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Environmental
Protection Agency

Science Advisory Board
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AN SAB REPORT: REVIEW OF THE RESEARCH PROGRAM ON DISINFECTANTS AND DISINFECTION BY-PRODUCTS IN THE RISK REDUCTION RESEARCH LABORATORY

PREPARED BY THE DRINKING WATER COMMITTEE

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

December 29, 1993

EPA-SAB-DWC-94-006

Honorable Carol M. Browner
Administrator
U.S. Environmental Protection Agency
401 M Street, SW
Washington, DC 20460

Subject: SAB Review of the Research Program on Disinfectants and Disinfection By-Products in the Risk Reduction Research Laboratory

Dear Ms. Browner:

On December 2-3, 1992, the Drinking Water Committee of the Science Advisory Board (SAB) met at the Risk Reduction Engineering Laboratory to review the Agency's research program on disinfectants and disinfection by-products. This review was initiated by the Committee. In general, the Committee found that, within the constraints of available resources, the Agency is doing an excellent job in the planning and conduct of its research activities in this area.

The Committee is very concerned, however, that continuing reductions in funding levels for drinking water research are creating serious delays in the acquisition of data that are critically needed in the microbial, disinfectant and disinfection by-products areas, as evidenced by many of the concerns we describe below and in the accompanying report. These delays will seriously impact the Agency's ability to promulgate rules with the necessary scientific basis in these areas. The Committee's fundamental recommendation, therefore, is that the Agency commit sufficient resources to develop a critical mass of research funding and personnel budgets for drinking water research, especially pollutant

and disinfectant research. The Committee feels that, for such a research program to be worthwhile, the funding would have to be in the order of $5-6 million in the next five years.

With specific reference to by-product research activity, it is clear that the Agency's work has been primarily on *chlorination by-products*. The Committee strongly recommends additional research concerning *by-products associated with alternate disinfectants*, especially those by-products that may be associated with the use of ozone, as well as those associated with the use of *combinations* of disinfectants. Such research is critical, because recent discoveries have indicated the possibility of hazardous by-products arising from the use of ozone. Ozonation, as well as chlorination, can lead to the formation of bromate (an established animal carcinogen) and brominated organic analogs of chlorination by-products. Additional research efforts should also include a systematic chemical characterization of major by-products of alternate forms of disinfection, which in turn should be linked to the identification of any potential etiologic agents for potential non-cancer disease endpoints such as neurotoxicity, reproductive and developmental effects.

With regard to field research devoted to the control of disinfection by-products (DBPs), the Committee found that the ongoing activities by the Agency are very valuable, but we also found need for additional research in areas such as the use of granulated organic carbon and/or membranes for removal of by-product precursors, as well as development of new technologies for use by small water systems. These additional research activities would require increased funding.

This review did not attempt a comprehensive look at microbiologic research needs related to the disinfection debate, and a discussion of the Committee's views related to these needs can be found in a recent letter from the Committee (EPA-SAB-DWC-COM-002). With regard to the Ground Water Survey for Viruses, however, the Committee concluded that it is an important first step in determining virus occurrence in the Nation's ground waters used as drinking water sources, and has the potential to provide virus occurrence data towards the worst-case end of the spectrum. Data on virus occurrence in groundwater sources of drinking water in the United States are very limited, and yet such data are crucial to the formulation of a scientific, risk-based approach to the Ground Water Disinfection Rule. Because this study is not a representative survey of groundwater sources of drinking water, however, we urge the Agency to clearly define the criteria for interpretation and use of the data.

Most importantly, this survey will not satisfy the critical need for a reliable survey of viruses in ground waters to be used as drinking water sources. In order to formulate a realistic and meaningful Ground Water Disinfection Rule, a groundwater survey for human enteric viruses is essential, and the Committee recommends that the Agency undertake such a survey.

The attached report discusses these and other issues in more detail. The Committee was very pleased with the quality of the presentations by Agency staff during this review and wishes to convey its appreciation all the participants. They also appreciate the opportunity to conduct this review, and they look forward to your response to the scientific advice transmitted herein.

Sincerely,

Genevieve M. Matanoski

Dr. Genevieve M. Matanoski, Chair
Executive Committee
Science Advisory Board

Verne A. Ray

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Drinking Water Committee
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ABSTRACT

On December 2-3, 1992, the Drinking Water Committee of the Science Advisory Board (SAB) met to review, at the request of the Committee, the Agency's research program on disinfectants and disinfection by-products. The Committee concluded that the Agency is doing an excellent job in the performance of research activities in this area, but that reductions in funding levels are seriously delaying the acquisition of critical data in the microbial, disinfectant and disinfection by-products areas. The Committee strongly recommended the addition of additional resources.

The Committee recommended additional research efforts regarding: (a) by-products associated with alternative (non-chlorine) disinfectants, especially ozone; (b) brominated compounds arising from both ozonation and chlorination; (c) the use of granular activated carbon and membranes for control of by-product precursors; (d) new technologies with promise for small systems.

The Committee also found the Ground Water Survey of Viruses to be a valuable undertaking, but recommended that the Agency undertake a representative survey of human enteric viruses in ground waters. Finally, the Committee recommended that the Agency undertake efforts to establish criteria for the interpretation of biotechnological methods currently used for detection of viruses.

Key Words: Disinfection, By-products, Research, Microbial, Brominated, Chlorinatioon, Activated Carbon, Membranes, Viruses.

ENVIRONMENTAL PROTECTION AGENCY
SCIENCE ADVISORY BOARD
DRINKING WATER COMMITTEE

Review of Draft Drinking Water Criteria Document for Inorganic Arsenic

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TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

1.1 General Findings

In general, the Committee found that, within the constraints of available resources, the Agency is doing an excellent job in the planning and conduct of its research activities in the area of disinfection and disinfection by-products (D/DBPs). The Committee is very concerned that continuing reductions in funding levels for drinking water research are creating serious delays in the acquisition of data that are critically needed in the microbial, disinfectant and disinfection by-products areas. The Committee strongly recommends that the Agency commit sufficient resources to develop a critical mass of research funding and personnel budgets for drinking water research, especially pollutant and disinfectant research. The Committee feels that, for such a research program to be worthwhile, the funding would have to be in the order of $5-6 million in the next five years.

1.2 Disinfection/Disinfection By-Products (D/DBPs)

The Agency is doing an excellent job of determining how various water treatment processes affect the formation of *chlorination* by-products. Very valuable information has been generated indicating how the levels of such by-products may be modified by utilizing alternate disinfectant strategies and/or mixed disinfection. The research efforts correctly attempt to find ways to reduce the formation of DBPs while also maintaining minimum requirements for preventing waterborne infectious disease.

The focus of by-product research, however, has been primarily on chlorination by-products. The Committee strongly recommends additional research concerning by-products associated *with alternate disinfectants*, especially those by-products that may be associated with the use of ozone. Such research is critical, because recent discoveries have indicated the possibility of hazardous by-products arising from the use of ozone. Ozonation, as well as chlorination, can lead to the formation of bromate (an established animal carcinogen) and brominated organic analogs of chlorination by-products. Additional research efforts should include a systematic chemical characterization of major by-products of alternate forms of disinfection. These chemical characterization efforts should also be linked to the identification of potential etiologic agents for non-cancer disease endpoints such as neurotoxicity,

reproductive and developmental effects. In addition, the Committee feels that additional work on mutagenic activity (*in vitro* tests) in waters treated with varying disinfectants should be continued *only* if there is a commitment to subject each potential mutagen so identified to subsequent chemical characterization and *in vivo* testing.

1.3 Field Studies for Control of Disinfection By-Products

The Committee feels that research using different waters with the major disinfectants used in parallel must be performed to determine the performance and cost of Granular Activated Carbon (GAC) compared to other technologies for controlling DBPs. Of special interest is the use of ozone prior to GAC and the effect on DBPs. This research needs to be done, in the field, under similar conditions of typical treatment plants.

The Agency's research concerning the use of membranes for control of DBP precursors has only scratched the surface. The Committee recommends increased research in: a) developing efficient ways of disposing of membrane concentrate; b) determining the right combination of membranes (Membrane Filtration, Ultra-Filtration, Nano-Filtration) for use on surface waters; c) understanding the performance reliability of membranes under stressed conditions such as fibers breaking in a hollow-fiber membrane or rupture of spiral-wound membranes; and d) understanding how to control fouling of membranes.

The Agency's research activities concerning small systems are very valuable, but there is a need to increase research to evaluate technologies other than those now under scrutiny. These evaluations need to be in-depth and for extended periods of time. Data on the performance of package plants and Point-of-Use/Point-of-Entry (POU/POE) approaches, for example, for meeting the Surface Water Treatment Rule or the Disinfection/Disinfection Byproduct Rule are not available and should be developed. Working closely with the Office of Ground Water and Drinking Water, the research arms of the Agency should find ways to overcome institutional barriers and customer non-acceptance to the adoption of new technologies, as well as a need to resolve numerous operation and maintenance problems that face such new technologies.

1.4 Non-Disinfection By-Products

In general, the non-DBP research program appears to be doing a good job of evaluating existing treatment technologies and processes. The Committee recommends expansion to include more intensive research related to new and emerging technologies such as membrane filtration and advanced oxidation techniques.

1.5 Microbiological Issues

The Committee believes that the Ground Water Survey for Viruses is an important first step in determining virus occurrence in the Nation's ground waters used as drinking water sources, and has the potential to provide virus occurrence data towards the worst-case end of the spectrum. Data on virus occurrence in groundwater sources of drinking water in the United States are very limited, and yet such data are crucial to the formulation of a scientific, risk-based approach to the Ground Water Disinfection Rule. The Committee supports the use of fecal indicator data as part of the selection process for the wells to be ultimately investigated through the survey.

Because this study is not a representative survey of ground water sources of drinking water, it is essential that the criteria for interpretation and use of the resulting data be clearly defined. Most importantly, this study will not satisfy the critical need for a reliable survey of viruses in ground waters to be used as drinking water sources. In order to formulate a realistic and meaningful Ground Water Disinfection Rule, a ground water survey for human enteric viruses is essential. The Committee recommends that the Agency undertake such a survey.

The Committee believes that virus detection data from model systems and seeded samples are essential in order to make rational interpretations of the data obtained by biotechnological methods. The Committee recommends that the Agency undertake efforts to establish that the biotechnological methods they use not only detect viruses but also that the data obtained using these methods can be understood and interpreted in relation to virus infectivity to cell cultures.

2. BACKGROUND AND CHARGE

The Drinking Water Committee (DWC) of the EPA's Science Advisory Board has long had a keen interest in the Agency's disinfectant-disinfectant by-product (D/DBP) program. In August of 1992, the Committee wrote a commentary to then-Administrator William Reilly asking for his support in providing greater resources for research of combined disinfectant practices. As a result of this commentary and the succeeding Committee discussions concerning the status of technology for meeting the D/DBP rule, the Committee decided to request a meeting to further address this topic. Specifically, the Committee requested that the Agency arrange presentations for the Committee on the following subjects:

a. An overview of the in-house and extramural program of the Office of Research and Development on the D/DBP issue.

b. An overview by the Drinking Water Issue Planner concerning the distribution of the overall drinking water research budget and how the individual components have changed from FY89 to FY93.

c. A presentation by the Office of Water's Technical Support Division (TSD) on the studies they are conducting on measurement of DBPs generated at operating utilities.

d. A briefing or status report by TSD on the "ground water virus survey" and how it is providing scientific support for the ground water disinfection rule.

The Committee sought to better understand the fiscal resources being devoted to each aspect of drinking water research as well as the details of the current research monitoring program on D/DBPs. They also sought to obtain an overview of the Risk Reduction Engineering Laboratory's major research efforts other than those focused on D/DBPs, a description of how the Lab supports the Agency drinking water programs, and a discussion of research needs that are not identified or that have been identified but are not funded.

With these topics as their charge, the Committee met on December 7-8, 1992, at the Agency's Risk Reduction Engineering Laboratory (RREL) in Cincinnati, Ohio.

3. FINDINGS

3.1 General Findings: Research Planning and Budgeting Issues

Two of the key presentations provided to the Committee during the review concerned strategic research planning efforts by the Agency, with emphasis on drinking-water related research. Mr. Joseph DeSantis provided an overview of ORD's three-tiered process for identifying and funding research projects, a process which includes development of a Strategic Plan, Specific Research Plans for each of a range of research issues, and Implementation Plans for each laboratory by issue. Dr. Thomas Harvey, the Issue Planner for drinking water, provided a detailed review of these planning activities for Issue 19, which addresses pollutant and disinfection research strategy planning. The Committee also received information regarding funding levels in fiscal years 1992 and 1993 for the Office of Research and Development (ORD) as a whole, and for drinking water research budgets in particular.

In fiscal year (FY) 1993, the ORD budget sustained a $38.7 million reduction, which resulted in a substantive impact on a drinking water research budget that had *already* sustained considerable reductions in the past several years. In FY1992, the research and development budget for pollutant and disinfectant research was $6.2 million, in FY1993 it was $4.2, and for FY1994 it is $5.2 million. The Committee is very concerned that budgeting at these levels will create serious delays in the acquisition of data that are critically needed in the microbial, disinfectant and disinfection by-products areas. Some of the research areas that would be negatively impacted are:

a. Research on alternate disinfectants/by-products and combination treatments such as ozone followed by chlorine or chloramine and attendant risks.

b. Research concerning effective treatments for difficult to treat pathogens including Norwalk, Norwalk-like viruses and *Cryptosporidium*, as well as research on endemic risks of waterborne microbial infection.

c. Research on complex mixtures.

d. Research on the health risks associated with a series of water pollutants, including selected organics, aluminum, and microbes.

e. Epidemiologic research.

The briefings provided to the Committee projected a series of estimated delays that would result from the lack of adequate resources. Research on alternative disinfectants/by-products will be delayed substantially (3-5 years), for example, as would research on microbial health risks and treatment modalities (3-5 years). Further, the lack of adequate research data on disinfectants/by-products has prevented the Agency from promulgating rules based on a firm scientific basis and forced the process of negotiated regulations.

In addition to the concerns regarding research priorities that have not been addressed because of lack of funding, it was also brought to the Committee's attention that 40 percent or more of staff are within five years of retirement. This statistic poses important issues of staff development and expertise which the Committee recommends the Agency address.

In view of these findings, the Committee strongly recommends that the Agency add adequate resources, conceivably an additional $6 million/year for five years, to increase both research funding and personnel budgets for drinking water research, especially pollutant and disinfectant research.

3.2 Disinfection/Disinfection By-Products

3.2.1 General Issues

The research activities related to disinfectants and disinfection by-products at the Drinking Water Research Division (DWRD) are conducted at three levels:

a) Bench scale studies of by-product formation with alternative disinfectants.

b) Pilot plant studies within EPA facilities to investigate bench-scale observations and to determine how water treatment variables might affect the production of by-products.

c) Pilot to full-scale experimentation conducted cooperatively at sites around the country.

When research findings from these three areas are brought together with the monitoring database of the Technical Support Division (TSD), estimates of the magnitude and extent of the by-product problem with differing water qualities, water treatment trains and disinfectants can be made. This type of information is developed through carefully coordinated efforts between DWRD and TSD, who in turn collaborate profitably with the water works industry, represented by the American Water Works Association (AWWA) and the American Water Works Association Research Foundation (AWWARF). The common objective is to develop as comprehensive a picture as possible of the manner in which modifications of treatment processes will change the production of disinfection by-products.

The focus of these research activities, however, has been strongly biased towards the known by-products of *chlorine* disinfection which, perhaps understandably, tends to make chlorine disinfection appear undesirable. The Committee feels that it is important to emphasize that little is known about by-products associated with alternate disinfectants. The possibility of hazardous by-products arising from the use of alternative disinfectants has received attention only after the recent discoveries that ozone contributes to the formation of bromate (an established animal carcinogen) and brominated organic analogs of chlorination by-products.

Research staff in the Drinking Water Research Division are well aware of the lack of information on by-products of other forms of disinfection. They collaborate with the Environmental Research Laboratory in Athens, Georgia to attempt to address this lack of information, but severely restricted budgets have prevented them from mounting a systematic effort to address it. A particularly critical issue is the question of the use of mixed disinfectants, where the primary focus needs to be expanded beyond the simple formation of chlorination by-products.

Despite the shortcomings of the available data, the Office of Drinking Water must develop a rational regulatory strategy and estimate the impact of regulation. In a similar manner, the Health Effects Research Laboratory must pay specific attention to both the nature of the by-products that are produced and their concentrations to set research priorities that address regulatory issues

surrounding disinfectants and their by-products as efficiently as possible, despite the clearly inadequate resources that are available in this area.

Within the constraints of available resources, the DWRD is doing an excellent job of determining how various water treatment processes increase or decrease the formation of certain by-products (primarily chlorinated) under more or less realistic water treatment conditions. Very valuable information has been generated indicating how the levels of such by-products may be modified by utilizing alternate disinfectant strategies and/or mixed disinfection. The research efforts correctly attempt to find ways to reduce the formation of chlorination DBPs while also maintaining minimum requirements for preventing waterborne infectious disease. Since a sizable fraction of the chlorination by-products have been identified and characterized as to their toxicological properties, these data can be used by the industry as a guide for the management of chlorination plants to minimize by-product formation. The major unanswered question surrounding these efforts is whether sufficient information is available to demonstrate that the use of alternate disinfectants can provide any additional safety.

Included within the studies of disinfectant by-products are data concerning the production of mutagenic activity in waters treated with varying disinfectants. These efforts were very important in calling attention to the lack of data in this area and were quite valuable when their findings were utilized to provide impetus for better characterization of potential hazards. However, such data alone cannot be utilized as the basis for assessing hazards in either a qualitative or quantitative way. Since there appears to be little commitment on the part of the Agency to follow up on the risk characterization of mutagenic by-products suggested by these tests, the continuance of these experiments is of doubtful significance. It has been well established that chlorination is the major contributor to the formation of such mutagenic substances in drinking water and that alternative disinfectants contribute little to their creation. The presentations to the Committee suggested that further *in vitro* characterization of mutagenic activity might be appropriate, but in times of limited resources and commitment to follow up on these screening activities, continued expenditure of resources to such an effort is difficult to defend.

On the other hand, if the Agency would follow through on screening efforts with development of the appropriate hazard identification efforts, the Ames test and a method for measuring clastogenic effects could be valuable in a

screening and identification effort for potentially carcinogenic by-products. This means that in most cases where a mutagenic compound is identified there must be a commitment to subject that compound to *in vivo* testing. It must be remembered that most of the carcinogenic by-products associated with chlorination are not mutagenic or are only weakly so. Consequently, analytical efforts to identify major by-products of alternate forms of disinfection are at least as important as this biological screening activity.

Chemical identification is also important for identifying non-mutagenic endpoints, such as neurotoxicity or reproductive and developmental (teratogenic) effects, potentially associated with by-products. The very large number of halogenated acidic by-products that are produced with both chlorination and chloramination is of real concern, for example, because dichloroacetate has been shown to be a reproductive, developmental and nervous system toxicant as well as a carcinogen. Clearly, HERL should be charged with the toxicological characterization of this and other major classes of disinfection by-products (based on concentrations produced) in a manner that will allow the Agency to be responsive to regulatory mandates in this area under the Safe Drinking Water Act.

In summary, a clear deficiency in EPA's overall program in drinking water is a lack of the basic science component necessary to systematically study the chemistry of alternative forms of disinfection and to identify and characterize the potential health hazards they may pose. By calculation, chlorination by-products appear to be the largest health threat from organic chemicals in drinking water, but there is very limited knowledge about potential hazards of by-products formed by alternate disinfectants. The basic research is essential in order for the treatment research to be meaningful. The required research effort, however, clearly goes beyond the resources in staff and extramural support available to the DWRD and other contributors to drinking water research in the Agency. The lack of attention to this area in the past several years has clearly contributed to the need to negotiate regulations in this area. Proper prioritization of this research area over the past 6-8 years likely would have resolved many of these issues, or at least provided a much more rational basis for regulation than is now available.

3.2.2 Field Studies for Control of Disinfection By-Products

3.2.2.1 Granular Activated Carbon (GAC)

Clearly, much research has been carried out on the performance, reactivation, cost, and other parameters of GAC for removing disinfection byproduct precursors as determined by TOC (Total Organic Carbon) and TOX (Total Oxidant). Limited research (one source water) on removal of specific disinfection byproducts (DBP) has been performed at Jefferson Parish, Louisiana. Some data are available from other sources. Research using different waters with the major disinfectants used in parallel must be performed as was done at Jefferson Parish. This will enable the determination of the performance and cost of GAC compared to other technologies for controlling DBPs. Of special interest is the use of ozone prior to GAC and the effect on DBPs. This research needs to be done, in the field, under conditions similar to those of typical treatment plants.

3.2.2.2 Membranes

Agency research concerning the use of membranes for control of DBP precursors has only scratched the surface. Some work has been performed in high TOC Florida waters using both ground and surface water. Selected membranes (NF) have performed well removing 95 and 96% of the THM (Trihalomethane) and TOX precursors, respectively, from the Flagler Beach groundwater. For the surface water at Punta Gorda 94 and 97% of the THM and TOX precursors, respectively, were removed. This required extensive pretreatment. Subsequent studies at the Daytona Beach groundwater site showed halogenated precursor removal for the sum of 22 DBPs as chloride to be less than 100 µg/L and for a majority of the time less than 25 µg/L. Other membrane studies have begun at the University of Colorado. These studies are focusing on lower TOC waters and some work on concentrate disposal by using a bioreactor. In 1990, a membrane workshop was held in Cincinnati to discuss among manufacturers, researchers, and regulatory personnel the status of membrane technology to control disinfection byproducts and to investigate any new research that was anticipated for improving membrane performance. In light of the Japanese initiative (MAC 21), the Office of Water has recommended another workshop to discuss the latest knowledge about membrane performance and the possibility of establishing membranes as Best Available Technology (BAT).

Clearly, research needs exist in the membrane area such as: a) developing efficient ways of disposing of membrane concentrate; b) determining the right combination of membranes (Membrane Filtration, Ultra-Filtration, Nano-

Filtration) for use on surface waters; c) understanding the performance reliability of membranes under stressed conditions such as fibers breaking in a hollow-fiber membrane or rupture of spiral-wound membranes; and d) understanding how to control fouling of membranes.

3.2.2.3 Small Systems

The newest area of Agency research is concerned with small water treatment systems. This is important because Congress has stated that equity should prevail when considering drinking water. They have indicated that all citizens should have safe drinking water regardless of whether they are on a large or small system. Therefore, regulations are expected to apply to small systems in the future. EPA research has focused on developing an in-house program that is supplemented with extramural research. The in-house research is being done at the Test and Evaluation Facility located near the Cincinnati EPA laboratory. At this facility ultrafiltration, Ozone/Ultraviolet (O_3/UV), and package plants are being evaluated with other technologies such as nanofiltration, bag filters, and Point-of-Use/Point-of-Entry (POU/POE) devices planned for future evaluation.

At this time the major focus of the research is on technologies that are affordable and that can meet the Surface Water Treatment Rule and the Disinfection/ Disinfection Byproduct Rule. With the in-house capabilities, these systems can be challenged with microorganisms such as *Giardia* and *Cryptosporidium*, organics, inorganics, and turbidity. In addition, under an "electronic circuit rider" approach to monitoring and operating the small systems is planned. Also, design plans have been developed for constructing a pipe loop to simulate distribution system effects.

Extramural projects have focused on two completely different types of communities. One is located in West Virginia and the other is with the Chemehuevi Indian tribe in California. In both cases, an ultrafiltration unit is being used. Long-term performance and cost data, customer acceptance, reliability, operation and maintenance, and other information is being collected. In addition, a cooperative agreement with the American Water Works Association (AWWA) has recently been completed where 58 small systems were visited. Performance and cost data, operational information, reliability, research needs, and other variables of these small systems were some of the information collected during this study. Studies concerning micro-small systems, those

serving less than 100 customers, are receiving priority because they constitute most of the small systems and they have the greatest problems.

The research activities summarized above are very valuable, but there is a need to increase research to evaluate additional small system technologies. These evaluations need to be in-depth and for extended periods of time. Some individuals have stated that the technology is available for small systems but that seems uncertain. Data on the performance of package plants and POU/POE for meeting the Surface Water Treatment Rule or the Disinfection/Disinfection Byproduct Rule are not available. Working closely with the Office of Ground Water and Drinking Water, ways to overcome institutional barriers, customer non-acceptance, and operation and maintenance problems must be found.

3.2.2.4 Alternative Disinfectants

One alternative disinfectant that has been evaluated is chlorine dioxide (ClO_2). At Evansville, Indiana, ClO_2 added to the raw water allowed coagulation/settling to remove enough DBP precursors to lower the THM concentrations from about 120 µg/L to about 50 µg/L. Although ClO_2 seemed to be a viable alternative, the generation of too much chlorite and chlorate was a concern. Bench-scale studies showed that reducing agents such as sulfur dioxide and metabisulfite can reduce the $Cl0_2$ and chlorite,but that chlorate concentrations increase. Ferrous chloride, however, seems to be a viable reducing agent for controlling the total oxidants of ClO_2 as long as the chlorate concentration is kept to a minimum. Pilot plant studies were performed to evaluate the use of ferrous chloride as a reducing agent under simulated actual plant operations. A generator was donated to the project that was as efficient as any available. The objective was to produce ClO_2 without any or limited chlorate or chlorine, reduce the ClO_2 and chlorite, with ferrous chloride, and control the iron concentration by chlorine addition prior to dual media filtration. This procedure appears to be successful. Other studies were performed comparing liquid and gaseous phase chlorine dioxide. Mutagenicity testing showed that gaseous ClO_2 and liquid ClO_2 produced less revertants per liter than liquid chlorine. Samples were sent to the EPA lab in Athens, Georgia for further testing to see if additional disinfection byproducts could be identified.

Research needs include further evaluations on different waters of the treatment process that appears to work well at Evansville. Also, additional

evaluations by the Athens lab need to be made to see if additional disinfection byproducts attributable to ClO_2 can be identified.

In Jefferson Parish, Louisiana, the opportunity to evaluate the four major disinfectants in parallel (O_3, ClO_2, Cl_2, NH_2Cl) exists. Disinfectant concentrations typical of those used in operating plants were used in this study. Many different parameters were evaluated in this study including TOX. During a one-year evaluation, chlorine produced the highest TOX concentrations followed by NH_2Cl, ClO_2, nondisinfected water, and ozone. Also, the 22 specific disinfection byproducts on the Office of Ground Water and Drinking Water's short list have been evaluated. From these studies, when only chlorine was used, the concentrations were the highest. Concentrations decreased respectively using the following disinfectants: O_3/Cl_2, NH_2Cl/NH_2Cl, and O_3/NH_2Cl. Although O_3/NH_2Cl would appear to be the best disinfectant alternative for controlling disinfection byproducts, one also has to consider the control of microorganisms and Assimilable Organic Carbon (AOC). Mutagenicity testing also showed the same trend as TOX and the specific byproducts: chlorine-highest reaction, O_3/NH_2Cl lowest reaction. Future studies at Jefferson Parish will focus on ozone disinfection and biostabilization. Objectives will be to further evaluate biological degradation of disinfection byproducts as noted in the previous study and to control AOC concentration.

Research needs include working with the various EPA laboratories to further identify byproducts associated with the various disinfectants and to try to determine associated risks. A proposal to do this study was submitted for RREL core research, but was not selected for funding.

3.3 Non-Disinfection By-Products Issues

In general, the non-DBP research program appears to be doing a good job of evaluating existing treatment technologies and processes, including minor refinements to existing technologies. The research program needs to be expanded to include more intensive research related to new and emerging technologies such as membrane filtration and advanced oxidation techniques, as well as greatly increased research efforts in the area of microbial treatment, as discussed below.

3.4 Microbiological Issues

As part of the overall consideration of the disinfection and by-products program of the Risk Reduction Engineering Laboratory (RREL), the DWC was briefed on two major microbiological aspects of the drinking water research program: (a) the ground water study of viruses, which is being done in support of the ground water disinfection rule, and (b) the microbiological aspects of the biological stability of drinking water, which is integral to all of the rules being formulated on disinfection and by-products.

3.4.1 Status of the Ground Water Survey for Viruses

The DWC reviewed the status of the Ground Water Survey for Viruses that is being performed by EPA and supported by both EPA and the American Water Works Association Research Foundation. As was stressed in EPA's presentation, this study is not a true survey based on randomly selected ground water supplies. instead, it is based on the selection and examination of vulnerable supplies and also is intended to advance the methodology for human enteric virus detection in water. This is being done in the context of collecting data on human enteric virus ocurrence in ground water sources that are particulalrly impacted by or vulnerable to human sewage (fecal) contamination.

The Committee believes that this study is an important first step in determining virus occurrence in the Nation's ground waters used as drinking water sources. Data on virus occurrence in groundwater sources of drinking water in the United States are very limited, and yet such data are crucial to the formulation of a scientific, risk-based approach to the Ground Water Disinfection Rule. Human enteric viruses are considered the key target organisms to control in drinking water derived from ground water sources. Therefore, this study of vulnerable ground water sites has the potential to provide virus occurrence data towards the worst-case end of the spectrum.

The site selection information provided to the Committee showed that water samples from about one-third of the 89 candidate wells were positive for at least 1 bacterial or coliphage indicator. The Committee supports this use of fecal indicator data as part of the selection process for the 25-30 wells to be ultimately surveyed for human enteric viruses. However, the Committee is concerned about how and on what basis the enteric virus results obtained from these 25-30 wells will be interpreted and used for the ground water disinfection rule.

Because the study is not a representative survey of ground water sources of drinking water, it is essential that the criteria for interpretation and use of the data be clearly defined. During the EPA's presentation of the virus study, it was stated that the results on virus occurrence in these wells will be used to refine the models on virus transport and fate in the subsurface. The Commitee believes that this is a potentially useful endeavor. However, the Committee recommends that before such application of the data, EPA must be certain to have obtained the following essential information: (a) geohydrologic characteristics of the wellheads and their impacted ground waters and subsurface sediments; (b) characterization of the pollution sources; (c) clear articulation of the virus transport and fate models; and (d) validation of these models with experimental data.

In presenting the strategy and features of the ground water virus study, EPA neither presented data on nor articulated a basis for the comparative detection of viruses by cell culture infectivity or biotechnical (Polymerase Chain Reaction and gene probe) methods. The Committee believes that virus detection data from model systems and seeded samples are essential in order to make rational interpretations of the data obtained by biotechnological methods. It must be established that the biotechnological methods not only detect viruses but also that the data obtained using these methods can be understood and interpreted in relation to virus infectivity to cell cultures. These requirements must be met in order to avoid the biotechnological methods giving either false negatives (failure to detect viruses when they are present) and false positives (detection of viral nucleic acid that is not associated with potentially infectious viruses).

Overall, the Committee believes that this research program has the potential to produce important data on virus ocurrence for the ground water disinfection rule. However, the study will not satisfy the critical need for a reliable survey of viruses in ground waters to be used as drinking water sources. In order to formulate a realistic and meaningful ground water disinfection rule, a ground water survey for human enteric viruses is essential.

3.4.2 Biological Stability of Drinking Water

The Committee received information on the RREL's research program on biological stabilization of drinking water. This program is attempting to address a number of scientific and technical questions about the colonization

and proliferation of microbes in drinking water, especially as a consequence of water treatment and distribution effects and altered water quality. The research also is attempting to control microbial growth in drinking water supplies and to deal with excess microbial proliferation by means that are compatible with the control of disinfection by-products (DBPs).

The Committee was apprised of biological stabilization and related research being done in a model, pilot scale system consisting of sequential pipe loops receiving water of controllable quality. The facility, which is in Nancy, France, gives an opportunity to evaluate what happens to water quality after it leaves the treatment plant. The pilot facility consists of two parallel pilot plants and six loops, three for each pilot plant effluent. Each loop is four inches in diameter and 102 feet in length. Pipes are cement-lined cast iron containing 21 sampling devices (probes) per loop for water and biofilm. Pipe materials being tested include polyvinly chloride (PVC), polyethylene (PE) and cement. One pilot plant was used as the reference train with chlorine added to raw water and after filtration. The chlorine control was compared against alternative ozone disinfectant schemes used in the second parallel pilot plant. The effects of using chlorine, ozone without biological stabilization, and ozone-granular activated carbon on the formation of biofilm on cupons was determined. In the last phase of the project, chlorine decay, hydraulic effects, and possibly nanofiltration will be studied. Further research on pipe loop simulation of distribution systems will be done at the RREL's Test and Evaluation Facility.

In addition to the research on biological stability, microbial stabilization and related aspects of water quality at the pipe loop facilities, research was also presented on the following topics: (a) comparative impacts of the disinfection processes of free chlorine and chloramine on distribution system bacteria; (b) the role of particle size on bacterial colonization of particles, (c) the stimulatory effects of organic carbon in water; and (d) the influences of chloramination on proliferation of nitrifying bacteria.

The DWC believes that this research on biological stabilization is crucial to the overall drinking water technology research program on treatment and distribution. The RREL should be encouraged to meet this important and timely research agenda. However, in order to make the most productive use of these data, it will be important to integrate the treatment and distribution results with corresponding health effects research for the same topics.

Biological stabilization of drinking water is important because it has implications for the health effects of microbes, disinfectants and DBPs.

3.5 Miscellaneous Issues

During the course of several excellent presentations, a large number of important issues were brought before the Committee. The following comments identify a partial selection of issues upon which the Committee wishes to comment:

a) Substantial amounts of chlorate are produced in hypochlorite solutions that result in high concentrations of this ion in drinking water (up to 600 ug/L). The health effects of this ion have been poorly defined. The switch to hypochlorite solutions has essentially been mandated by the EPA to avoid accidents with chlorine dioxide.

b) Chlorination does not produce bromate. This is important because bromate is the most potent of the identified carcinogens produced by disinfection processes.

c) The Committee was pleased to note that bromate occurrence and the chemistry of bromate formation during ozonation are both receiving serious attention.

d) Identification of research investigating the effects of mixed disinfection on by-product formation was of importance. The Committee was pleased to see that work has begun in this area and supports expansion of research in this area.

e) The Committee was pleased to learn of the conduct of some very practical investigations of the influence of water quality parameters, such as pH and temperature, on by-product formation. However, the Committee recommends that more fundamental studies of the chemistry of by-product formation also be conducted with the hope of developing more systematic predictions of by-product formation in the range of field conditions which might be expected in the real world. Included in this work should be the

question of mixed disinfection and more focussed research on nonhalogenated by-products.

f) In-house studies can be done with the existing staff to fit a regular 40-hour work week, but existing EPA staff is insufficient to perform 24 hour/day (multiple processes in series) pilot plant studies. Additional resources, both in-house and extramural are needed. In-house resources are needed to hire technicians and engineers. Extramural resources are woeful, and the little that is available is used, in part, on-site.

g) Additional EPA staff need to be hired with the following priorities: (1) full-time technicians, (2) part-time technicians, (3) an engineer. Additional extramural research funds are needed as they are at an all-time low. Fortunately the laboratories and pilot plants are well maintained, but crowded. Equipment funds are also reportedly adequate.

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