

STAR REPORT

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DRINKING WATER RESEARCH

The challenge in delivering safe drinking water is one of balance. In protecting the public from health effects caused by microbial pathogens, public water supplies must achieve levels of disinfection that destroy the greatest number of pathogens while minimizing levels of disinfection byproducts that might themselves cause health effects. Providing safe drinking water involves meeting this challenge and simultaneously complying with federal and state standards that ensure protection from chemical contaminants.

Tap water that meets all EPA and state standards is considered safe to drink for the general public. However, there are occasional, rare incidents of disease outbreaks in U.S. populations served by Public Water Systems (PWSs), in some cases because standards have not been met, and in other cases apparently because the standards did not protect all exposed individuals. In particular, it has been found that some contaminants in even low concentrations pose special health risks to particular groups of people. These groups include infants, young children and the elderly. They also include people with compromised immune systems due to certain illnesses, or because they are undergoing chemotherapy. Drinking water standards are

being strengthened to reduce the risk of outbreaks. However, some scientific uncertainty remains about the degree to which current standards and monitoring requirements protect all individuals from all possible effects of microbial pathogens or chemical pollutants.

While typically only very small numbers, if any, of U.S. residents served by PWSs experience waterborne diseases in any given year, an unprecedented situation occurred in 1993, in which over 400,000 people in Milwaukee became ill, and there were 104 deaths of highly susceptible individuals due to a single outbreak of disease caused by the microorganism *Cryptosporidium*. At that time, over the course of one year, approximately 2000 additional U.S. residents experienced a total of sixteen other outbreaks of *Cryptosporidium* or other microorganisms (*Giardia*, *Campylobacter*, *Salmonella* and organisms that cause shigellosis and cholera).



The United States enjoys one of the best supplies of drinking water in the world. Ninety percent of Americans receive their tap water from public water systems (PWSs) regulated by EPA and the states or tribes.



Chemical contaminants are typically associated with fewer than a handful of nationally reported acute illnesses in any given year, and these typically involve contamination of private water supplies. (Nitrates, which can cause illness in young infants at levels that don't harm other people, may be the most common cause of chemically-induced illness associated with private wells.) However, there is concern among scientists that the potential for longer-term effects of all chemical pollutants that may occur in water supplies is not yet fully understood. To address these concerns, and based on requirements of the 1996 amendments to the Safe Drinking Water Act, EPA has developed a "Contaminant Candidate List" (CCL) of chemicals not presently subject to regulation that may occur in drinking water supplies, and that have been identified as priorities for research, monitoring, guidance development, and for determining which contaminants need to be selected for drinking water regulation.

EPA's Overall Research Strategy for Drinking Water

This report summarizes research grants funded in 1996 and 1997 through EPA's principal external research program, the Science to Achieve Results (STAR) program. To address microbial contaminant and DBP issues, EPA has developed a comprehensive Microbial Contaminants and Disinfection Byproducts (M/DBP) study plan to support future regulations for microbial disinfectants and disinfection

byproducts. In addition, EPA has identified priority research questions concerning possible sources of risk from chemicals on the CCL. Together, these questions form an overall "Drinking Water Research Strategy" on which EPA has consulted with other federal agencies, states, tribes, PWSs and the academic community. Studies summarized in this report support each of the microbial, DBP and chemical contaminant components of the overall drinking water research strategy.

In addition to the STAR research described here, EPA, the National Institutes of Health, the Centers for Disease Control and Prevention, other federal agencies and members of the American Water Works Association Research Foundation are conducting components of the M/DBP study plan and CCL research. More information on EPA's drinking water research strategy and related work by other groups is available from Internet Websites listed at the end of this report.

EPA's STAR grants are typically awarded for three-year time periods. On-going research is described in this report; results will be presented in future reports as findings are completed and peer reviewed.

General Information

Grants described in this report are part of EPA's Science to Achieve Results (STAR) program, a major research initiative designed to improve the quality of scientific information available to support environmental decision making. The STAR program is managed by EPA's National Center for Environmental Research and Quality Assurance in the Office of Research and Development (ORD). The program funds approximately 200 new grants every year, with the typical grant lasting three years. Funding levels vary from \$50,000 to over \$500,000 per year, with FY 1998 funding level at about \$80 million for grants to individual principal investigators or groups of investigators. Additional STAR funds are provided for a number of Research Centers specializing in scientific areas of particular concern to EPA, and for a fellowship program supporting graduate students conducting environmental research.

STAR Research Addressing Drinking Water Issues

Cryptosporidium Research

Cryptosporidium parvum is the pathogen that caused illness in over 400,000 people in Milwaukee in 1993. Contamination of the city's water supply occurred because of treatment plant failures that let *Cryptosporidium* oocysts pass through filters and into the distribution system. The disinfectant added did not provide an additional protective barrier because chlorine cannot effectively inactivate *Cryptosporidium*. Ingestion of a small number of oocysts may cause illness in otherwise healthy individuals. The resulting disease outbreak was detected because of an increase in anti-diarrheal drug sales. *Cryptosporidium* may be present in fifty percent or more of the surface waters in the U.S. at levels that require careful operation of treatment facilities and for some possibly a change to a more effective disinfectant such as ozone. However, data collected on the occurrence of the microorganism is difficult to interpret because of current uncertainties concerning analytical methodology problems. Four research projects supported by STAR grants are attempting to reduce these uncertainties concerning *Cryptosporidium* monitoring and disinfection.

The **Metropolitan Water District of Southern California** is developing an assay to identify live and infectious *C. parvum* oocysts from environmental samples. This may be useful in developing a species-specific analytical method for environmental samples. A method to monitor oocyst survival will help to ensure that disinfection processes have been effective. The genetic information can be used by other researchers to refine methods for studying the growth and infectivity of *C. parvum* and other *Cryptosporidium* species in laboratory and field situations. Investigators hope to increase understanding of differences between species, and among individuals of the same species, which affect how likely the pathogens are to infect people or other host organisms. An investigator from **Kansas State University** is going to construct DNA libraries for various species and subgroups of *Cryptosporidium*. This *Cryptosporidium* genetic information will support research across the country, helping others to develop and verify new analytic methods for a wide variety of purposes.

St. Luke's Hospital and the **University of Texas** are studying whether different strains of *Cryptosporidium parvum* differ in virulence (affecting how many people become ill and the severity of the illness). Mice and human volunteers are being evaluated to determine the typical infectious dose, and to evaluate individual responses. In addition to assessing the clinical response in healthy, previously unexposed humans to different strains of *C. parvum*, the research examines the immune response and a number of biological "markers" that may be useful to diagnose exposed and infected individuals. This will also be useful in assessing the prevalence of

cryptosporidiosis in human populations. In work on related issues, **Ohio State University** is using pigs as test animals to study the virulence of *C. parvum* isolates. Pigs of different immunological status (normal and immunologically compromised) will be tested to improve understanding of how this affects susceptibility to *Cryptosporidium*.

Other Microbial Contamination Studies.

Researchers at the **University of North Carolina at Chapel Hill** are working with human volunteers to study infectivity of two viruses, Norwalk virus and Snow Mountain Agent. They will examine immune responses of individuals most susceptible to infection, and evaluate models of dose infectivity. Results will help to refine risk assessments.

The 1996 Amendments to the Safe Drinking Water Act require disinfection of groundwater used for drinking water unless "natural disinfection" can be demonstrated to occur. Researchers at the **University of California** and the **Baylor College of Medicine** are using recombinant Norwalk virus particles to evaluate their survival in groundwater. Preliminary data suggest pH may be the most important factor. Results of this research will be relevant to establishing suitable set-back distances between potential contaminant sources and intake points.

Enhancing natural bacterial activity may aid in situ (in-place) bioremediation of contaminated ground water. The **New York State Department of Health** and the **U.S. Geological Survey** are evaluating field methods to measure bacterial activity by monitoring oxygen consumption. Preliminary results indicate low bacterial respiration

rates in the aquifer, indicating that introducing oxygen is probably an effective way to speed up natural bioremediation. Early results from a study being done by **El Paso Community College** and **Texas A&M** indicates that viruses can exist in groundwater in a "reversibly inactivated" state, unable to cause infection until reactivated. This may explain contradictory results in testing effectiveness of disinfection procedures. This study will investigate inactivation mechanisms and environmental factors that could promote or retard reactivation.

Monitoring microbial pathogens is often costly and time consuming. Low sample volume methods are needed that identify only live viruses. The **University of Arizona** is developing a combined cell culture/PCR technique for enteroviruses from sewage. This technique, combining advantages of the two approaches, is expected to be sensitive and cost-effective. (In addition to drinking water, this is applicable to marine recreational waters.)

Fecal coliform contamination of drinking water sources is monitored with standard tests that do not distinguish human from animal and other sources of coliform bacteria. Human fecal wastes have a much higher likelihood of containing human pathogens than livestock and other animal wastes. In preliminary studies, researchers at the **University of North Carolina** have developed techniques by which human fecal contamination can be distinguished from that of animals or other wildlife, with the exception of waste from pigs. These investigators have received a STAR grant to refine their methodology. Methods that could accurately distinguish fecal sources would help in assessing potential public health risk.

Socio-Economic Study of Protecting Upstream Water Sources

Cornell University is assessing public opinion on watershed protection issues, based on interviews with upstate New York watershed residents and New York City residents whose drinking water comes from the watershed. Results will provide information useful in the on-going public process by which the City, other local governments, the State and the U.S. EPA are assessing options for protecting water quality in the watershed, in an effort to avoid the need for a new filtration plant with a projected cost of \$5 billion.

Research Concerning Disinfection By-products (DBPs)

Health Effects Studies: The potential for cancer-causing effects of trihalomethanes is being evaluated through rodent studies at the **Medical College of Ohio**. Results should decrease uncertainties of estimates of the human health hazards of these DBPs. Investigators from the **University of Illinois at Urbana-Champaign** are evaluating the use of mammalian cell cultures rather than bacterial genotoxicity tests to predict DBP risks. The cell cultures may be more representative of potential human impacts.

Investigators at **Pacific Northwest National Laboratories** theorize that the human system can detoxify small amounts of haloacetate DBPs from drinking water, but that ingestion beyond a threshold amount results in partial or complete inactivation of the enzymes needed for such detoxification. Rodents and human liver cell cultures will be used to study whether enzyme inactivation occurs,

where haloacetates are distributed after ingestion, and how they are eliminated. Results will allow more accurate risk assessment for haloacetate.

Exposure Studies: Exposure to DBPs in tap water can be from drinking the water, inhaling volatile DBPs (for example in showers and baths) and dermal exposure. The **University of Medicine and Dentistry of New Jersey** is investigating human exposure to haloacetic acid DBPs from dermal absorption and inhalation, to assess the relative importance of each exposure route.

Halogenated acetonitriles are DBPs that are both toxic and carcinogenic. Investigators from the **University of Texas Medical Branch** are attempting to identify halogenated acetonitrile "biomarkers", molecular-level changes in living tissues that demonstrate they have been exposed to these specific chemicals. These could be used to assess exposure and identify particular affected tissues. The **University of North Carolina at Chapel Hill** is also investigating the chemical nature and metabolite formation of haloacetic acid DBPs with an eye to identifying biomarkers. In particular, haloacetic acids may form macromolecular adducts that could serve as biomarkers.

Detection Methods: A new drinking water standard for the carcinogen bromate is being proposed at a level for which good detection methods are not widely available. The **University of North Carolina at Chapel Hill** is evaluating a cost-effective ion chromatographic system for detection of all oxyhalides (bromate, iodate and chlorite) using UV spectrophotometry.

Precise, low-cost methods to measure DBPs called haloacetic acids are being developed at **Pennsylvania**

State University, using a technique called "surface enhanced Raman scattering". The method requires a minimum of expertise to perform and thus would be practical for regular on-site monitoring at treatment plants. The **University of Massachusetts** is developing and refining analytical methods for DBPs of ozonation disinfection processes.



Improved Disinfection

Processes: The University of Washington and University of Colorado are investigating a method to reduce the quantity of metal coagulant necessary for satisfactory removal of natural organic matter and particles from drinking water. A graduate student at Michigan State University has received a STAR fellowship award to investigate methods for reducing DBPs in water containing natural humic substances, using ozonation and biological treatment. This study will include examining how humic substances are modified during ozonation, and the biodegradability of the ozonation by products, and will track formation of toxic organochlorine compounds during chlorine disinfection.

The **University of Michigan** and the **Hebrew University** are analyzing the DBPs resulting from a secondary disinfectant formulation using hydrogen peroxide and silver. They are evaluating the method for use in long-term residual disinfection. The **University of Colorado at Boulder** is studying the use of softening and coagulation treatments to remove DBP precursors as well as arsenic from drinking water.

Other Toxic Chemical Risks

Rodent studies are being used at the **University of Kentucky** and **Purdue University** to evaluate brain accumulation of aluminum from drinking water. Oral bioavailability, influence of water hardness, aluminum circulation and elimination from the brain will be studied.

Princeton University is studying the role of microorganisms in arsenic cycling in contaminated freshwater. Investigators propose that bacteria convert one form of arsenic into another, more mobile form, and also catalyze precipitation of arsenic sulfides. Results will help to refine assessments of actual human exposure and hazard from arsenic contamination of water supplies.

Drinking Water Research in EPA's Small Business Innovative Research Program

EPA conducts a Small Business Innovative Research Program (SBIR) to take advantage of the talents of small businesses to find solutions to priority environmental problems. A number of proposals funded through EPA's SBIR program are directly related to and supportive of EPA's overall drinking water research strategy. Subject areas on which drinking water SBIR projects focus include developing sensors and other monitoring equipment for microbial pathogens, and refining or developing new removal technologies for contaminants including DBPs, nitrates and toxic chemicals. More information about SBIR research projects is available at EPA's website, www.epa.gov/ncerqa/sbir

Future Directions for Drinking Water Research

A top priority for future STAR drinking water research is to complete studies of emerging contaminants from the currently drafted CCL. Work funded in 1998 and anticipated for 1999 will emphasize filling information gaps with respect to potential health risks of these contaminants at levels that are likely to occur in drinking water, and of the mechanisms ("modes of action") by which they might cause adverse effects.

In addition, future work will build on the findings of earlier work concerning microbial pathogens, moving into establishing approaches for determining the general impact of susceptibility factors (e.g., age, pregnancy, nutrition, protective immunity, pre-existing diseases, and behavioral patterns) on infectious disease incidence associated with exposure to primary waterborne pathogens and to emerging pathogens. At present little is known about the occurrence of some emerging pathogens in U.S. source waters. It is possible that some of these poorly understood pathogens may have caused some disease outbreaks for which no explanation has yet been found. Analytical

methods to detect emerging pathogens will be a principle focus of this future research. In another area of microbial research, methods for counteracting the action of "biofilms" that can form in treatment systems and protect pathogenic microorganisms from disinfectants will be also be a subject of future study.

In the area of DBPs, much of the research work already completed or now underway is paving the way for improved and more cost-effective techniques for treatment by large and small PWSs. But additional research is still needed relative to some disinfection processes. The technique of ozonation followed by a secondary disinfectant is a potential treatment alternative for water utilities to avoid chlorinated byproduct formation. However, the reaction of ozone with natural organic matter is not entirely understood, so research will be supported to identify and quantify byproducts of ozonation and secondary disinfection as a function of source water quality.

Find Out More About the STAR Research Program

General information on EPA's STAR research program is available from the following sources:

ORD's National Center for Environmental Research and Quality Assurance (NCERQA): Internet website: <http://www.epa.gov/ncerqa>

Mailing Address:

Office of Research and Development
National Center for Environmental Research and Quality Assurance
Office of the Director (8701 R)
401 M Street, SW
Washington, DC 20460

STAR Research Projects Described in this Report

*Development of a Quantitative Cell Culture-Based Infectivity Assay for *Cryptosporidium parvum* in Source and Finished Water.* **Metropolitan Water District of Southern California.**

*Genomic Database for *Cryptosporidium* spp.,* **Kansas State University.**

*Virulence Factors in *Cryptosporidium* and Infective Dose in Humans.* **University of Texas.**

*Understanding Risk Factors to *Cryptosporidium parvum*: Studies in Gnotobiotic Pigs.* **The Ohio State University.**

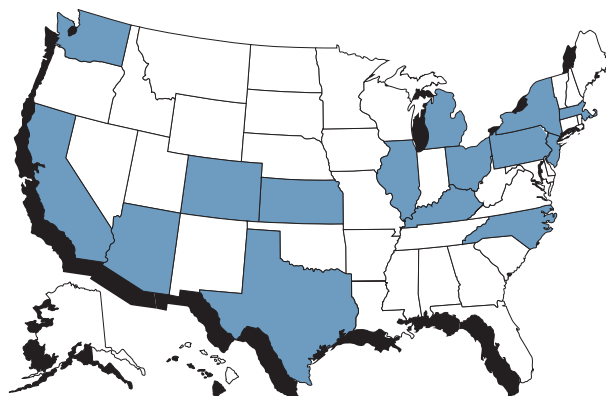
PCR Based Detection of cytopathogenic and Non-Cytopathogenic Viruses in Water. **University of Arizona.**

Norwalk Virus-Like-Particles (VLPs) for Studying Natural Groundwater Disinfection. **University of California Irvine; Baylor College of Medicine.**

Studies of the Infectivity of Norwalk and Norwalk-Like Viruses. **University of North Carolina at Chapel Hill.**

In Situ Assessment of the Transport and Microbial Consumption of Oxygen in Groundwater. **New York State Department of Health.**

Reversible Inactivation of Viruses in Groundwater. **El Paso Community College; Texas A&M**



Direct Quantitation of Haloacetic Acids by Surface Enhanced Raman Scattering. **Pennsylvania State University.**

Combined Ozonation and Biological Treatment for the Removal of Humic Substances from Drinking Waters. **Michigan State University.**

Investigation and Optimization of Dual Coagulation Processes., **University of Washington.**

Evaluation of the Efficacy of a New Secondary Disinfectant Formulation Using Hydrogen Peroxide and Silver and the Formulation of Disinfection By-Products Resulting from Interactions with Conventional Disinfectants. **University of Michigan.**

Health Risk of the Trihalomethanes Found in Drinking Water: Carcinogenic Activity and Interactions. **Medical College of Ohio.**

Analysis of Organic By-Products from the Use of Ozone / Chlorine and Ozone / Chloramines in Drinking Water Treatment. **University of Massachusetts.**

Development of a New, Simple, Innovative Procedure for the Analysis of Bromate and Other Oxy-Halides at Sub ppb Levels in Drinking Water. **University of North Carolina at Chapel Hill.**

Inhalation and Dermal Exposure to Disinfection By-Products of Chlorinated Drinking Water. **University of Medicine and Dentistry of New Jersey.**

Evaluate the Disposition, Toxicokinetics and Metabolism of Selected Haloacids on Fischer 344 Rats and B63F1 Mice and Investigate the Effect of Chronic Exposure and co-Administration of Haloacids on Toxicokinetics. **Pacific Northwest National Laboratories.**

Development of Biomarkers for Haloacetonitriles: Induced Cell Injury in Peripheral Blood. **The University of Texas Medical Branch.**

Genotoxicity and Occurrence Assessment of disinfection By-Product (DBP) Mixtures in Drinking Water. **University of Illinois at Urbana.**

Metabolic Fate of Halogenated disinfection By-Products In-Vivo, and Relation to Biological Activity. **University of North Carolina at Chapel Hill.**

The Microbial Transformations of Arsenic in Anoxic Waters. **Princeton University.**

Arsenic removal by Softening and Coagulation. **University of Colorado-Boulder.**

Detecting Fecal Contamination and Its Sources in Water and Watersheds. **University of North Carolina.**

Public Opinion on Environment and Water Quality Management in the New York City Watershed. **Cornell University.**

Aluminum Toxicokinetics: Oral Absorption from Drinking Water and Brain Retention. **University of Kentucky Research Foundation.**



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