP   | NA                               |                              |     |       |                         |                     |                 |                |                      | 0.11  |                                                        |
|               |                           | BghiP | NA                               |                              |     |       |                         |                     |                 |                |                      | 0.08  |                                                        |
|               |                           | CH    | NA                               |                              |     |       |                         |                     |                 |                |                      | 0.2   |                                                        |
|               |                           | CPcdP | NA                               |                              |     |       |                         |                     |                 |                |                      | 1.5   |                                                        |
|               |                           | DBacA | NA                               |                              |     |       |                         |                     |                 |                |                      | 0.77  |                                                        |
|               |                           | DBahA | NA                               |                              |     |       |                         |                     |                 |                |                      | 0.08  |                                                        |

**Table E-9. In vitro bacterial mutagenicity: RPF calculations**

| Record number | Reference                  | PAH      | Data type: quantal or continuous | Relative potency calculation |     |       |                         |                     |                 |                |                      |  | RPF   | Comments                                                                                             |
|---------------|----------------------------|----------|----------------------------------|------------------------------|-----|-------|-------------------------|---------------------|-----------------|----------------|----------------------|--|-------|------------------------------------------------------------------------------------------------------|
|               |                            |          |                                  | BMR                          | BMD | Slope | Point estimate response | Point estimate dose | Dose units      | Converted dose | Converted dose units |  |       |                                                                                                      |
|               |                            | DBbeF    | NA                               |                              |     |       |                         |                     |                 |                |                      |  | 0.88  |                                                                                                      |
|               |                            | FA       | NA                               |                              |     |       |                         |                     |                 |                |                      |  | 1     |                                                                                                      |
|               |                            | Pery     | NA                               |                              |     |       |                         |                     |                 |                |                      |  | 6     |                                                                                                      |
|               |                            | Pyr      | NA                               |                              |     |       |                         |                     |                 |                |                      |  | 0.07  |                                                                                                      |
|               |                            | Tphen    | NA                               |                              |     |       |                         |                     |                 |                |                      |  | 0.07  |                                                                                                      |
| 24680         | Lafleur et al., 1993       | BaP      | Q                                |                              |     |       | 0.00026                 | 8                   | µg/mL           |                |                      |  | 1     | RPF based on peak; BMD doesn't coincide with selected BMR                                            |
|               |                            | BghiF    | Q                                |                              |     |       | 0.00044                 | 10                  | µg/mL           |                |                      |  | 1.4   |                                                                                                      |
|               |                            | CPcdP    | Q                                |                              |     |       | 0.00048                 | 8                   | µg/mL           |                |                      |  | 1.9   |                                                                                                      |
|               |                            | CPhiACEA | Q                                |                              |     |       | 0.00059                 | 4                   | µg/mL           |                |                      |  | 4.6   |                                                                                                      |
|               |                            | CPhiAPA  | Q                                |                              |     |       | 0.00017                 | 100                 | µg/mL           |                |                      |  | 0.05  |                                                                                                      |
|               |                            | ACEA     | Q                                |                              |     |       | 0.00059                 | 35                  | µg/mL           |                |                      |  | 0.53  |                                                                                                      |
|               |                            | APA      | Q                                |                              |     |       | 0.00026                 | 30                  | µg/mL           |                |                      |  | 0.27  |                                                                                                      |
| 19320         | LaVoie et al., 1979        | BaP      | C                                |                              |     |       | 480                     | 20                  | µg              |                |                      |  | 1     | Continuous data, no SD; RPF based on peak or lowest dose approaching peak                            |
|               |                            | BeP      | C                                |                              |     |       | 20                      | 10                  | µg              |                |                      |  | 0.08  |                                                                                                      |
|               |                            | Pery     | C                                |                              |     |       | 70                      | 20                  | µg              |                |                      |  | 0.15  |                                                                                                      |
| 23650         | McCann et al., 1975        | BaP      | NA                               |                              |     | 121   |                         |                     | revertants/nmol | 479,550        | revertants/mg        |  | 1     | RPFs based on potency estimates as reported by authors; authors caution that dose-response nonlinear |
|               |                            | BaA      | NA                               |                              |     | 11    |                         |                     | revertants/nmol | 48,184         | revertants/mg        |  | 0.10  |                                                                                                      |
|               |                            | BeP      | NA                               |                              |     | 0.6   |                         |                     | revertants/nmol | 2,378          | revertants/mg        |  | 0.005 |                                                                                                      |
|               |                            | CH       | NA                               |                              |     | 38    |                         |                     | revertants/nmol | 166,455        | revertants/mg        |  | 0.35  |                                                                                                      |
|               |                            | DBacA    | NA                               |                              |     | 175   |                         |                     | revertants/nmol | 628,698        | revertants/mg        |  | 1.3   |                                                                                                      |
|               |                            | DBahA    | NA                               |                              |     | 11    |                         |                     | revertants/nmol | 39,521         | revertants/mg        |  | 0.082 |                                                                                                      |
|               |                            | DBaiP    | NA                               |                              |     | 20    |                         |                     | revertants/nmol | 66,138         | revertants/mg        |  | 0.14  |                                                                                                      |
| 20220         | Pahlman and Pelkonen, 1987 | BaP      | NA                               |                              |     | 272   |                         |                     | revertants/mg   | 1,077,996      | revertants/mg        |  | 1     | RPFs based on potency estimates as reported by authors                                               |
|               |                            | BaA      | NA                               |                              |     | 10    |                         |                     | revertants/mg   | 43,804         | revertants/mg        |  | 0.041 |                                                                                                      |
|               |                            | CH       | NA                               |                              |     | 9.7   |                         |                     | revertants/mg   | 42,490         | revertants/mg        |  | 0.039 |                                                                                                      |
|               |                            | DBacA    | NA                               |                              |     | 35    |                         |                     | revertants/mg   | 125,740        | revertants/mg        |  | 0.12  |                                                                                                      |
|               |                            | DBahA    | NA                               |                              |     | 4     |                         |                     | revertants/mg   | 14,371         | revertants/mg        |  | 0.013 |                                                                                                      |
|               |                            | Tphen    | NA                               |                              |     | 4     |                         |                     | revertants/mg   | 17,521         | revertants/mg        |  | 0.016 |                                                                                                      |

**Table E-9. In vitro bacterial mutagenicity: RPF calculations**

| Record number | Reference                      | PAH   | Data type: quantal or continuous | Relative potency calculation |     |       |                         |                     |            |                |                      |       | RPF                                                       | Comments |
|---------------|--------------------------------|-------|----------------------------------|------------------------------|-----|-------|-------------------------|---------------------|------------|----------------|----------------------|-------|-----------------------------------------------------------|----------|
|               |                                |       |                                  | BMR                          | BMD | Slope | Point estimate response | Point estimate dose | Dose units | Converted dose | Converted dose units |       |                                                           |          |
| 20450         | Phillipson and Ioannides, 1989 | BaP   | C                                |                              |     |       | 119                     | 10                  | µg/plate   |                |                      | 1     | No SD; RPFs based on peak or lowest dose approaching peak |          |
|               |                                | BaA   | C                                |                              |     |       | 110                     | 20                  | µg/plate   |                |                      | 0.46  |                                                           |          |
|               |                                | DBaiP | C                                |                              |     |       | 65                      | 20                  | µg/plate   |                |                      | 0.27  |                                                           |          |
|               |                                | DBahA | C                                |                              |     |       | 51                      | 10                  | µg/plate   |                |                      | 0.43  |                                                           |          |
| 21000         | Sakai et al., 1985             | BaP   | C                                |                              |     |       | 1,565                   | 10                  | µg         |                |                      | 1     | No SD; RPFs based on peak or lowest dose approaching peak |          |
|               |                                | FE    | C                                |                              |     |       | 65                      | 5                   | µg         |                |                      | 0.083 |                                                           |          |
|               |                                | AC    | C                                |                              |     |       | 320                     | 10                  | µg         |                |                      | 0.2   |                                                           |          |
|               |                                | PH    | C                                |                              |     |       | 345                     | 10                  | µg         |                |                      | 0.22  |                                                           |          |
|               |                                | FA    | C                                |                              |     |       | 835                     | 10                  | µg         |                |                      | 0.53  |                                                           |          |
|               |                                | CH    | C                                |                              |     |       | 638                     | 10                  | µg         |                |                      | 0.41  |                                                           |          |
|               |                                | Pyr   | C                                |                              |     |       | 2,400                   | 10                  | µg         |                |                      | 1.5   |                                                           |          |
|               |                                | BeP   | C                                |                              |     |       | 923                     | 10                  | µg         |                |                      | 0.59  |                                                           |          |
|               |                                | Pery  | C                                |                              |     |       | 2,607                   | 4                   | µg         |                |                      | 4.2   |                                                           |          |
|               |                                | BghiP | C                                |                              |     |       | 814                     | 20                  | µg         |                |                      | 0.26  |                                                           |          |
|               |                                | CO    | C                                |                              |     |       | 223                     | 10                  | µg         |                |                      | 0.14  |                                                           |          |
| 11860         | Sangaiah et al., 1983          | BaP   | C                                |                              |     |       | 384                     | 6                   | µg/plate   |                |                      | 1     | No SD; RPFs based on peak or lowest dose approaching peak |          |
|               |                                | BjAC  | C                                |                              |     |       | 940                     | 10                  | µg/plate   |                |                      | 1.4   |                                                           |          |
| 21360         | Simmon, 1979a                  | BaP   | C                                |                              |     |       | 1,141                   | 5                   | µg         |                |                      | 1     |                                                           |          |
|               |                                | BaA   | C                                |                              |     |       | 280                     | 50                  | µg         |                |                      | 0.025 |                                                           |          |
|               |                                | BeP   | C                                |                              |     |       | 57                      | 50                  | µg         |                |                      | 0.005 |                                                           |          |
| 21640         | Teranishi et al., 1975         | BaP   | C                                |                              |     |       | 39                      | 50                  | µg/plate   |                |                      | 1     |                                                           |          |
|               |                                | DBaiP | C                                |                              |     |       | 64                      | 50                  | µg/plate   |                |                      | 1.6   |                                                           |          |
|               |                                | BaP   |                                  |                              |     |       | 254                     | 50                  | µg/plate   |                |                      | 1     |                                                           |          |
|               |                                | DBaeP |                                  |                              |     |       | 63                      | 50                  | µg/plate   |                |                      | 0.25  |                                                           |          |
| 16180         | Utesch et al., 1987            | BaP   | C                                |                              |     |       | 839                     | 6                   | µg/plate   |                |                      | 1     | No SD; RPF based on peak or lowest dose approaching peak  |          |
|               |                                | BaA   | C                                |                              |     |       | 3,347                   | 25                  | µg/plate   |                |                      | 1     |                                                           |          |

**Table E-9. In vitro bacterial mutagenicity: RPF calculations**

| Record number | Reference         | PAH   | Data type: quantal or continuous | Relative potency calculation |     |       |                         |                     |            |                |                      |     | RPF                                                      | Comments |
|---------------|-------------------|-------|----------------------------------|------------------------------|-----|-------|-------------------------|---------------------|------------|----------------|----------------------|-----|----------------------------------------------------------|----------|
|               |                   |       |                                  | BMR                          | BMD | Slope | Point estimate response | Point estimate dose | Dose units | Converted dose | Converted dose units |     |                                                          |          |
| 16440         | Wood et al., 1980 | BaP   | C                                |                              |     |       | 99                      | 15                  | µg/plate   |                |                      | 1   | No SD; RPF based on peak or lowest dose approaching peak |          |
|               |                   | CPcdP | C                                |                              |     |       | 685                     | 15                  | µg/plate   |                |                      | 6.9 |                                                          |          |

1  
2

**Table E-10. In vitro mammalian mutagenicity: RPF calculations**

| Record number | Reference                 | PAH    | Relative potency calculation |     |                         |                       |            |                |                      |      |                                                                                                                                                                                                                   |
|---------------|---------------------------|--------|------------------------------|-----|-------------------------|-----------------------|------------|----------------|----------------------|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|               |                           |        | BMR                          | BMD | Point estimate response | Point estimate dose   | Dose units | Converted dose | Converted dose units | RPF  | Comments                                                                                                                                                                                                          |
| 16920         | Amacher and Paillet, 1982 | BaP    |                              |     | 0.00023                 | 10                    | µg/mL      |                |                      | 1    | No model fit; RPF based on peak                                                                                                                                                                                   |
|               |                           | BaA    |                              |     | 0.000068                | 10                    | µg/mL      |                |                      | 0.3  | No model fit; RPF based on peak                                                                                                                                                                                   |
| 16940         | Amacher and Turner, 1980  | BaP    |                              |     | 0.00025                 | $1.25 \times 10^{-5}$ | M          | 3.15           | mg/L                 | 1    | Control without S9 treatment                                                                                                                                                                                      |
|               |                           | BaA    |                              |     | 0.00027                 | $3.22 \times 10^{-5}$ | M          | 7.35           | mg/L                 | 0.46 |                                                                                                                                                                                                                   |
| 16910         | Amacher et al., 1980      | BaP    |                              |     | 0.00033                 | $3.96 \times 10^{-5}$ | M          | 9.99           | mg/L                 | 1    | No model fit; RPF based on peak                                                                                                                                                                                   |
|               |                           | BaA    |                              |     | 0.00007                 | $4.3 \times 10^{-5}$  | M          | 9.82           | mg/L                 | 0.22 | BMD doesn't coincide with selected BMR; RPF based on peak                                                                                                                                                         |
| 17140         | Barfknecht et al., 1982   | BaP    | 0.00001                      | 1.8 |                         |                       | µM         | 0.45           | mg/L                 | 1    |                                                                                                                                                                                                                   |
|               |                           | BaA    | 0.00001                      | 23  |                         |                       | µM         | 5.25           | mg/L                 | 0.09 |                                                                                                                                                                                                                   |
|               |                           | CH     | 0.00001                      | 16  |                         |                       | µM         | 3.65           | mg/L                 | 0.12 |                                                                                                                                                                                                                   |
|               |                           | CPcdP  |                              |     | 0.0000083               | 23                    | µM         | 5.20           | mg/L                 | 0.07 | BMD doesn't coincide with selected BMR; RPF based on response closest to BMR of 0.00001                                                                                                                           |
|               |                           | FA     | 0.00001                      | 3.9 |                         |                       | µM         | 0.79           | mg/L                 | 0.58 |                                                                                                                                                                                                                   |
|               |                           | Tphen  | 0.00001                      | 54  |                         |                       | µM         | 12.33          | mg/L                 | 0.04 |                                                                                                                                                                                                                   |
| 24670         | Durant et al., 1999       | BaP    |                              |     | 0.00017                 | 1,000                 | ng/mL      |                |                      | 1    | RPF based on peak response; single dose BaP response at upper end or above data range for most other data sets; model fit required dropping high doses but not appropriate given BMR target at BaP response level |
|               |                           | BaPery |                              |     | 0.00018                 | 100                   | ng/mL      |                |                      | 11   |                                                                                                                                                                                                                   |
|               |                           | BbPery |                              |     | 0.000036                | 100                   | ng/mL      |                |                      | 2.2  |                                                                                                                                                                                                                   |
|               |                           | DBaeF  |                              |     | 0.00017                 | 100                   | ng/mL      |                |                      | 10   |                                                                                                                                                                                                                   |
|               |                           | DBaFF  |                              |     | 0.00017                 | 1,000                 | ng/mL      |                |                      | 1    |                                                                                                                                                                                                                   |
|               |                           | DBaHP  |                              |     | 0.000061                | 100                   | ng/mL      |                |                      | 3.7  |                                                                                                                                                                                                                   |
|               |                           | DBaIP  |                              |     | 0.00013                 | 100                   | ng/mL      |                |                      | 7.8  |                                                                                                                                                                                                                   |
|               |                           | DBeIP  |                              |     | 0.000034                | 1,000                 | ng/mL      |                |                      | 0.21 |                                                                                                                                                                                                                   |
|               |                           | N23aP  |                              |     | 0.000073                | 100                   | ng/mL      |                |                      | 4.4  |                                                                                                                                                                                                                   |

**Table E-10. In vitro mammalian mutagenicity: RPF calculations**

| Record number | Reference                    | PAH      | Relative potency calculation |     |                         |                     |            |                |                      |       |                                                         |
|---------------|------------------------------|----------|------------------------------|-----|-------------------------|---------------------|------------|----------------|----------------------|-------|---------------------------------------------------------|
|               |                              |          | BMR                          | BMD | Point estimate response | Point estimate dose | Dose units | Converted dose | Converted dose units | RPF   | Comments                                                |
|               |                              | N23eP    |                              |     | 0.000079                | 1,000               | ng/mL      |                |                      | 0.48  |                                                         |
| 14250         | Hass et al., 1982            | BaP      |                              |     | 0.00026                 | 0.3                 | µg/mL      |                |                      | 1     | No model fit; response at low dose (approaching peak)   |
|               |                              | DBaiP    |                              |     | 0.0012                  | 0.3                 | µg/mL      |                |                      | 4.6   | No model fit; RPF based on peak                         |
|               |                              | DBahP    |                              |     | 0.00066                 | 0.3                 | µg/mL      |                |                      | 2.5   | No model fit; RPF based on peak                         |
| 18740         | Huberman and Sachs, 1976     | BaP      |                              |     | 0.0042                  | 1                   | µg/mL      |                |                      | 1     |                                                         |
|               |                              | DBacA    |                              |     | 0.00016                 | 1                   | µg/mL      |                |                      | 0.04  |                                                         |
|               |                              | DBahA    |                              |     | 0.00011                 | 1                   | µg/mL      |                |                      | 0.03  |                                                         |
| 18990         | Jotz and Mitchell, 1981      | BaP      |                              |     | 0.00014                 | 4.5                 | µg/mL      |                |                      | 1     | With metabolic activation                               |
|               |                              | Pyr      |                              |     | 0.000034                | 11                  | µg/mL      |                |                      | 0.1   | With metabolic activation                               |
| 24720         | Kligerman et al., 1986       | BaP      |                              |     | 0.00047                 | 4                   | nmol/mL    | 0.001          | mg/mL                | 1     | No model fit; RPF based on peak                         |
|               |                              | BIAC     |                              |     | 0.00028                 | 5                   | nmol/mL    | 0.0013         | mg/mL                | 0.48  | No model fit; RPF based on peak                         |
| 19180         | Krahn and Heidelberger, 1977 | BaP      |                              |     | 0.00012                 | 15.9                | nmol/mL    | 0.004          | mg/mL                | 1     | 3-MC S9; 40% survival                                   |
|               |                              | BaA      |                              |     | 0.00005                 | 46.5                | nmol/mL    | 0.011          | mg/mL                | 0.16  | 3-MC S9; 40% survival                                   |
| 24680         | Lafleur et al., 1993         | BaP      |                              |     | 0.000024                | 0.2                 | µg/mL      |                |                      | 1     | No model fit                                            |
|               |                              | ACEA     |                              |     | 0.000013                | 3                   | µg/mL      |                |                      | 0.037 | No model fit                                            |
|               |                              | CPcdP    |                              |     | 0.000015                | 2                   | µg/mL      |                |                      | 0.061 | No model fit                                            |
|               |                              | CPhiACEA |                              |     | 0.000022                | 0.3                 | µg/mL      |                |                      | 0.62  | No model fit                                            |
| 7550          | Li and Lin, 1996             | BaP      |                              |     | 0.00003                 | 10                  | ng/mL      |                |                      | 1     |                                                         |
|               |                              | BaA      |                              |     | 0.000036                | 10                  | ng/mL      |                |                      | 1.2   |                                                         |
| 11450         | Nesnow et al., 1984          | BaP      |                              |     | 0.00019                 | 5                   | µg/mL      |                |                      | 1     |                                                         |
|               |                              | BeAC     |                              |     | 0.00042                 | 5                   | µg/mL      |                |                      | 2.2   | No model fit; RPF based on lowest dose approaching peak |

**Table E-10. In vitro mammalian mutagenicity: RPF calculations**

| Record number | Reference                       | PAH   | Relative potency calculation |       |                         |                     |            |                |                      |          |                                                           |
|---------------|---------------------------------|-------|------------------------------|-------|-------------------------|---------------------|------------|----------------|----------------------|----------|-----------------------------------------------------------|
|               |                                 |       | BMR                          | BMD   | Point estimate response | Point estimate dose | Dose units | Converted dose | Converted dose units | RPF      | Comments                                                  |
|               |                                 | BjAC  |                              |       | 0.00025                 | 5                   | µg/mL      |                |                      | 1.3      | No model fit; RPF based on lowest dose approaching peak   |
|               |                                 | BIAC  |                              |       | 0.00044                 | 2.5                 | µg/mL      |                |                      | 4.6      | No model fit; RPF based on lowest dose approaching peak   |
| 15630         | Raveh and Huberman, 1983        | BaP   | 0.0001                       | 0.11  |                         |                     | µg/mL      |                |                      | 1        |                                                           |
|               |                                 | CPcdP | 0.0001                       | 0.58  |                         |                     | µg/mL      |                |                      | 0.18     | Uses QL; MS didn't converge                               |
| 15640         | Raveh et al., 1982              | BaP   | 0.00001                      | 0.16  |                         |                     | µg/mL      |                |                      | 1        | Uses QL, high dose dropped; MS didn't fit                 |
|               |                                 | CPcdP | 0.00001                      | 1.1   |                         |                     | µg/mL      |                |                      | 0.14     | Uses QL; MS didn't converge                               |
| 21410         | Slaga et al., 1978              | BaP   | 0.0001                       | 0.048 |                         |                     | µM         | 0.012          | mg/L                 | 1        |                                                           |
|               |                                 | BaA   | 0.0001                       | 32    |                         |                     | µM         | 7.3            | mg/L                 | 0.001658 |                                                           |
| 16190         | Vaca et al., 1992               | BaP   |                              |       | 0.00027                 | 10                  | µM         | 2.5            | mg/L                 | 1        | BMD doesn't coincide with selected BMR; RPF based on peak |
|               |                                 | FA    |                              |       | 0.00021                 | 10                  | µM         | 2.02           | mg/L                 | 0.97     | BMD doesn't coincide with selected BMR; RPF based on peak |
| 21900         | Wangenheim and Bolcsfoldi, 1988 | BaP   |                              |       | 0.0008                  | 0.00001             | mol/L      | 2.5            | mg/L                 | 1        | BMD doesn't coincide with selected BMR; RPF based on peak |
|               |                                 | FE    |                              |       | 0.000086                | 0.00012             | mol/L      | 19.9           | mg/L                 | 0.014    | BMD doesn't coincide with selected BMR; RPF based on peak |
|               |                                 | Pyr   |                              |       | 0.00053                 | 0.00003             | mol/L      | 6.1            | mg/L                 | 0.28     | BMD doesn't coincide with selected BMR; RPF based on peak |

1

**Table E-11. In vitro morphological/malignant transformation: RPF calculation**

| Record number | Reference              | PAH         | Data type: quantal or continuous | Relative potency calculation |       |                         |                     |                              |            |                |                      |      | Comments |                                                                                    |
|---------------|------------------------|-------------|----------------------------------|------------------------------|-------|-------------------------|---------------------|------------------------------|------------|----------------|----------------------|------|----------|------------------------------------------------------------------------------------|
|               |                        |             |                                  | BMR                          | BMD   | Point estimate response | Point estimate dose | Slope of dose-response curve | Dose units | Converted dose | Converted dose units | RPF  |          |                                                                                    |
| 17610         | Casto, 1979            | BaP         | Q                                | 0.00001                      | 0.1   |                         |                     |                              |            | µg/mL          |                      |      | 1        |                                                                                    |
|               |                        | DBahA       | Q                                | 0.00001                      | 2.5   |                         |                     |                              |            | µg/mL          |                      |      | 0.042    |                                                                                    |
| 17970         | DiPaolo et al., 1969   | BaP         | Q                                |                              |       | 0.058                   | 10                  |                              |            | µg/mL          |                      |      | 1        |                                                                                    |
|               |                        | DBahA       | Q                                |                              |       | 0.031                   | 10                  |                              |            | µg/mL          |                      |      | 0.54     |                                                                                    |
|               |                        | BaA         | Q                                |                              |       | 0.011                   | 10                  |                              |            | µg/mL          |                      |      | 0.18     |                                                                                    |
|               |                        | BeP         | Q                                |                              |       | 0.0058                  | 10                  |                              |            | µg/mL          |                      |      | 0.1      |                                                                                    |
|               |                        | DBacA       | Q                                |                              |       | 0.011                   | 10                  |                              |            | µg/mL          |                      |      | 0.19     |                                                                                    |
| 18080         | Emura et al., 1980     | BaP Expt I  | Q                                | 0.001                        | 0.044 |                         |                     |                              |            | µg/mL          |                      |      | 1        |                                                                                    |
|               |                        | BbF         | Q                                | 0.001                        | 0.75  |                         |                     |                              |            | µg/mL          |                      |      | 0.059    |                                                                                    |
|               |                        | BaA         | Q                                | 0.001                        | 0.85  |                         |                     |                              |            | µg/mL          |                      |      | 0.052    |                                                                                    |
|               |                        | BaP Expt II | Q                                | 0.001                        | 0.046 |                         |                     |                              |            | µg/mL          |                      |      | 1        |                                                                                    |
|               |                        | IP          | Q                                | 0.001                        | 0.82  |                         |                     |                              |            | µg/mL          |                      |      | 0.056    |                                                                                    |
| 14130         | Greb et al., 1980      | BaP         | NA                               |                              |       |                         |                     | 277                          | %/mmol     | 1.10           | %/mg                 |      | 1        | Relative transformation potencies reported; RPFs are ratio of potencies            |
|               |                        | BaA         | NA                               |                              |       |                         |                     | 13.9                         | %/mmol     | 0.061          | %/mg                 |      | 0.055    |                                                                                    |
|               |                        | BbF         | NA                               |                              |       |                         |                     | 11.5                         | %/mmol     | 0.046          | %/mg                 |      | 0.042    |                                                                                    |
|               |                        | BeP         | NA                               |                              |       |                         |                     | 3.1                          | %/mmol     | 0.012          | %/mg                 |      | 0.011    |                                                                                    |
|               |                        | CH          | NA                               |                              |       |                         |                     | 37                           | %/mmol     | 0.16           | %/mg                 |      | 0.15     |                                                                                    |
|               |                        | DBahA       | NA                               |                              |       |                         |                     | 0.3                          | %/mmol     | 0.001          | %/mg                 |      | 0.000982 |                                                                                    |
| 14640         | Krolewski et al., 1986 | BaP         | Q                                |                              |       | 0.0055                  | 5                   |                              |            | µM             | 1.3                  | mg/L | 1        |                                                                                    |
|               |                        | CPcdP       | Q                                |                              |       | 0.0017                  | 5                   |                              |            | µM             | 1.1                  | mg/L | 0.34     |                                                                                    |
| 14700         | Laaksonen et al., 1983 | BaP         | Q                                |                              |       | 0.000009                | 10                  |                              |            | µM             | 2.5                  | mg/L | 1        | RPF based on peak; inverse dose-response relationship possibly due to cytotoxicity |
|               |                        | BaA         | Q                                |                              |       | 0.000018                | 11                  |                              |            | µM             | 2.5                  | mg/L | 2.0      |                                                                                    |
| 14850         | Lubet et al., 1983     | BaP         | Q                                | 0.1                          | 1.9   |                         |                     |                              |            | µg/mL          |                      |      | 1        |                                                                                    |
|               |                        | BeP         | Q                                | 0.1                          | 41    |                         |                     |                              |            | µg/mL          |                      |      | 0.046    |                                                                                    |
| 24710         | Mohapatra et al., 1987 | BaP         | Q                                |                              |       | 0.92                    | 1                   |                              |            | µg/mL          |                      |      | 1        |                                                                                    |
|               |                        | BjAC        | Q                                | 0.92                         | 0.93  |                         |                     |                              |            | µg/mL          |                      |      | 1.1      |                                                                                    |
|               |                        | BaP         | Q                                |                              |       | 0.83                    | 1                   |                              |            | µg/mL          |                      |      | 1        |                                                                                    |
|               |                        | BIAC        | Q                                | 0.83                         | 7.5   |                         |                     |                              |            | µg/mL          |                      |      | 0.13     |                                                                                    |
|               |                        | BaP         | Q                                |                              |       | 0.86                    | 1                   |                              |            | µg/mL          |                      |      | 1        |                                                                                    |
|               |                        | BeAC        | Q                                | 0.86                         | 18    |                         |                     |                              |            | µg/mL          |                      |      | 0.056    |                                                                                    |
| 24700         | Nesnow et al., 1990    | BaP         | C                                |                              |       | 47                      | 10                  |                              |            | µg/mL          |                      |      | 1        | Based on peak response; no SD for control                                          |
|               |                        | BIAC        | C                                |                              |       | 120                     | 10                  |                              |            | µg/mL          |                      |      | 2.5      |                                                                                    |
| 7980          | Nesnow et al., 1997    | BaP         | C                                |                              |       | 2.5                     | 4                   |                              |            | µM             | 1.01                 | mg/L | 1        | Based on peak response; no SD for control                                          |
|               |                        | DBalP       | C                                |                              |       | 1.7                     | 0.33                |                              |            | µM             | 0.10                 | mg/L | 6.9      |                                                                                    |
| 7990          | Nesnow et al., 1994    | BaP         | C                                |                              |       | 0.94                    | 1                   |                              |            | µg/mL          |                      |      | 1        | Based on peak response; no continuous linear model fit                             |
|               |                        | DBahA       | C                                |                              |       | 0.37                    | 1                   |                              |            | µg/mL          |                      |      | 0.39     |                                                                                    |
| 8000          | Nesnow et al., 1993a   | BaP         | C                                |                              |       | 1.4                     | 3                   |                              |            | µg/mL          |                      |      | 1        | Based on peak response; no SD for control                                          |
|               |                        | DBkmnoAPH   | C                                |                              |       | 1.1                     | 5                   |                              |            | µg/mL          |                      |      | 0.47     |                                                                                    |

**Table E-11. In vitro morphological/malignant transformation: RPF calculation**

| Record number | Reference           | PAH   | Data type: quantal or continuous | Relative potency calculation |     |                         |                     |                              |            |                |                      |  | RPF | Comments                                 |
|---------------|---------------------|-------|----------------------------------|------------------------------|-----|-------------------------|---------------------|------------------------------|------------|----------------|----------------------|--|-----|------------------------------------------|
|               |                     |       |                                  | BMR                          | BMD | Point estimate response | Point estimate dose | Slope of dose-response curve | Dose units | Converted dose | Converted dose units |  |     |                                          |
| 23720         | Pienta et al., 1977 | BaP   | Q                                | 0.01                         | 15  |                         |                     |                              |            | µg/mL          |                      |  | 1   | High dose dropped                        |
|               |                     | BaA   | Q                                | 0.01                         | 8.2 |                         |                     |                              |            | µg/mL          |                      |  | 1.9 | Caution: changing slope in region of BMR |
|               |                     | DBahA | Q                                | 0.01                         | 0.4 |                         |                     |                              |            | µg/mL          |                      |  | 34  | Two highest doses dropped                |

1  
2

**Table E-12. In vitro DNA adducts: RPF calculations<sup>a</sup>**

| Record number | Reference <sup>b</sup>      | PAH  | Relative potency calculation |                     |            |                |                      |       |                   |
|---------------|-----------------------------|------|------------------------------|---------------------|------------|----------------|----------------------|-------|-------------------|
|               |                             |      | Point estimate response      | Point estimate dose | Dose units | Converted dose | Converted dose units | RPF   | Comments          |
| 16890         | Allen and Coombs, 1980      | BaP  | 7.5                          | 0.24                | µg/mL      |                |                      | 1     | Nuclear DNA       |
|               |                             | BaA  | 0.44                         | 0.64                | µg/mL      |                |                      | 0.021 |                   |
|               |                             | BaP  | 413                          | 0.24                | µg/mL      |                |                      | 1     | Mitochondrial DNA |
|               |                             | BaA  | 104                          | 0.64                | µg/mL      |                |                      | 0.092 |                   |
| 6300          | Binkova et al., 2000        | BaP  | 258                          | 1                   | µM         | 0.25           | mg/L                 | 1     |                   |
|               |                             | DBaP | 2,317                        | 0.1                 | µM         | 0.03           | mg/L                 | 75    |                   |
| 9510          | Bryla and Weyand, 1992      | BaP  | 5.5                          | 600                 | nmol       | 0.15           | mg                   | 1     | Light conditions  |
|               |                             | BaA  | 1                            | 600                 | nmol       | 0.14           | mg                   | 0.20  |                   |
|               |                             | DBaA | 1.8                          | 600                 | nmol       | 0.17           | mg                   | 0.30  |                   |
| 22800         | Grover and Sims, 1968       | BaP  | 1.4                          | 5                   | µg         |                |                      | 1     |                   |
|               |                             | DBaH | 0.44                         | 5                   | µg         |                |                      | 0.31  |                   |
|               |                             | DBaA | 0.56                         | 5                   | µg         |                |                      | 0.40  |                   |
|               |                             | BaA  | 0.7                          | 5                   | µg         |                |                      | 0.50  |                   |
|               |                             | Pyr  | 0.31                         | 5                   | µg         |                |                      | 0.22  |                   |
|               |                             | PH   | 0.05                         | 5                   | µg         |                |                      | 0.040 |                   |
| 10670         | Johnsen et al., 1997        | BaP  | 0.05                         | 30                  | µg/mL      |                |                      | 1     | Clara cells       |
|               |                             | BjAC | 0.15                         | 30                  | µg/mL      |                |                      | 3     |                   |
|               |                             | BlAC | 0.24                         | 30                  | µg/mL      |                |                      | 4.8   |                   |
|               |                             | BaP  | 0.02                         | 30                  | µg/mL      |                |                      | 1     | Type 2 cells      |
|               |                             | BjAC | 0.06                         | 30                  | µg/mL      |                |                      | 3     |                   |
|               |                             | BlAC | 0.03                         | 30                  | µg/mL      |                |                      | 1.5   |                   |
| 10660         | Johnsen et al., 1998        | BaP  | 0.33                         | 30                  | µg/mL      |                |                      | 1     | Human lymphocytes |
|               |                             | BjAC | 0.11                         | 30                  | µg/mL      |                |                      | 0.33  |                   |
|               |                             | BlAC | 1.1                          | 30                  | µg/mL      |                |                      | 3.3   |                   |
|               |                             | BaP  | 0.24                         | 30                  | µg/mL      |                |                      | 1     | HL-60 cells       |
|               |                             | BjAC | 0.15                         | 30                  | µg/mL      |                |                      | 0.62  |                   |
| 7870          | Melendez-Colon et al., 2000 | BaP  | 34                           | 2                   | µM         | 0.50           | mg/L                 | 1     |                   |
|               |                             | DBaP | 348                          | 2                   | µM         | 0.60           | mg/L                 | 8.5   |                   |

**Table E-12. In vitro DNA adducts: RPF calculations<sup>a</sup>**

| Record number | Reference <sup>b</sup>      | PAH   | Relative potency calculation |                     |            |                |                      |       |          |
|---------------|-----------------------------|-------|------------------------------|---------------------|------------|----------------|----------------------|-------|----------|
|               |                             |       | Point estimate response      | Point estimate dose | Dose units | Converted dose | Converted dose units | RPF   | Comments |
| 21200         | Segerback and Vodicka, 1993 | BaP   | 15                           | 100                 | mM         | 25,232         | mg/L                 | 1     |          |
|               |                             | BaA   | 30                           | 100                 | mM         | 22,829         | mg/L                 | 2.2   |          |
|               |                             | BbF   | 3.7                          | 100                 | mM         | 25,232         | mg/L                 | 0.25  |          |
|               |                             | BghiP | 0.5                          | 100                 | mM         | 27,634         | mg/L                 | 0.03  |          |
|               |                             | CH    | 50                           | 100                 | mM         | 22,829         | mg/L                 | 3.7   |          |
|               |                             | DBahA | 2.8                          | 100                 | mM         | 27,833         | mg/L                 | 0.17  |          |
|               |                             | FA    | 1.5                          | 100                 | mM         | 20,226         | mg/L                 | 0.12  |          |
|               |                             | Pyr   | 0.14                         | 100                 | mM         | 20,226         | mg/L                 | 0.012 |          |

<sup>a</sup>All RPFs are point estimates based on peak response as adequate model fit was not achieved for any multidose dataset.

<sup>b</sup>No control data were available for any of these studies.

Table E-13. In vitro DNA damage: RPF calculations

| Record number | Reference                      | PAH   | Relative potency calculation |     |                         |                     |                              |            |                |                      |       |                                                                                  |
|---------------|--------------------------------|-------|------------------------------|-----|-------------------------|---------------------|------------------------------|------------|----------------|----------------------|-------|----------------------------------------------------------------------------------|
|               |                                |       | BMR                          | BMD | Point estimate response | Point estimate dose | Slope of dose-response curve | Dose units | Converted dose | Converted dose units | RPF   | Comments                                                                         |
| 16840         | Agrelo and Amos, 1981          | BaP   |                              |     | 2,093                   | 10                  |                              | µg/mL      |                |                      | 1     | Control responses for BaP and Pyr differ by 10 times                             |
|               |                                | Pyr   |                              |     | 548                     | 100                 |                              | µg/mL      |                |                      | 0.026 | RPF based on peak; continuous data without SD                                    |
| 23790         | Ichinotsubo et al., 1977       | BaP   |                              |     | 6                       | 70                  |                              | µg/well    |                |                      | 1     |                                                                                  |
|               |                                | DBaiP |                              |     | 10                      | 600                 |                              | µg/well    |                |                      | 0.19  |                                                                                  |
|               |                                | DBahA |                              |     | 10                      | 25                  |                              | µg/well    |                |                      | 4.7   |                                                                                  |
| 10660         | Johnsen et al., 1998           | BaP   |                              |     | 7.9                     | 3                   |                              | µg/mL      |                |                      | 1     | Human lymphocytes; no model fit; lowest response point estimate                  |
|               |                                | BjAC  | 7.6                          | 18  |                         |                     |                              | µg/mL      |                |                      | 0.16  | Human lymphocytes; BMR is BaP point estimate response                            |
|               |                                | BlAC  |                              |     | 4.9                     | 30                  |                              | µg/mL      |                |                      | 0.062 | Human lymphocytes; no model fit; response point estimate closest to BaP response |
|               |                                | BaP   |                              |     | 5.4                     | 30                  |                              | µg/mL      |                |                      | 1     | HL-60 cells                                                                      |
|               |                                | BjAC  |                              |     | 1.8                     | 30                  |                              | µg/mL      |                |                      | 0.33  | HL-60 cells                                                                      |
|               |                                | BlAC  |                              |     | 3.8                     | 30                  |                              | µg/mL      |                |                      | 0.7   | HL-60 cells                                                                      |
| 19740         | Martin et al., 1978            | BaP   |                              |     | 210                     | $1 \times 10^{-5}$  |                              | M          | 2.5            | mg/L                 | 1     | Increase over background                                                         |
|               |                                | BaA   |                              |     | 59                      | $1 \times 10^{-7}$  |                              | M          | 0.023          | mg/L                 | 31    |                                                                                  |
|               |                                | BeP   |                              |     | 256                     | $1 \times 10^{-6}$  |                              | M          | 0.25           | mg/L                 | 12    |                                                                                  |
|               |                                | DBacA |                              |     | 97                      | $1 \times 10^{-5}$  |                              | M          | 2.8            | mg/L                 | 0.42  |                                                                                  |
|               |                                | DBahA |                              |     | 96                      | $1 \times 10^{-5}$  |                              | M          | 2.8            | mg/L                 | 0.41  |                                                                                  |
| 19830         | Mersch-Sundermann et al., 1992 | BaP   |                              |     |                         |                     | 0.61                         | µg/assay   |                |                      | 1     | SOS induction potential - slope of SOS induction dose-response curve as reported |
|               |                                | AA    |                              |     |                         |                     | 0.14                         | µg/assay   |                |                      | 0.23  |                                                                                  |
|               |                                | BaA   |                              |     |                         |                     | 0.1                          | µg/assay   |                |                      | 0.17  |                                                                                  |
|               |                                | BbF   |                              |     |                         |                     | 0.045                        | µg/assay   |                |                      | 0.074 |                                                                                  |
|               |                                | BghiF |                              |     |                         |                     | 0.34                         | µg/assay   |                |                      | 0.56  |                                                                                  |
|               |                                | BjF   |                              |     |                         |                     | 0.25                         | µg/assay   |                |                      | 0.42  |                                                                                  |
|               |                                | BbFE  |                              |     |                         |                     | 0.024                        | µg/assay   |                |                      | 0.04  |                                                                                  |
|               |                                | BghiP |                              |     |                         |                     | 0.033                        | µg/assay   |                |                      | 0.055 |                                                                                  |
|               |                                | BeP   |                              |     |                         |                     | 0.032                        | µg/assay   |                |                      | 0.053 |                                                                                  |
|               |                                | CH    |                              |     |                         |                     | 0.22                         | µg/assay   |                |                      | 0.37  |                                                                                  |
|               |                                | DBacA |                              |     |                         |                     | 0.10                         | µg/assay   |                |                      | 0.17  |                                                                                  |
|               |                                | DBahA |                              |     |                         |                     | 0.039                        | µg/assay   |                |                      | 0.064 |                                                                                  |

**Table E-13. In vitro DNA damage: RPF calculations**

| Record number | Reference                   | PAH   | Relative potency calculation |     |                         |                     |                              |            |                |                      |       |                                      |
|---------------|-----------------------------|-------|------------------------------|-----|-------------------------|---------------------|------------------------------|------------|----------------|----------------------|-------|--------------------------------------|
|               |                             |       | BMR                          | BMD | Point estimate response | Point estimate dose | Slope of dose-response curve | Dose units | Converted dose | Converted dose units | RPF   | Comments                             |
|               |                             | DBaP  |                              |     |                         |                     | 2.1                          | µg/assay   |                |                      | 3.5   |                                      |
|               |                             | DBaH  |                              |     |                         |                     | 0.12                         | µg/assay   |                |                      | 0.19  |                                      |
|               |                             | DBaI  |                              |     |                         |                     | 0.17                         | µg/assay   |                |                      | 0.29  |                                      |
|               |                             | FA    |                              |     |                         |                     | 0.41                         | µg/assay   |                |                      | 0.68  |                                      |
|               |                             | IP    |                              |     |                         |                     | 0.036                        | µg/assay   |                |                      | 0.06  |                                      |
|               |                             | PH    |                              |     |                         |                     | 0.053                        | µg/assay   |                |                      | 0.088 |                                      |
|               |                             | Tphen |                              |     |                         |                     | 0.26                         | µg/assay   |                |                      | 0.43  |                                      |
| 20810         | Robinson and Mitchell, 1981 | BaP   |                              |     | 89                      | 10                  |                              | µg/mL      |                |                      | 1     |                                      |
|               |                             | Pyr   |                              |     | 63                      | 7.2                 |                              | µg/mL      |                |                      | 0.98  |                                      |
| 20940         | Rosman et al., 1991         | BaP   |                              |     | 10.4                    | 12.5                |                              | µg/mL      |                |                      | 1     | Enhancement over background          |
|               |                             | AC    |                              |     | 4.8                     | 12.5                |                              | µg/mL      |                |                      | 0.46  |                                      |
|               |                             | DBaC  |                              |     | 8                       | 1.44                |                              | µg/mL      |                |                      | 6.7   |                                      |
|               |                             | DBaH  |                              |     | 4                       | 2                   |                              | µg/mL      |                |                      | 2.4   |                                      |
|               |                             | PH    |                              |     | 4.5                     | 25                  |                              | µg/mL      |                |                      | 0.22  |                                      |
| 21730         | Tong et al., 1981b          | BaP   |                              |     | 65.5                    | 0.001               |                              | M          | 252            | mg/L                 | 1     |                                      |
|               |                             | BaA   |                              |     | 17.1                    | 0.0005              |                              | M          | 114            | mg/L                 | 0.58  | Based on peak response; no model fit |

1  
2  
3

**Table E-14. In vitro clastogenicity or sister chromatid exchange: RPF calculations**

| Record number | Reference              | PAH   | Endpoint                   | Data type: quantal or continuous | BMR | BMD | Point estimate response | Point estimate dose | Dose units | Converted dose | Converted dose units | RPF  | Comments                                            |
|---------------|------------------------|-------|----------------------------|----------------------------------|-----|-----|-------------------------|---------------------|------------|----------------|----------------------|------|-----------------------------------------------------|
| 14620         | Kochhar, 1982          | BaP   | Aberrations                | Q                                |     |     | 0.53                    | 5                   | µg/mL      |                |                      | 1    | BMD doesn't reflect selected BMR; RPF based on peak |
|               |                        | BaA   |                            |                                  |     |     | 0.34                    | 5                   | µg/mL      |                |                      | 0.64 | BMD doesn't reflect selected BMR; RPF based on peak |
| 14640         | Krolewski et al., 1986 | BaP   | Sister chromatid exchanges | C                                |     |     | 0.79                    | 5                   | µM         | 1.3            | mg/L                 | 1    |                                                     |
|               |                        | CPcdP |                            |                                  |     |     | 0.29                    | 5                   | µM         | 1.1            | mg/L                 | 0.41 | No model fit; RPF based on peak response            |
| 19690         | Mane et al., 1990      | BaP   | Sister chromatid exchanges | C                                |     |     | 2.7                     | 1                   | µg/mL      |                |                      | 1    |                                                     |
|               |                        | BaA   |                            |                                  |     |     | 0.4                     | 1                   | µg/mL      |                |                      | 0.15 |                                                     |
| 21710         | Tong et al., 1981a     | BaP   | Sister chromatid exchanges | C                                |     |     | 92                      | $1 \times 10^{-4}$  | M          | 25.2           | mg/L                 | 1    |                                                     |
|               |                        | BaA   |                            |                                  |     |     | 13                      | $1 \times 10^{-4}$  | M          | 22.8           | mg/L                 | 0.16 | No n provided; RPF based on peak response           |

1 **APPENDIX F. EXAMPLE CALCULATION OF RPF DETECTION LIMIT**

2  
3 **Table F-1. Example data for calculation of RPF detection limit**

| Group                                                             | Dose | Number with tumors | Number in group | Incidence | Extra risk response <sup>a</sup> |
|-------------------------------------------------------------------|------|--------------------|-----------------|-----------|----------------------------------|
| <i>Actual responses</i>                                           |      |                    |                 |           |                                  |
| Control                                                           | 0    | 2                  | 30              | 0.067     | NA                               |
| Anthanthrene                                                      | 0.25 | 2                  | 29              | 0.069     | NA                               |
| Benzo[a]pyrene                                                    | 0.25 | 24                 | 30              | 0.800     | 0.786                            |
| <i>Theoretical statistically significant response<sup>b</sup></i> |      |                    |                 |           |                                  |
| Anthanthrene                                                      | 0.25 | 8                  | 29              | 0.276     | 0.224                            |

<sup>a</sup>Calculated as described below in Step 1.

<sup>b</sup>Calculated as described below in Step 2.

Source: Hoffmann and Wynder (1966).

4  
5 *Step 1.* Estimate the number of tumor-bearing animals that would represent a statistically  
6 significant response (one-sided  $p \leq 0.05$  using Fisher's exact test) in the number of animals  
7 exposed to anthanthrene (29) given the observed control response (2/30). In this case,  
8 8/29 tumor-bearing animals (incidence of 0.276) would represent a statistically significant  
9 response to anthanthrene.

10  
11 *Step 2.* Calculate the extra risk response associated with the theoretical statistically significant  
12 incidence for anthanthrene and the observed benzo[a]pyrene incidence as follows:

$$\text{Extra risk response} = \frac{P(d) - P(0)}{[1 - P(0)]}$$

13  
14  
15  
16  
17 For the theoretical statistically significant response to anthanthrene,

$$\text{Extra risk response} = (0.276 - 0.067)/(1 - 0.067) = 0.224$$

18  
19  
20  
21 *Step 3.* Calculate the RPF detection limit as the ratio of the slopes associated with extra risk  
22 response and the actual doses of anthanthrene and benzo[a]pyrene as follows:

$$\text{RPF detection limit} = \frac{(\text{theoretical anthanthrene extra risk response/dose anthanthrene})}{(\text{benzo[a]pyrene extra risk response/dose benzo[a]pyrene})}$$

$$\text{RPF detection limit} = (0.224/0.25)/(0.786/0.25) = 0.28$$

## APPENDIX G. EVALUATION OF ALTERNATIVES FOR RANKING RPFs

For many of the PAHs evaluated in this report, a number of datasets were available for use in calculating RPFs. The resulting RPFs are derived from tumor bioassays using different exposure routes, species, sexes, or tumor endpoints (incidence or multiplicity) and from a variety of different cancer-related endpoint assays. The various RPFs are derived from studies of varying design and quality (different numbers of animals, follow-up time, single or multiple dose groups, response levels low or high on the dose-response curve, etc.). In order to derive a single final RPF for each individual PAH, the various results from different datasets must be ranked or combined in some manner. This appendix details the options that were considered for ranking RPFs.

A series of options were considered for prioritizing RPFs for the purpose of selecting a single RPF for each PAH or exposure route. An a priori decision was made to consider tumor bioassay data to be preferable to cancer-related endpoint data because the tumor bioassay data are derived from whole animals and address the endpoint of interest for RPFs (tumorigenicity). Thus, options for ranking or combining tumor bioassays and for cancer-related endpoint data were considered separately; Section G.1 discusses options considered for use of tumor bioassay RPFs and Section G.2 discusses options considered for use of cancer-related endpoint RPFs.

### G.1. OPTIONS FOR RANKING TUMOR BIOASSAY RPFs

Approaches considered for ranking tumor bioassay RPFs were: (1) ranking by exposure route, (2) ranking by target organ, and (3) preference for modeled data over point estimates.

*Ranking by exposure route.* One option for ranking RPFs derived from tumor bioassay data would be to order the datasets by exposure routes that are considered most relevant to environmental exposure routes (oral, dermal, and inhalation). RPFs for many PAHs were calculated from dermal tumor bioassays. The available database for PAHs included one oral and no inhalation studies that were suitable for RPF calculation; thus, route-to-route extrapolation is necessary to derive RPFs applicable to all routes of exposure.

Some earlier RPF approaches, primarily in the course of assessing risks from inhalation exposure to PAHs, have proposed hierarchies of bioassay types based on route of administration. Collins et al. (1998) proposed a hierarchy for PAH cancer potencies for use in assessing air contaminants. The hierarchy for inhalation potencies proposed by Collins et al. (1998) ordered the exposure routes as follows: intratracheal or intrapulmonary administration > oral administration > skin-painting studies > subcutaneous or intraperitoneal administration. However, Collins et al. (1998) did not provide any empirical data supporting the ordering of these exposure routes, other than the intuitive preference for intratracheal or intrapulmonary administration as a surrogate for inhalation. In another review of data available for relative potency assessment for PAHs as air contaminants, Pufulete et al. (2004) suggested that

1 intratracheal instillation of low doses of PAHs might be an appropriate surrogate exposure model  
2 for assessing relative potency of inhalation exposure. The basis for this suggestion was the  
3 authors' observation that clearance of PAHs administered in solution via intratracheal instillation  
4 exhibited a biphasic pattern similar to that observed after inhalation exposure to benzo[a]pyrene  
5 bound to particulates. However, the authors acknowledged that the high concentrations of PAHs  
6 used in intratracheal and intrapulmonary instillation studies may lead to major differences in  
7 pharmacokinetics compared with inhalation exposure (Pufulete et al., 2004). Further, the authors  
8 expressed this suggestion as a path for future research, rather than as a means of examining  
9 available data on PAHs; no intratracheal instillation studies were identified in the search for  
10 studies from which to calculate RPFs for PAHs. Pufulete et al. (2004) did not provide any  
11 specific information on the relevance of intrapulmonary administration (a route used in several  
12 of the bioassays used to calculate RPFs) to inhalation exposure.

13 To assess exposure-route differences in RPFs calculated in this review, a table comparing  
14 the average RPF for each PAH across exposure routes was prepared (Table G-1). Dermal studies  
15 are shown collectively as well as separated by study type (complete carcinogenesis or initiation  
16 only). Likewise, intraperitoneal studies are shown grouped as well as separated by target organ  
17 (lung and liver).

**Table G-1. Comparisons among average nonzero tumor bioassay-based RPF values by exposure route**

| PAH              | Dermal, target organ = skin |         | Dermal complete |         | Dermal initiation |         | Intraperitoneal |                   | Intraperitoneal, target organ = lung |         | Intra-peritoneal, target organ = liver |         | Lung implantation, target organ = lung |         | Oral, target organ = lung |         |
|------------------|-----------------------------|---------|-----------------|---------|-------------------|---------|-----------------|-------------------|--------------------------------------|---------|----------------------------------------|---------|----------------------------------------|---------|---------------------------|---------|
|                  | n                           | Average | n               | Average | n                 | Average | n               | Average           | n                                    | Average | n                                      | Average | n                                      | Average | n                         | Average |
| AA               | 1                           | 0.5     | 1               | 0.5     | –                 | –       | –               | –                 | –                                    | –       | –                                      | –       | 1                                      | 0.2     | –                         | –       |
| AC               | –                           | –       | –               | –       | –                 | –       | –               | –                 | –                                    | –       | –                                      | –       | –                                      | –       | –                         | –       |
| BaA              | 1                           | 0.02    | –               | –       | 1                 | 0.02    | 2               | 0.2 <sup>a</sup>  | 1                                    | 0.08    | 1                                      | 0.4     | –                                      | –       | –                         | –       |
| BbcAC (1,12-MBA) | 1                           | 0.05    | –               | –       | 1                 | 0.05    | –               | –                 | –                                    | –       | –                                      | –       | –                                      | –       | –                         | –       |
| BbF              | 2                           | 0.4     | 1               | 0.3     | 1                 | 0.4     | 2 <sup>b</sup>  | 1 <sup>c</sup>    | 1                                    | 1       | –                                      | –       | 1                                      | 0.1     | –                         | –       |
| BcFE             | –                           | –       | –               | –       | –                 | –       | 1               | 1 <sup>d</sup>    | 1                                    | 1       | –                                      | –       | –                                      | –       | 1                         | 50      |
| BeAC             | 2                           | 0.8     | –               | –       | 2                 | 0.8     | –               | –                 | –                                    | –       | –                                      | –       | –                                      | –       | –                         | –       |
| BghiP            | –                           | –       | –               | –       | –                 | –       | –               | –                 | –                                    | –       | –                                      | –       | 1                                      | 0.009   | –                         | –       |
| BjAC             | –                           | –       | –               | –       | –                 | –       | 1               | 60 <sup>d</sup>   | 1                                    | 60      | –                                      | –       | –                                      | –       | –                         | –       |
| BjF              | 2                           | 0.03    | –               | –       | 2                 | 0.03    | 2 <sup>b</sup>  | 0.7 <sup>a</sup>  | 1                                    | 0.4     | 1                                      | 1       | 1                                      | 0.03    | –                         | –       |
| BkF              | 1                           | 0.03    | –               | –       | 1                 | 0.03    | –               | –                 | –                                    | –       | –                                      | –       | 1                                      | 0.03    | –                         | –       |
| BlAC             | 2                           | 5       | –               | –       | 2                 | 5       | –               | –                 | –                                    | –       | –                                      | –       | –                                      | –       | –                         | –       |
| CH               | 5                           | 0.1     | –               | –       | 5                 | 0.1     | 1               | 0.2 <sup>a</sup>  | –                                    | –       | 1                                      | 0.2     | 1                                      | 0.04    | –                         | –       |
| CPcdP            | 4                           | 0.3     | 2               | 0.4     | 2                 | 0.2     | 1               | 1 <sup>d</sup>    | 1                                    | 1       | –                                      | –       | –                                      | –       | –                         | –       |
| CPdefC           | 2                           | 0.3     | –               | –       | 2                 | 0.3     | –               | –                 | –                                    | –       | –                                      | –       | –                                      | –       | –                         | –       |
| DBacA            | –                           | –       | –               | –       | –                 | –       | –               | –                 | –                                    | –       | –                                      | –       | –                                      | –       | –                         | –       |
| DBaeF            | 2                           | 0.9     | 1               | 1       | 1                 | 0.7     | –               | –                 | –                                    | –       | –                                      | –       | –                                      | –       | –                         | –       |
| DBaeP            | 2                           | 0.4     | 1               | 0.3     | 1                 | 0.4     | –               | –                 | –                                    | –       | –                                      | –       | –                                      | –       | –                         | –       |
| DBahA            | 1                           | 1       | –               | –       | 1                 | 1       | 1               | 40 <sup>d</sup>   | 1                                    | 40      | –                                      | –       | 1                                      | 2       | –                         | –       |
| DBahP            | 1                           | 0.9     | –               | –       | 1                 | 0.9     | –               | –                 | –                                    | –       | –                                      | –       | –                                      | –       | –                         | –       |
| DBaiP            | 2                           | 0.6     | 1               | 0.7     | 1                 | 0.5     | –               | –                 | –                                    | –       | –                                      | –       | –                                      | –       | –                         | –       |
| DBalP            | 2                           | 30      | –               | –       | 2                 | 30      | 1               | 30 <sup>d</sup>   | 1                                    | 30      | –                                      | –       | –                                      | –       | –                         | –       |
| FA               | –                           | –       | –               | –       | –                 | –       | 5               | 0.08 <sup>a</sup> | 4                                    | 0.05    | 1                                      | 0.2     | –                                      | –       | –                         | –       |
| IP               | –                           | –       | –               | –       | –                 | –       | –               | –                 | –                                    | –       | –                                      | –       | 1                                      | 0.07    | –                         | –       |
| N23eP            | 1                           | 0.3     | –               | –       | 1                 | 0.3     | –               | –                 | –                                    | –       | –                                      | –       | –                                      | –       | –                         | –       |

**Table G-1. Comparisons among average nonzero tumor bioassay-based RPF values by exposure route**

| PAH | Dermal, target organ = skin |         | Dermal complete |         | Dermal initiation |         | Intraperitoneal |         | Intraperitoneal, target organ = lung |         | Intra-peritoneal, target organ = liver |         | Lung implantation, target organ = lung |         | Oral, target organ = lung |         |
|-----|-----------------------------|---------|-----------------|---------|-------------------|---------|-----------------|---------|--------------------------------------|---------|----------------------------------------|---------|----------------------------------------|---------|---------------------------|---------|
|     | n                           | Average | n               | Average | n                 | Average | n               | Average | n                                    | Average | n                                      | Average | n                                      | Average | n                         | Average |
| PH  | -                           | -       | -               | -       | -                 | -       | -               | -       | -                                    | -       | -                                      | -       | -                                      | -       | -                         | -       |
| Pyr | -                           | -       | -               | -       | -                 | -       | -               | -       | -                                    | -       | -                                      | -       | -                                      | -       | -                         | -       |

<sup>a</sup>Newborn mouse model.

<sup>b</sup>Number of intraperitoneal RPFs includes those calculated for combined lung and liver incidence; these are not included in number of RPFs with lung or liver tumors.

<sup>c</sup>Includes both newborn mouse and adult A/J mouse models.

<sup>d</sup>Adult A/J mouse model.

1 The table shows a marked difference between the oral and intraperitoneal RPFs for  
2 benzo[c]fluorene (BcFE) (RPF = 50 for oral multiplicity and RPF = 1 for intraperitoneal  
3 incidence). However, as discussed earlier, this difference may result more from the use of a high  
4 tumor number to calculate the oral multiplicity RPF for this compound than route differences; if  
5 the oral incidence RPF is used for comparison, the two routes are more similar (RPF = 1 for  
6 intraperitoneal incidence versus RPF = 5 for oral incidence). Based on the latter comparison,  
7 which represents the only data with which to compare oral RPFs with those calculated from  
8 other routes, there appears to be fairly good correspondence between intraperitoneal and oral  
9 RPFs; however, this is based on only one PAH.

10 Based on the comparisons in the table, RPFs based on initiation and complete dermal  
11 carcinogenicity studies are similar (within a factor of 2). However, there are few PAHs with  
12 both types of dermal studies.

13 With respect to other route comparisons, the table generally shows that RPFs calculated  
14 from lung implantation and dermal studies are of the same order of magnitude, while RPFs  
15 calculated from intraperitoneal studies are higher for most compounds. Among PAHs with RPFs  
16 derived from intraperitoneal and dermal data, 6/7 showed higher RPF values from intraperitoneal  
17 data, compared with dermal data (benz[a]anthracene, benzo[b]fluoranthene,  
18 benzo[j]fluoranthene, chrysene, cyclopenta[c,d]pyrene, dibenz[a,h]anthracene; Table G-1). The  
19 intraperitoneal RPF for dibenzo[a,l]pyrene (DBaP) is similar to its dermal RPF.

20 At first glance, one might attribute the higher intraperitoneal RPFs calculated from  
21 newborn mouse assays (footnoted "a" in the table) to greater sensitivity of the newborn mouse,  
22 compared with an adolescent or adult mouse, to the carcinogenic action of PAHs. However,  
23 since the RPFs reflect potency of the PAH relative to benzo[a]pyrene, and not potency of the  
24 newborn mouse relative to other systems, the higher RPF cannot reflect a greater sensitivity of  
25 the system, since both the PAH of interest and benzo[a]pyrene have been tested in the same  
26 system. There is little information to evaluate whether RPFs from newborn mouse studies tend  
27 to be higher or lower than the adult A/J mouse model when both are exposed via intraperitoneal  
28 injection. Only one compound, benzo[b]fluoranthene (BbF), had RPFs calculated from both  
29 newborn mouse and adult A/J mouse models; the average newborn mouse RPF was 2, while the  
30 average A/J mouse RPF was 0.9. In summary, it is not clear whether the intraperitoneal RPFs  
31 are higher than dermal or lung implantation RPFs due to route-specific differences or animal  
32 model differences (for example, differential metabolism in various animal systems).

33 *Ranking by target tissue.* An alternative approach to ranking tumor bioassay RPFs would  
34 be to prefer target tissue-specific RPFs (for example, to prefer RPFs derived from lung tumor  
35 data for inhalation RPFs). An analysis was conducted to assess whether RPFs calculated from  
36 lung tumor potency in intraperitoneal studies (both newborn mouse and adult A/J mouse models)  
37 were consistent with RPFs from lung implantation studies. Table G-1 shows RPFs calculated for  
38 lung tumors (separate from liver tumors also observed in some intraperitoneal studies) after

1 intraperitoneal administration. Only four compounds (benzo[b]fluoranthene, benzo[j]fluor-  
 2 anthene, chrysene, and dibenz[a,h]anthracene) had RPFs for both intraperitoneal and lung  
 3 implantation studies; for each of these, the intraperitoneal lung tumor RPF exceeded the lung  
 4 implantation RPF. One compound, benzo[c]fluorene, also had lung tumor RPFs from both  
 5 intraperitoneal and oral studies. In this case, the oral RPF for lung tumors exceeded the  
 6 intraperitoneal RPF for lung tumors. No information assessing the concordance between lung  
 7 tumor potency after intraperitoneal, lung implantation, or oral administration and inhalation  
 8 cancer potency was identified in the literature.

9 *Ranking by use of BMD.* A third approach considered for ranking of tumor bioassay data  
 10 was to prefer data amenable to BMD modeling (of either quantal or continuous data, depending  
 11 on whether incidence or multiplicity was modeled) over an analysis of data based on point  
 12 estimates. Table G-2 compares the average of RPFs for all bioassays with RPFs calculated using  
 13 BMD modeling, and RPFs calculated using a point-estimate approach.

14

**Table G-2. Comparisons among average nonzero tumor bioassay-based RPF values by calculation method**

|        | All bioassays |             | BMD model |             | Point estimate |             |
|--------|---------------|-------------|-----------|-------------|----------------|-------------|
|        | n             | Average RPF | n         | Average RPF | n              | Average RPF |
| AA     | 2             | 0.4         | 1         | 0.2         | 1              | 0.5         |
| AC     | –             | –           | –         | –           | –              | –           |
| BaA    | 3             | 0.2         | –         | –           | 3              | 0.2         |
| BbcAC  | 1             | 0.05        | –         | –           | 1              | 0.05        |
| BbF    | 5             | 0.8         | 3         | 0.6         | 2              | 1.0         |
| BcFE   | 2             | 20          | –         | –           | 2              | 20          |
| BeAC   | 2             | 0.8         | 1         | 0.9         | 1              | 0.7         |
| BghiP  | 1             | 0.009       | 1         | 0.009       | –              | –           |
| BjAC   | 1             | 60          | –         | –           | 1              | 60          |
| BjF    | 5             | 0.3         | 1         | 0.03        | 4              | 0.4         |
| BkF    | 2             | 0.03        | 2         | 0.03        | –              | –           |
| BIAC   | 2             | 5           | 2         | 5           | –              | –           |
| CH     | 7             | 0.1         | 2         | 0.1         | 5              | 0.1         |
| CPcdP  | 5             | 0.4         | 1         | 0.07        | 4              | 0.5         |
| CPdefC | 2             | 0.3         | 1         | 0.5         | 1              | 0.2         |
| DBacA  | –             | –           | –         | –           | –              | –           |
| DBaeF  | 2             | 0.9         | 1         | 1           | 1              | 0.7         |
| DBaeP  | 2             | 0.4         | 1         | 0.3         | 1              | 0.4         |
| DBahA  | 3             | 10          | 2         | 20          | 1              | 1           |
| DBahP  | 1             | 0.9         | –         | –           | 1              | 0.9         |
| DBaiP  | 2             | 0.6         | 1         | 0.7         | 1              | 0.5         |
| DBalP  | 3             | 30          | 1         | 30          | 2              | 30          |
| FA     | 5             | 0.08        | 4         | 0.08        | 1              | 0.09        |
| IP     | 1             | 0.07        | 1         | 0.07        | –              | –           |
| N23eP  | 1             | 0.3         | –         | –           | 1              | 0.3         |
| PH     | –             | –           | –         | –           | –              | –           |
| Pyr    | –             | –           | –         | –           | –              | –           |

15

1 While this ranking could be justified based on a general preference for multidose data and  
2 modeling to identify a point of departure, there are important limitations to this approach. First,  
3 RPFs based on BMD modeling may still use a point of departure high on the dose-response  
4 curve, if a single benzo[a]pyrene dose with an elevated response level (BMR)<sup>1</sup> was used to  
5 calculate the RPF. In some cases, an RPF based on a point estimate approach from a point of  
6 departure lower on the dose-response curve may be a better predictor of relative potency at  
7 environmental exposure levels. Second, unless RPFs based on BMD modeling are available for  
8 all of the relevant exposure routes (dermal initiation and complete carcinogenicity, lung  
9 implantation, and intraperitoneal), there may be differences between the RPFs calculated from  
10 BMD modeling and those calculated using a point estimate approach that are unrelated to study  
11 quality (i.e., route, species, sex differences). Thus, ranking RPFs based on a preference for  
12 modeled data over point estimate data would neglect other sources of variability in the estimates  
13 (exposure route, species, sex, target organ, dosing intervals, etc.)

14 In summary, the analysis of options for ranking bioassay RPFs does not suggest a clear  
15 basis for selecting among the available data types. As a consequence, none of the available data  
16 types were considered preferable to any other; all bioassay RPFs were considered equally  
17 relevant.

## 18 19 **G.2. RANKING NONBIOASSAY DATA**

20 In view of the fact that the present work created a large database of RPFs for multiple  
21 endpoints, an empirical approach to assigning ranks was explored. The database of PAH RPFs  
22 was analyzed to determine whether any individual cancer-related endpoint was more closely  
23 correlated with RPFs based on tumor bioassay data. The premise behind this analysis is that  
24 RPFs based on bioassay data represent the best available information, and that the genotoxicity  
25 endpoints that best predict bioassay RPFs should be preferred over those that show little  
26 relationship to tumor bioassay RPFs. The semiquantitative analysis was, of necessity, restricted  
27 to those PAHs for which at least one RPF based on bioassay data was available.

28 For each of the 23 PAHs with nonzero RPFs based on bioassay data, the average bioassay  
29 RPF was compared with the average RPF for several endpoints that could be correlated with  
30 cancer potency (in vivo DNA adducts, in vivo micronuclei and sister chromatid exchanges  
31 together, and in vitro mutagenicity). TIDAL values were not analyzed separately from other  
32 measures of DNA adducts because there were only four PAHs with both TIDAL and bioassay  
33 RPFs; similarly, micronuclei and sister chromatid exchange endpoints were grouped to increase  
34 the number of observations in the regression. In addition to analyzing these endpoints, analyses  
35 of several endpoints grouped across class (e.g., all in vivo nonbioassay endpoints, all in vitro  
36 endpoints, and all nonbioassay endpoints) were performed. Linear regression was performed on

---

<sup>1</sup>The BMR selected for multidose PAH data for studies with a single benzo[a]pyrene dose was the response level observed in the benzo[a]pyrene dose group.

1 the log-transformed average RPF values to assess the predictive power of each endpoint or  
 2 grouping, and to assess whether there was a quantitative basis for ordering them.

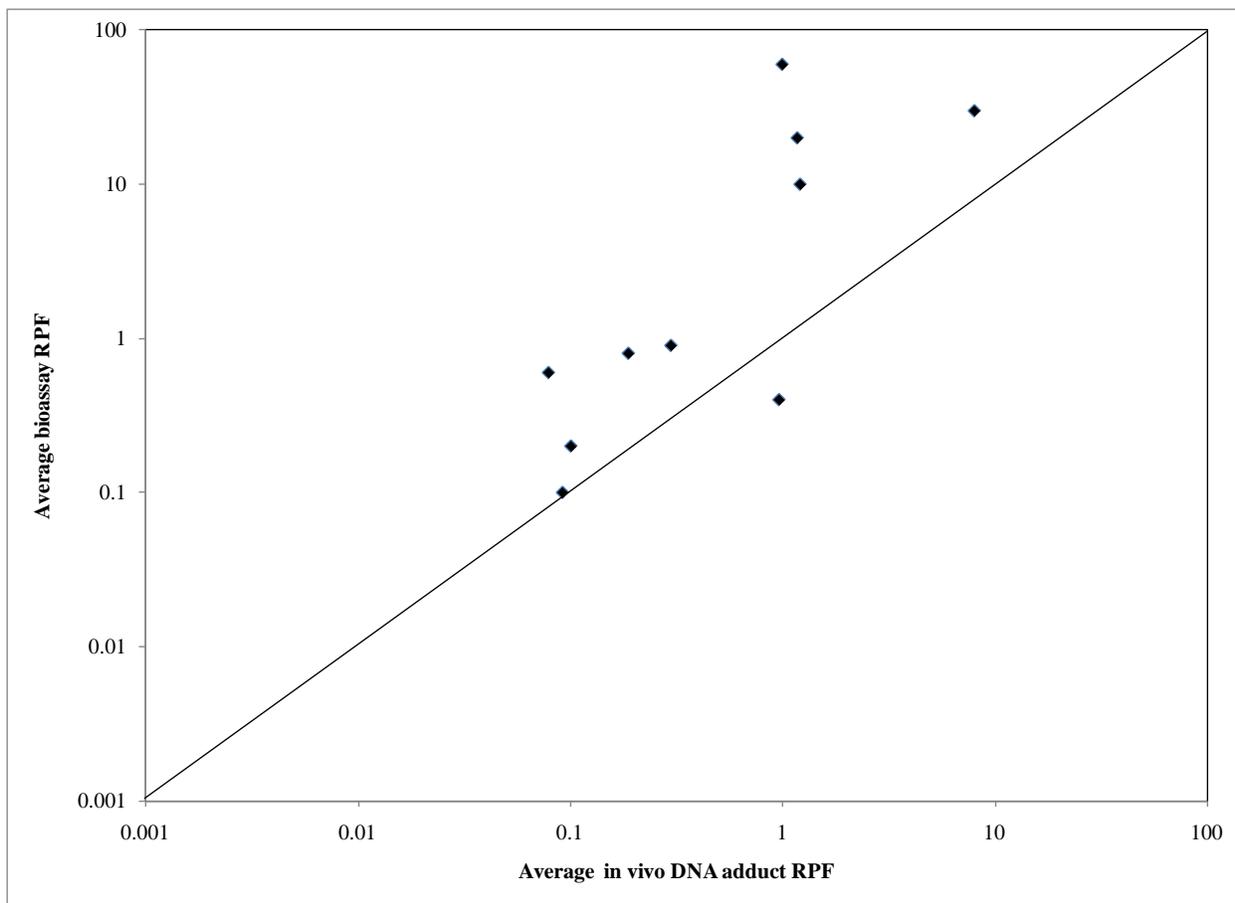
3 Table G-3 shows the results of regression analyses assessing how well the average RPFs  
 4 for several endpoints correlated with average bioassay RPFs. The table shows that neither in  
 5 vivo clastogenicity RPFs (micronuclei and sister chromatid exchanges) nor in vitro mutagenicity  
 6 RPFs were significantly correlated with bioassay RPFs for the dataset examined here. Among  
 7 those showing a significant ( $p < 0.05$ ) linear relationship, in vivo DNA adducts provided the best  
 8 correlation ( $r^2 = 0.64$ ), followed by all in vivo nonbioassay endpoints ( $r^2 = 0.55$ ), all nonbioassay  
 9 endpoints ( $r^2 = 0.40$ ), and all in vitro nonbioassay endpoints ( $r^2 = 0.39$ ). Although in vivo DNA  
 10 adducts provided the strongest correlation, the slope for this regression was 1.22, indicating that  
 11 RPFs for in vivo DNA adducts systematically underpredicted bioassay RPFs. Figure G-1  
 12 demonstrates this underprediction; as the figure shows, most of the average RPF values are to the  
 13 left of the 1:1 correspondence line. The slope for in vivo nonbioassays and Figure G-2 shows a  
 14 similar result for this endpoint. The slopes for all nonbioassays and all in vitro nonbioassays are  
 15 somewhat closer to 1.0. Plots showing the average RPF comparisons for all nonbioassays and all  
 16 in vitro nonbioassays are shown in Figures G-3 and G-4. These plots suggest that all  
 17 nonbioassay RPFs slightly underpredict bioassay RPFs, while all in vitro nonbioassays tend  
 18 toward overprediction.

19

**Table G-3. Results of simple linear regression of log-transformed average genotoxicity RPF versus log average tumor bioassay RPF**

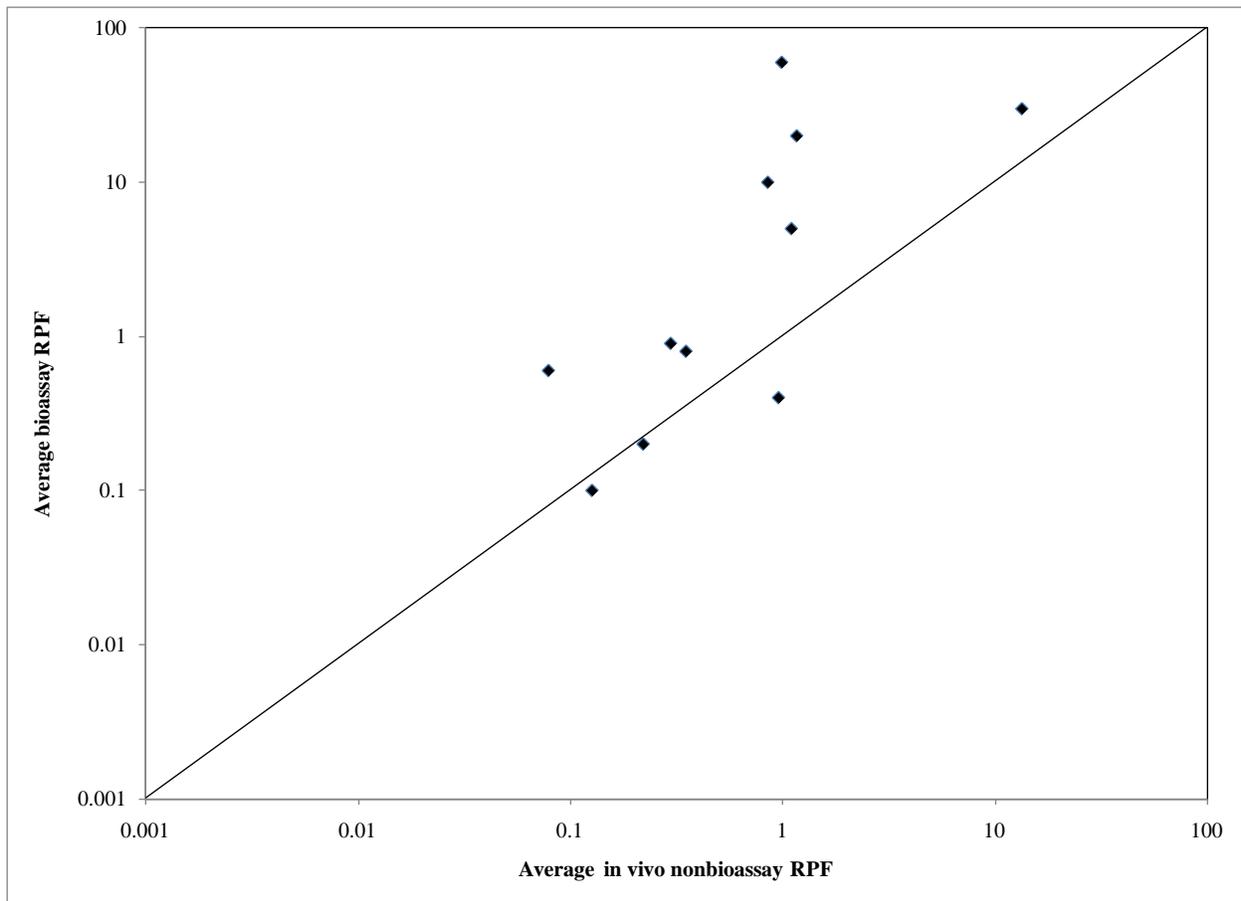
| Genotoxicity endpoint                                  | $r^2$ | Slope | $p$ -Value             | n  |
|--------------------------------------------------------|-------|-------|------------------------|----|
| All in vivo DNA adducts                                | 0.64  | 1.22  | <0.01                  | 10 |
| All in vivo nonbioassays                               | 0.55  | 1.16  | <0.01                  | 11 |
| All nonbioassay endpoints (in vitro and in vivo)       | 0.40  | 1.10  | <0.01                  | 20 |
| All in vitro nonbioassays                              | 0.39  | 0.95  | <0.01                  | 19 |
| All in vivo micronuclei and sister chromatid exchanges | 0.39  | 0.81  | >0.05 (nonsignificant) | 6  |
| All in vitro mutagenicity                              | 0.032 | 0.33  | >0.05 (nonsignificant) | 17 |

20



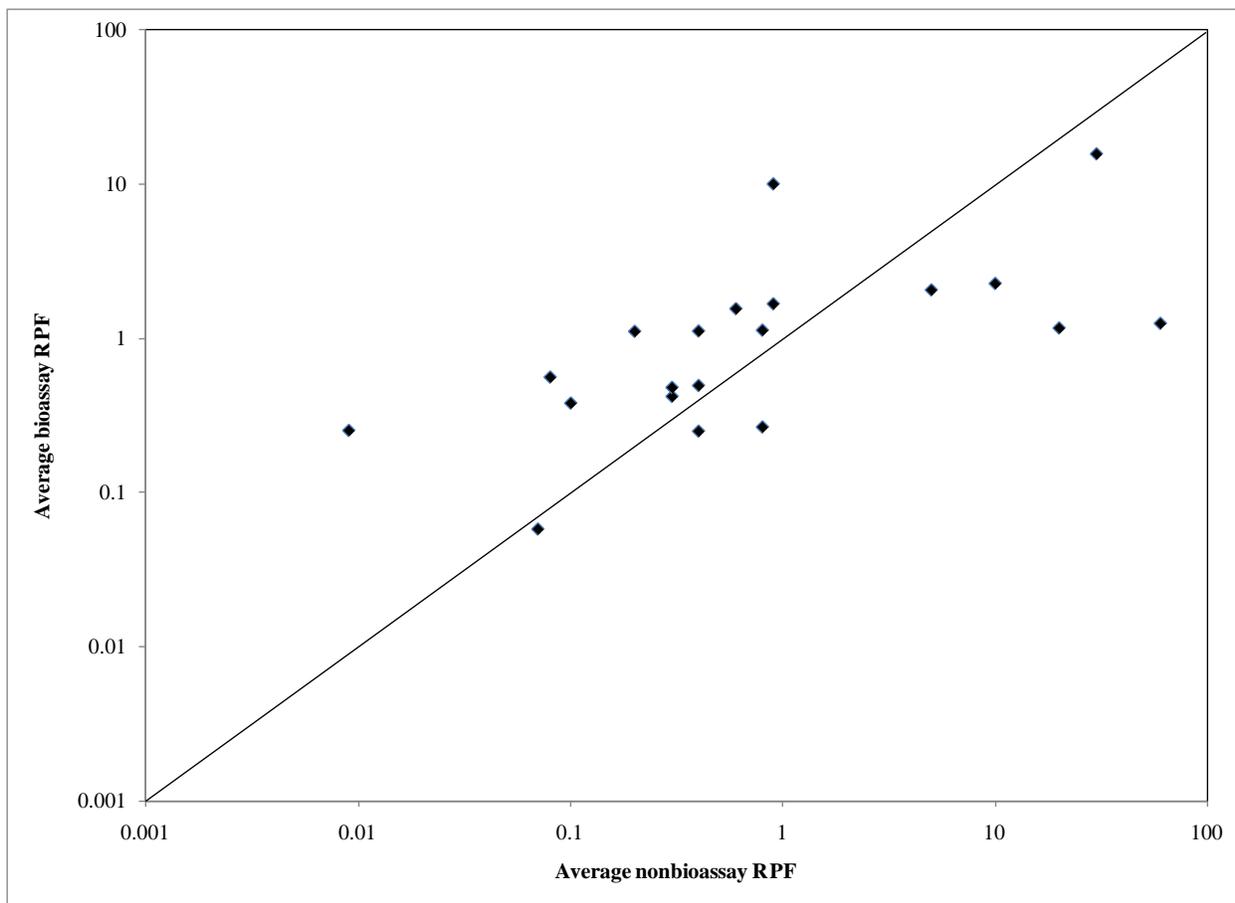
1  
2

**Figure G-1. Average bioassay RPF versus average in vivo DNA adduct RPF.**



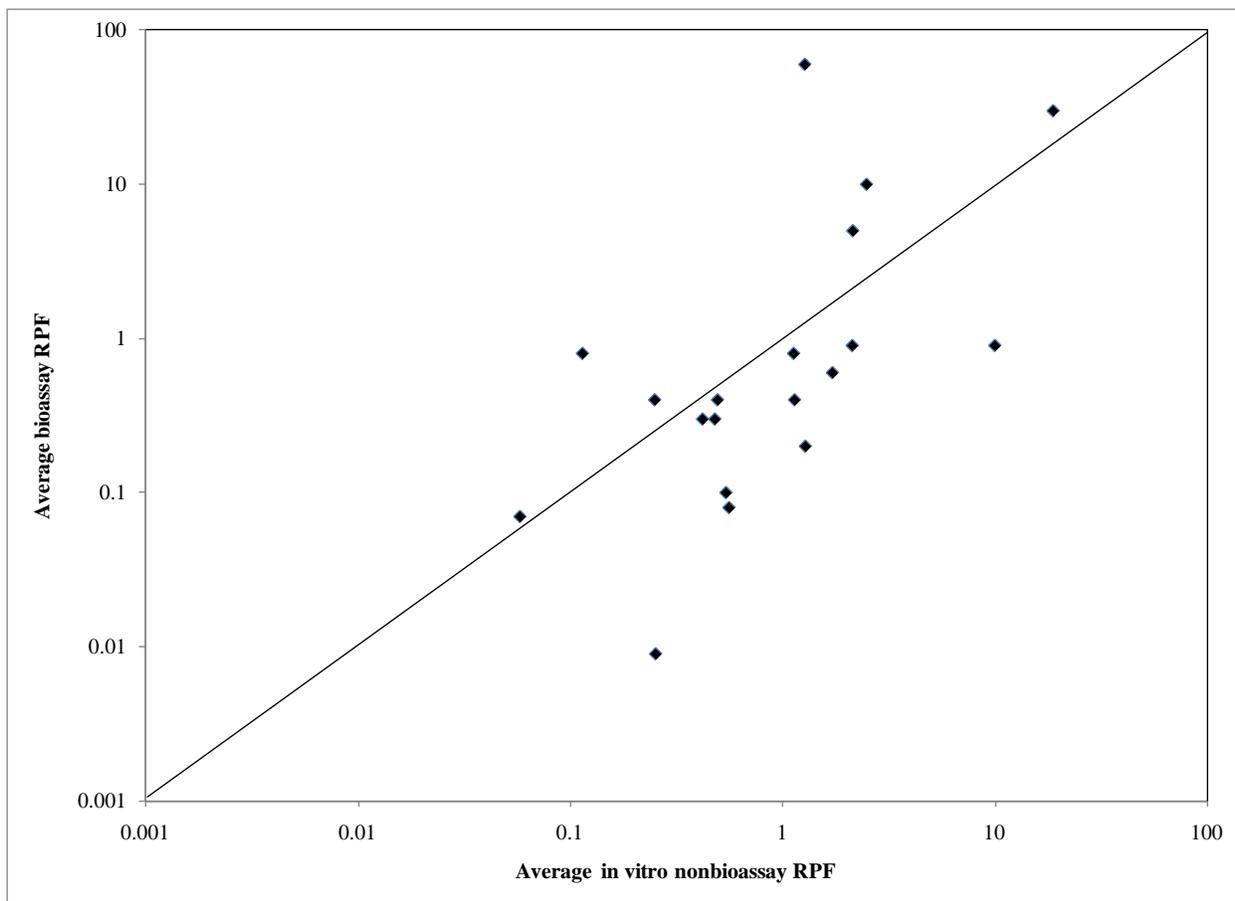
1  
2  
3

**Figure G-2. Average bioassay RPF versus average in vivo nonbioassay RPF.**



1  
2

**Figure G-3. Average bioassay RPF versus average nonbioassay RPF.**



**Figure G-4. Average bioassay RPF versus average in vitro nonbioassay RPF.**

Based on the results of the linear regression analyses comparing PAH RPFs calculated for genotoxicity endpoints and RPFs calculated for bioassays (Table G-3), an argument could be made for the following ranking: (1) bioassays, (2) in vivo nonbioassays, and (3) in vitro nonbioassays. However, the improvement in correlation that is achieved with subdividing all nonbioassays into in vivo and in vitro endpoints is small, and the plot for in vivo nonbioassay RPFs (Figure G-2) shows that this grouping exhibits a slight tendency to underpredict bioassay RPFs.

In summary, as with the findings for tumor bioassay data, the analysis of options for ranking cancer-related endpoint RPFs did not suggest any clear basis for prioritizing the available data for the purpose of selecting RPFs. Thus, for PAHs without any tumor bioassay RPFs but with adequate information to suggest potential carcinogenicity, the cancer-related endpoint data were combined to calculate a final RPF as described in Chapter 7.