Clean water, healthy water?

Assessing the health risks of treated drinking water

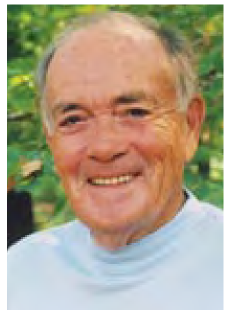
BY KATHLEEN KEARNS

Are substances used to purify drinking water creating other dangers? That's one of the biggest challenges the drinking water industry faces. It's also one that Carolina School of Public Health researchers are taking a lead to investigate.

Many municipalities and companies that provide drinking water add chlorine to disinfect raw water, killing bacteria and other potentially harmful substances found in ground and surface water. As scientists have known for some time, chlorine reacts with substances in the water and forms byproducts that may be harmful to human health. These disinfection byproducts (DBPs) may be linked with bladder cancer, miscarriage and birth defects. Concern over such adverse health effects has grown in recent years as more DBPs have been identified. Officials who operate water treatment facilities grapple constantly with a critical question: how do you remove harmful substances from raw water without creating new harmful substances in the process? The ongoing effort to answer that question depends on research into how DBPs form, how to detect them, which of them are harmful and what health impacts they can have. These questions drive some of the faculty and students in the Department of Environmental Sciences and Engineering.

Finding the source

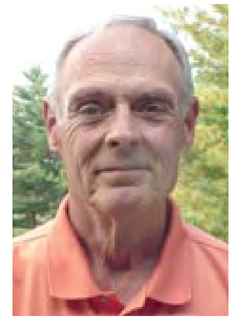
Carolina School of Public Health Environmental Sciences and Engineering professor Dr. Russell Christman, now retired, did pioneering work on the detection of DBPs and the mechanisms of their formation. His interest was piqued in 1974 when Johannes Rook, a chemist at a water plant in Rotterdam, Netherlands, discovered chloroform (or trichloromethane) in the finished drinking water of that city's water plant. Rook hypothesized it was produced when the chlorine used for disinfection reacted with organic matter—extracts from leaves, bark, soil, etc., from the natural biosphere—in raw water. After U.S. Environmental Protection Agency Scientist John Bellar found chloroform in treated water in Cincinnati, Christman and his colleague, UNC School of Public Health Environmental Sciences and Engineering Professor Dr. J. Donald Johnson, now retired, took up the challenge of discovering why.



Dr. Russell Christman

"Johnson was a world-class chlorine chemist," Christman says. "His interests and mine in natural organic matter were a natural combination. Given the complexity of natural organic matter and the great reactivity of chlorine, we suspected that there were many more products than chloroform and that most of them would be more acidic." Using mass spectroscopy and a modified extraction procedure, Johnson, Christman and their team ultimately found 100 or more DBPs that presented potential health hazards.

"It established that most of the products were in fact polar acids, notably dichloroacetic and trichloroacetic acids," Christman explains. In other words, chlorine's interaction with natural organic matter was creating these compounds. In fact, many of the products did not contain chlorine, but those that did were worrisome from a health perspective. "I was on the National Drinking Water Advisory Council for the Environmental Protection Agency (EPA) at the time and can tell you that our results and those of other scientists were the subject of intense discussion," Christman says. "The quandary that's set up is how to balance the risk between disinfection to control disease transmission and that created by the disinfection process itself. This debate continues today."



Dr. J. Donald Johnson

In 1979, the EPA began regulating trihalomethanes as a group and since then has established regulations for additional DBPs, including the principal chlorinated acids.

Christman and Johnson followed up their work with a series of studies to see whether other water disinfection methods, including using chloramines, chlorine dioxide and ozone, produced DBPs. To varying extents, Christman says, they all do.

The team's work in identifying many of the compounds created in the water disinfection process led both to regulation of those known to be harmful and to investigations by other scientists into whether more of the compounds were dangerous. In National Cancer Institute and EPA studies, a number of compounds turned out to be carcinogenic. Christman says that one compound for which the team can claim joint discovery—MX, a cyclical organic structure

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that contains chlorine and oxygen—was "off the scale in the toxicology index."

"Fortunately, our work with Dr. Leif Kronberg, a visiting scientist from Abo Akademi University in Turku, Finland, established that MX concentrations in drinking water were a thousand times less than trihalomethanes," Christman says.

EPA began regulating more DBPs in the late 1980s. Epidemiologic studies followed, but they were plagued by the difficulty of determining exactly what was in the water that study subjects were exposed to, given that both their water sources and the day-to-day levels of DBPs in that water would change. "You couldn't sort out statistically whether these products were causing these health problems. Even animal toxicity tests are difficult to interpret as animals are exposed to single compounds, whereas people drink the entire DBP mixture," Christman says.

As other scientists wrestled with the health implications of the discoveries he'd helped make, Christman returned to his original research interest, the structures of natural organic matter. He estimates that only about half of the DBPs created when chlorine reacts with the organic matter in raw water have been identified to date. Since Christman completed his work, other researchers, notably Dr. Susan Richardson of the EPA, have used the latest, most advanced instruments to help identify many more compounds.

Officials who operate water treatment facilities grapple constantly with a critical question: how do you remove harmful substances from raw water without creating new harmful substances in the process? UNC researchers are helping answer that question.

Detecting DBPs

The search for DBPs continues at UNC with interdisciplinary teams. Analytical and environmental chemist Dr. Howard S. Weinberg, assistant professor of environmental sciences and engineering, recently was asked by the EPA to look for what are called "emerging DBPs." An expert toxicology review identified 50 potentially harmful compounds and asked Weinberg and colleagues to develop detection methods, then to look for them in drinking water treatment plants across the country.

The team targeted plants that treat water high in organic material and/or bromide, which often occurs from saltwater intrusion or natural background. Chlorine can react with bromide and natural organic material to produce bromine- or iodine-containing compounds, which may have adverse health impacts even more significant than those associated with currently regulated DBPs.

Weinberg's role was to develop methods to detect emerging DBPs. He and his colleagues tracked occurrence of the 50 chosen compounds. They found 28 additional, previously unidentified DBPs as well. They also discovered, or in some cases confirmed, that while disinfectants other than chlorine (ozone, chlorine dioxide and chloramines) result in lower levels of the regulated DBPs, they create higher levels of several emerging DBPs than chlorine does.

Though their impact on humans remains to be studied, the new compounds are highly toxic in animals, Weinberg says. "It turns out that the iodine-containing species are sometimes hundreds of times more toxic than the chlorine-containing ones, but they're found at much lower levels. That means we need to be developing methods that are much more sensitive for these emerging contaminants. What we are learning is that if we find a toxic compound in drinking water today that doesn't have iodine, we need to be prepared to go look for the iodine form, because it could be orders of magnitude more toxic than the ones we're currently regulating or considering for future regulation."

Weinberg has new projects underway to study implications of emerging DBPs on animal health. Meanwhile, the EPA is using the occurrence data he and his team collected to evaluate the next level of regulation.

"Regulations we have in place now are based on science that took place in the 1970s," Weinberg says. Partly because of the work Weinberg did on the 50 compounds, the EPA is establishing a faster track to regulate chemicals newly found in drinking water. The agency has adopted many of the analytical methods Weinberg developed as the official methods that utilities and government laboratories must follow to generate the data used to regulate the compounds.

Weinberg and his Carolina colleagues also have evolved new procedures to measure some currently regulated haloacetic acids, including those containing bromine. Their methods generate very precise and reliable results, a level of accuracy essential to studying these compounds' impacts on human health.

DBPs and pregnancy loss

Since the 1970s, DBPs have been linked with cancers of the digestive and urinary tracts, particularly bladder cancer. The EPA has set regulatory levels aimed at limiting lifetime exposure. More recently, however, the potential risks of *acute* exposure also have raised concern, particularly in determining if DBPs might contribute to miscarriage or pregnancy loss. In 1998, a large cohort study in Northern California reported that pregnant women who consumed high levels of total trihalomethanes, one of the major classes of DBPs, suffered increased risk of pregnancy loss. In 2000, the EPA and the American Water Works Association Research Foundation asked an interdisciplinary team from Carolina to conduct a five-year, $3.5 million investigation into the issue. The conclusion that DBPs did *not* appear to increase the risk of pregnancy loss surprised the scientific community.

Dr. Philip Singer, director of the Drinking Water Research Center and Daniel A. Okun Distinguished Professor of environmental engineering, led the water side of the study; Dr. David A. Savitz, then chair of the Epidemiology Department at UNC and now professor of community and preventive medicine and director of the Institute for Epidemiology, Biostatistics and Prevention at Mount Sinai School of Medicine, led the reproductive health side. The team also included Weinberg, Dr. Amy H. Herring, associate professor of biostatistics at Carolina's School of Public Health, and Katherine E. Hartmann, then associate professor of epidemiology at the UNC School of Public Health and obstetrics and gynecology at the UNC School of Medicine, and now deputy director of the Institute for Medicine and Public Health at Vanderbilt University Medical Center in Nashville, Tenn.


Dr. Philip Singer

The interdisciplinary approach was critical. "To address the concern with drinking water and reproductive health," Savitz says, "it is essential to accurately measure both the exposure of concern (contaminants in drinking water) and the health outcome (pregnancy loss). That calls for a range of expertise, including drinking water engineering and chemistry, obstetrics, epidemiology and biostatistics." Water utility personnel in the study communities also had a key role; they provided technical information, water samples and complementary data.

The team chose three study locations: one where people were exposed to high levels of brominated DBPs, another where they were exposed to high levels of chlorinated DBPs and a third where exposure to either one was very low. The first two systems used chloramines rather than chlorine for disinfection. This led the team to eliminate a problem in previous studies: when chlorine is used for disinfection, DBPs continue to form in the water distribution system, and DBP exposure can vary depending on how far a subject lives from the treatment plant. "People who live very close to where water is treated (with chlorine) are probably exposed to lower levels of DBPs and those far away to higher levels," Singer explains. With chloramine disinfection, DBP exposure is relatively constant throughout the system.

TIP: Minimize the use of garbage disposals and save gallons of water. Throw food waste in a trash can, or better yet, start a compost pile.

"We had very close monitoring of the subjects' water quality," Weinberg says. "We monitored the trihalomethanes, the haloacetic acids and the total organic halide (a surrogate measure for the sum of all organohalogen-containing DBPs) every week and were able to prove that we were capturing the levels in all the consumers' drinking water." The study team also surveyed how much tap water and how much bottled water people drank and how much exposure they had through showering and bathing.

The epidemiology team interviewed approximately 2,400 pregnant women about the course and outcomes of their pregnancies, conducted early pregnancy ultrasounds and, in some cases, reviewed medical records. By assessing exposure more carefully, and by bringing together environmental engineering and epidemiological expertise, the study team obtained results that were more valid than those of earlier studies. The result was a strikingly different assessment: that high personal trihalomethane exposure did not increase risk of pregnancy loss.

Work in this area continues. Caroline Hoffman, a doctoral student in epidemiology, is using data from the study to determine whether DBP exposures affect other reproductive health measures, including birth weight, preterm birth and infertility. Dr. Andrew Olshan, chair of the Department of Epidemiology, and colleagues at UNC and the EPA assessed DBPs and male reproductive health, one of the first epidemiologic studies of this relationship. The study generally found no association between exposure to levels of DBPs near or below regulatory limits and decreased semen quality in their study group. Study results are published online in *Environmental Health Perspectives* at *www.ehponline.org/members/2007/10120/10120.pdf.* ■


Dr. Andrew Olshan