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Section 812 Benzene Case Study: Health Effects Methodology and Results

Henry Roman
Senior Associate
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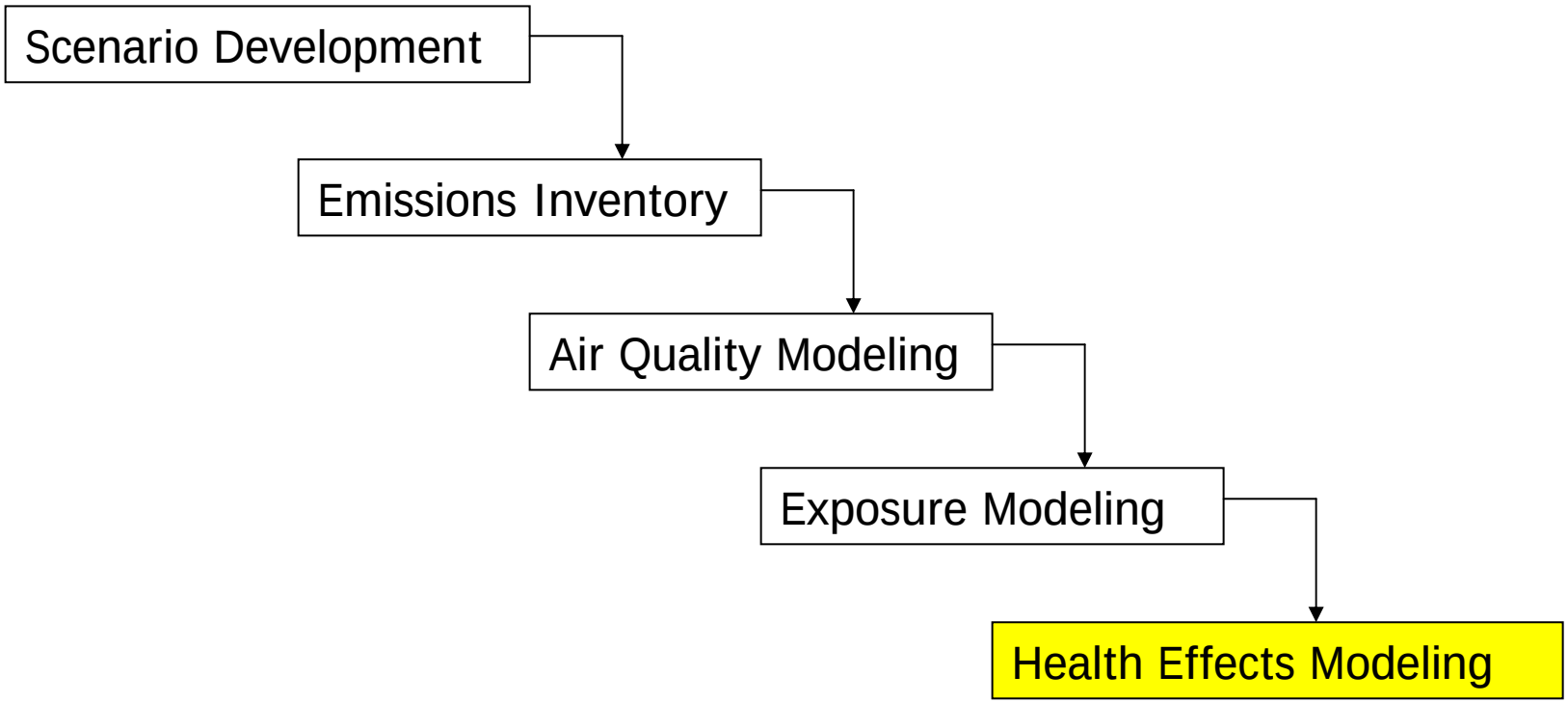
INDUSTRIAL ECONOMICS, INCORPORATED

Analytical Approach



Outline

- Risk Model
  - Benzene Health Endpoints
  - Life-Table Risk Model for Leukemia
  - Non-Cancer Evaluation
- Benefits Valuation
- Main Results
- Sensitivity Analysis / Uncertainty
- Individual Risk Analyses for Highly Exposed Populations
- Conclusions

Charge Questions – Life Table Approach for Health Benefits

Please comment on EPA's life table approach for estimating health benefits, specifically addressing the following:

- EPA's selection of leukemia as the primary health endpoint;
- EPA's use of weighted, cumulative exposure measures in the life table risk model to account for the cessation lag in the realization of benefits following benzene exposure reductions;
- EPA's interpretation of the literature on latency and cessation lag for benzene-induced leukemia;
- EPA's choice of a linear dose-response function;
- EPA's sensitivity analyses of the primary benefits estimate (i.e., choice of epidemiological cohort study, the health endpoints of all leukemia versus acute myelogenous leukemia, the lag length, and the exposure values used); and
- EPA's choice not to apply an adjustment for exposure to benzene in early life.

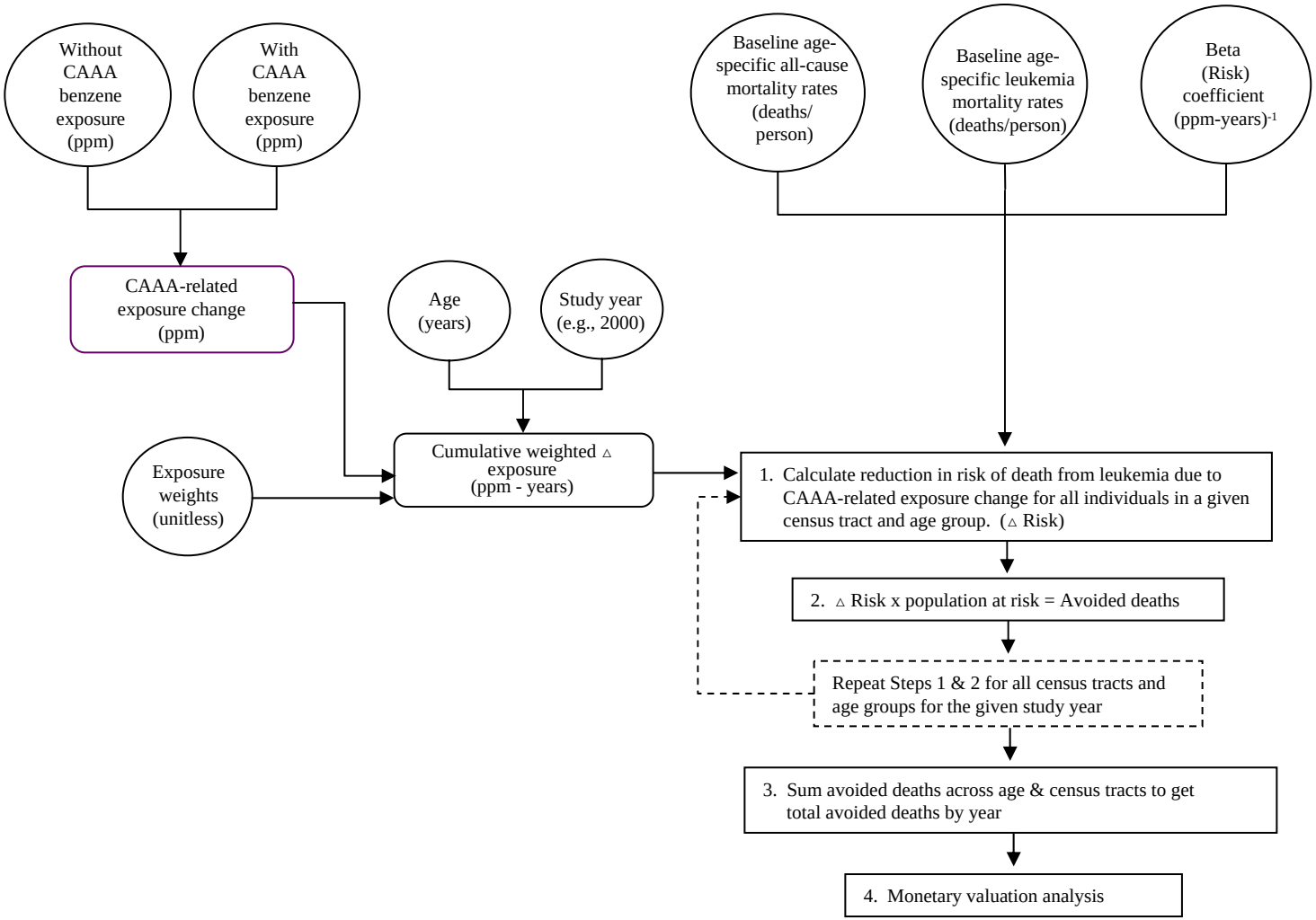
Key Health Endpoints

- Benzene literature review completed in July 2005
- Key benzene health endpoints identified
  - Cancer
    - All leukemias – most data rich endpoint
    - Leukemia subtypes – AML has some epidemiologic evidence, others are inconclusive
    - Other cancers include Hodgkin's and Non-Hodgkin's Lymphoma, but data is limited
  - Non-Cancer
    - Subclinical (e.g., changes in white blood cell counts) effects found at occupational levels. Limited data for ambient levels
    - Effects evaluated using the benzene Reference Concentration (RfC)

Approach to Estimating Avoided Cancer Cases

- Goal is to calculate the expected number of fatal and non-fatal cases of benzene-induced leukemia avoided as a result of the CAAA in the Houston area
- Lifetable approach
  - Patterned after NRC's BEIR IV report on radon exposure (1988)
  - Allows for estimation of benefits to age-specific cohorts
  - Allows us to model "cessation lag" effects on benefits directly by using cumulative weighted exposure estimates
  - Generates estimate of benefits expected in each year, not a rolled-up estimate to be spread across future years (as in criteria pollutant analysis)
  - Model was run with both leukemia mortality and incidence data. The difference between leukemia incidence and leukemia mortality results provide estimate of non-fatal cases.

Overview of Health Benefits Model



Note: This flowchart assumes the model is being run with leukemia mortality data. The model can also be run with leukemia incidence data. The difference between the model results for these two runs represents an estimate of avoided non-fatal cases of leukemia.

Model Selection

After reviewing the available literature, a main model was selected for estimating avoided cancer cases:

- Epidemiologic Data – Pliofilm cohort study (Crump et al., 1994), which informs the unit risk range in EPA's Integrated Risk Information System (IRIS)
- Cancer Endpoint – all leukemias
- Shape of the Dose-Response (D-R) Relationship – linear
- Exposure Weighting – D-R relationship weights exposures in the past differentially. The peak weight occurs at 5.3 years prior to current year (Crump et al., 1994).

$$w(t) = (t/K^2) \exp(-t/K)$$

Where: t = number of years before current year; and

K = number of years before current year where weight is maximum

Weighting consistent with review of peer-reviewed literature on latency/cessation lag (e.g., Silver et al., 2002; Hayes et al., 1997).

Model Inputs

- US Population data from the 2000 Census at the tract level
- Background Rates
  - All-cause mortality rate (1990)
  - Leukemia rate (average of 1990-2003 for mortality; average of 1999-2003 for incidence)
  - From the Texas Department of State Health Services, Center for Health Statistics
  - County Level

Risk Calculations

- Goal is to estimate the differences in risk of dying of leukemia in a given year between the with-CAAA and without-CAAA scenarios.
- Basic risk equation:

$$R = h/h^* \times S \times (1-q)$$

Where:

R = risk of dying from leukemia in the current year, given survival up to that year;

h = leukemia mortality rate;

h* = all-cause mortality rate;

S = probability of surviving up to the current year;

q = probability of surviving through the current year; and

1-q = probability of dying during the current year.

Charge Questions - Valuation

Please comment on EPA's approach to assigning economic value to avoided cases of leukemia, both fatal and non-fatal, with specific reference to:

- EPA's use of a "pre-mortality morbidity" supplement to VSL for fatal leukemias;
- EPA's development of a unit value for a non-fatal case of leukemia based on current literature and previous SAB advice; and
- EPA's choice not to include a "cancer premium," consistent with the SAB Environmental Economics Advisory Committee (EEAC) panel in 2001.

Benefits Valuation

- For fatal cancers, used placeholder value of statistical life (VSL) (starting at $5.5 million for 1990 income levels) plus $110,000 per case for pre-mortality morbidity from EPA's Cost of Illness Handbook (All values in 1999$).
- For non-fatal cancers, used geometric mean of WTP for chronic bronchitis and one stated preference study on non-fatal lymphoma ($1.0 million in 1990).
- Income growth incorporated for VSL, assuming an elasticity value of 0.4.
- Benefits discounted using 5% rate (3% and 7% used as a sensitivity analysis) per current guidance.

Results – Cumulative Avoided Cases of Leukemia

STUDY YEAR	CUMULATIVE AVOIDED CASES OF LEUKEMIA		
	AVOIDED FATAL CASES	AVOIDED NON-FATAL CASES	TOTAL AVOIDED CASES
1990	0	0	**0**
2000	0.5	0.4	**0.9**
2010	2	2	**4**
2020	5	4	**9**

- Seven of these cases occurred in Harris, with one in Brazoria and one in Galveston
- No differences found in the number of individuals experiencing benzene concentrations above the RfC under the *With-CAAA* and *Without-CAAA* scenarios (proposed approach in the original analytic plan)

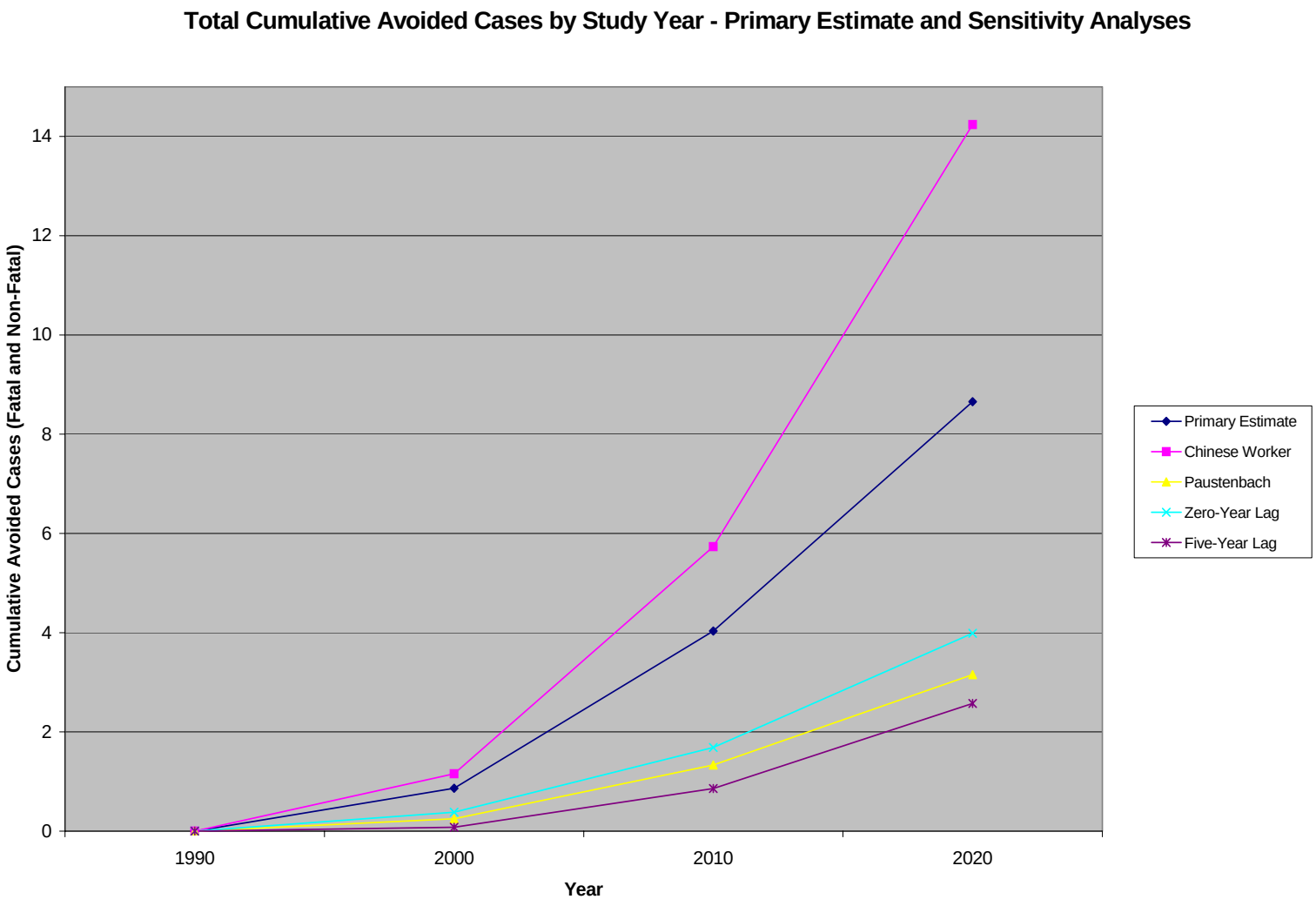
Results – Monetary Benefits

DISCOUNT PERCENTAGE	TOTAL BENEFITS (1990 NPV, MILLIONS OF1999$)		
	BENEFITS FROM FATAL CASES OF LEUKEMIA	BENEFITS FROM NON-FATAL CASES OF LEUKEMIA	TOTAL BENEFITS
Primary Estimate (5%)	**$11**	**$2**	**$13**
No Discounting	$29	$5	$34
Low Discount Rate (3%)	$16	$3	$19
High Discount Rate (7%)	$8	$1	$9

Results – Sensitivity Analyses

- Four sensitivity analyses performed to estimate the range of uncertainty surrounding the primary estimate
  1. Epidemiological Data: Used a dose-response estimate from the Chinese Worker Study from CalEPA's Public Health Goal for Benzene analysis
  2. Cancer Endpoint: Estimated avoided cases of AML
  3. Exposure Matrix: Used exposure estimates for Pliofilm cohort derived by Paustenbach et al.
  4. Exposure Weighting: Assumed all past exposures weighted equally (0-year lag) and assumed the past 5 years weighted with zero, all other years weighted equally (5-year lag)

Results – Sensitivity Analyses



Uncertainties

- Model sensitive to inputs – results range can vary by plus 50 percent to minus 67 percent
- Only quantified leukemia – potentially other health endpoints related to benzene (cancer and non-cancer)
- Use of occupational cohort study
  - Only included certain age groups
  - Potential for “healthy worker effect”
- Shape of dose-response function at low exposures uncertain (Supralinear? Threshold?)
- Model does not consider changes in population over time
- Uncertainty in valuation estimates
  - No “cancer premium” incorporated
  - Non-fatal cancer valuation based on only two data points

Charge Questions – Analyses of Individuals in High-Exposure Environments

Please comment on the data and methodological choices for these analyses with specific reference to:

- EPA's choices regarding the most useful high exposure scenarios to evaluate; and
- EPA's overall approach to valuing risk reductions using VSL, which does not account specifically for individuals who may have a higher than average baseline mortality risk due to high exposures to multiple HAPs and (as stated above in the question on a possible cancer premium) does not apply adjustments to account for the characteristics of the HAP risks being reduced.

Highly Exposed Subpopulations – Census Tracts with High Exposure

- Selected the two tracts in each county with the highest HAPEM concentrations under the *Without-CAAA* scenario.
- Calculated an estimate of lifetime reduction of leukemia risk due to the CAAA for each tract, assuming continuous exposure to median 2020 levels

$$\Delta \text{Risk of Leukemia} = (EC_{With} - EC_{Without}) \times IUR$$

Where:

EC_{With} = median 2020 exposure concentration from HAPEM6 under the *With-CAAA* scenario ($\mu g/m^3$);

$EC_{Without}$ = median 2020 exposure concentration from HAPEM6 under the *Without-CAAA* scenario ($\mu g/m^3$); and

IUR = benzene inhalation unit risk estimate from IRIS $(\mu g/m^3)^{-1}$

Results – Census Tracts with High Exposures

COUNTY	CENSUS TRACT	MEDIAN WITHOUT-CAAA RISK	MEDIAN WITH-CAAA RISK	PERCENT REDUCTION IN RISK	POPULATION OF CENSUS TRACT
Brazoria	6643	2×10^{-4}	3×10^{-6}	98	5,452
Brazoria	6638	3×10^{-5}	6×10^{-6}	77	4,470
Galveston	7222	1×10^{-4}	7×10^{-6}	95	3,487
Galveston	7224	5×10^{-5}	8×10^{-6}	82	1,108
Harris	1000	1×10^{-4}	1×10^{-5}	92	6,678
Harris	2523	3×10^{-5}	7×10^{-6}	72	12,686

Note: These risk values were calculated using the $7.8 \times 10\text{-}6$ per $\mu g/m^3$ benzene inhalation unit risk (IUR) from the range of IURs reported on IRIS.

Highly Exposed Subpopulations – Near Roadways

- Several exposure studies have found HAPs measured near homes within 200 meters of roadways are higher than urban background
- HAPEM6 incorporates a near-roadway algorithm
- Conducted additional HAPEM6 run, turning off near-roadway algorithm
- Assessed the difference in annual average benzene concentration between the *With-* and *Without-CAAA* scenarios for these two HAPEM runs.

Results – Near Roadways

COUNTY	CENSUS TRACT	BENZENE REDUCTION NEAR-ROADWAY OFF ($\mu g/m^3$)	BENZENE REDUCTION NEAR-ROADWAY ON ($\mu g/m^3$)	PERCENT CHANGE IN BENZENE DUE TO NEAR ROADWAY EFFECT	POTENTIALLY AFFECTED POPULATION[1]
Harris	321500	1.5	2.6	69	226
Harris	540200	1.3	2.5	89	247
Harris	310700	2.3	3.8	65	457
Harris	541900	2.0	2.5	25	436
Harris	431200	2.4	3.5	44	694
Harris	412100	1.6	2.5	60	98
Harris	450300	2.2	3.1	43	712
Harris	311900	2.0	2.8	42	278
Harris	431900	3.0	3.5	15	206
Harris	410900	2.7	3.3	21	282

[1] Because these values were calculated using 90th percentile exposure concentrations, we assumed that 10 percent of the population in the tracts may be associated with these changes in benzene exposure or higher.

Highly Exposed Subpopulations – Attached Garages

- Studies in homes with attached garages suggest that these homes have higher indoor benzene concentrations than homes without attached garages.
- Illustrative, back-of-the envelope calculations performed due to lack of local data
  - Step 1 - Assessed the percent reduction in total benzene emissions in the non-road and on-road categories expected to occur in 2020
  - Step 2 – Applied the percent reduction in emissions to an estimate of average benzene exposure attributable to attached garages (from MSAT RIA Appendix)
  - Step 3 – Calculated the annual avoided cases of leukemia

Results – Attached Garages

- Total benzene emissions in attached garages reduced by 89-90 percent
- Benzene exposures reduced by 1.1 $\mu g/m^3$
- Translates into an additional 0.1 – 0.5 annual avoided cases of leukemia in 2020 in Houston
- Adding this to the primary estimate could increase benefits by as much as 20 to 100 percent

Conclusions

- CAAA controls on benzene yield significant health benefits:
  - Reduced leukemia incidence
  - Reduced individual risk levels for highly exposed
- Successful application of life-table approach, but likely underestimates benefits
- Both cases avoided and individual risk changes important to include
- Weighting exposures an alternative approach to cessation lag
- Additional research needed to address VSL cancer premium and valuation of non-fatal cases
- Attached garage exposures warrant inclusion in future analyses