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Review

Chlorination disinfection by-products, public health risk tradeoffs and me

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ABSTRACT

Since 1974 when trihalomethanes (THMs) were first reported as disinfection by-products (DBPs) in drinking water, there has been an enormous research effort directed at understanding how DBPs are formed in the chlorination or chloramination of drinking water, how these chlorination DBPs can be minimized and whether they pose a public health risk, mainly in the form of cancer or adverse reproductive outcomes. Driven by continuing analytical advances, the original DBPs, the THMs, have been expanded to include over 600 DBPs that have now been reported in drinking water. The historical risk assessment context which presumed cancer could be mainly attributed to exposure to environmental carcinogens played a major role in defining regulatory responses to chlorination DBPs which, in turn, strongly influenced the DBP research agenda. There are now more than 30 years of drinking water quality, treatment and health effects research, including more than 60 epidemiology studies on human populations, directed at the chlorination DBP issue. These provide considerable scope to reflect on what we know now, how our understanding has changed, what those changes mean for public health risk management overall and where we should look to better understand and manage this issue in the future.

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1. The title and my topic – why read any further?

Having agreed with much enthusiasm to realize this opportunity to share my career perspectives on a truly fascinating topic, I must confess to considerable discomfort with using the personal review series title format – ''.... and me''. Disinfection by-products (DBPs) and public health risk provide a topic to which many excellent scientists and engineers have dedicated substantial portions of their careers, generating masses of knowledge about a subject that was unknown only 35 years ago. Thus, I worry about anyone hinting by means of a title including ''me'' at making any claims of even partial ownership of the topic. I certainly make no such ownership claims!

With the following account, I seek to provide my career perspective on a remarkably complex and challenging topic which has, over the past three decades, dramatically changed how we view drinking water quality and safety. DBPs and public health also provide an excellent case study of the broader issue of risk tradeoffs in environmental health. I believe that *Water Research* readers can gain useful insights about why things have happened as they have.

I must be clear that this review is not intended to be an account of the specific knowledge that we have amassed about what DBPs are known, how they are formed and how they can be managed. The reader seeking primarily such technical background and detail is referred to the classic treatise edited by Singer (1999), an engineering overview by Xie (2003), a comprehensive review of the chemistry, toxicology and epidemiology by the International Programme on Chemical Safety (ICPS, 2000) and more recent updates on current knowledge about new DBPs by Richardson et al. (2007) and Krasner et al. (2006).

My account addresses how chlorination DBPs have emerged as a public health issue, how the knowledge about health risks has been interpreted and where our current state of knowledge and residual uncertainty leaves us in deciding upon appropriate risk management. The chlorination DBP issue provides an excellent illustration of managing uncertain public health risks attributed to environmental exposures with additional complexity and character arising from the distinct health risk tradeoff involved.

Because we are discussing a subject that involves considerable scientific evidence, we should acknowledge while aspiring to the ideal of scientific research being the purest form of inquiry for seeking the truth, scientific research is inevitably conducted by imperfect humans who must rely on funding and support from social and political institutions that need not subscribe to all those ideals. This reality brings to mind a few salient observations from one of the most thoughtful scientists and science writers of our age, Sagan (1996):

> ''Science is far from a perfect instrument of knowledge. It's just the best we have. In this respect, as in many others, it's like democracy.''
> ''Science by itself cannot advocate courses of human action, but it can certainly illuminate the possible consequences of alternative courses of action.''

The need to distinguish clearly science from advocacy is a recurring theme in my review. Advocates, who may also be scientists, will hopefully call upon evidence generated from careful scientific inquiry to support their positions. If our knowledge, generated by the best available science, remains highly uncertain, risk management decisions cannot be determined strictly by an objective analysis of the evidence. We also need to understand some key features of scientific inquiry that are essential for it to be capable of revealing truths about nature (Sagan, 1996):

> ''Of course we must be willing to change our minds when warranted by new evidence. But the evidence must be strong. Not all claims to knowledge have equal merit.''
> ''...at the heart of science is an essential balance between two seemingly contradictory attitudes
> – an openness to new ideas, no matter how bizarre or counterintuitive,