DIOXIN: IF SCIENCE SHOULD DRIVE THE ENVIRONMENTAL REGULATORY PROCESS, WHY USE THE BCF?

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ABSTRACT

Given the current understanding of the environmental fate of dioxin, the appropriateness of the use of a BCF in the development of a water quality criterion for dioxin must be reassessed. A ramification of the regulatory methodology not keeping pace with current scientific advances is that many sources may currently be in compliance with the dioxin criterion because of the low levels of dissolved dioxin in rivers, lakes, estuaries and oceans.

INTRODUCTION

The United States Environmental Protection Agency (EPA), pursuant to the Clean Water Act, establishes water quality criteria to protect human health and to prevent adverse ecological impacts. Standards for protection of human health are generally the more restrictive. EPA and most states in the U.S. use a risk assessment formula for carcinogens to relate human health risks from consumption of contaminated fish and shellfish (as well as drinking water) to a water quality criterion:

$$WQC = \frac{RL/q^{*} \times W}{FC \times BCF} \qquad (1)$$

where WQC = ambient water quality criterion (mg/L)
RL = risk level
q^* = cancer potency factor $(mg/kg/day)^{-1}$
W = the weight of a human
FC = fish consumption
BCF = bioconcentration factor

State and federal water quality criteria for dioxin have been under close scrutiny by industry, regulators and the environmental community, and modifications to virtually all the terms in the equation have been proposed. There has been considerable debate in the scientific community regarding appropriate values for dioxin potency, the fish consumption rate and the bioconcentration factor (BCF). In addition, federal and state agencies required to make risk management decisions have selected different acceptable risk levels.

Regardless of the values chosen, all of the terms in the equation, with the exception of the BCF, should be used in the development of a water quality criterion for dioxin.

The BCF relates aquatic organism contaminant levels to concentrations of dissolved substances. Given the scientific community's current understanding of the environmental fate of dioxin, the use of a BCF in the development of a criterion for dioxin or other hydrophobic substances must be reassessed (1). Since the inception of the Clean Water Act, EPA has established water quality criteria designed to limit concentrations of dissolved pollutants. Hydrophobic substances such as dioxin and PCBs require an alternative approach which recognizes that these substances are found sorbed to organic material in the sediment and water column.

Inappropriateness of the Use of a Bioconcentration Factor for Hydrophobic Substances

A BCF is used to correlate concentrations of a compound dissolved in the water to aquatic organism concentrations of that compound. The BCF refers to the process of bioconcentration, in which an aquatic organism takes in a contaminant from the surrounding medium through its gill membranes (2). Only dissolved or extremely small constituents may pass through an organism's gill membranes. Therefore, by definition, the BCF and associated ambient water quality criterion consider only dissolved substances in the aqueous environment (1 and references within). The criterion does not consider substances sorbed to organic matter in an effluent, water column or sediments.

For pollutants which remain dissolved in the water column and are able to permeate aquatic organism gill membranes (bioconcentrate), the BCF may be successful at predicting the amount of contaminant uptake by aquatic organisms from their surroundings. For these pollutants, the BCF/water quality criterion regulatory approach is appropriate.

Dioxin, however, does not stay dissolved in the water column. Dioxin is extremely hydrophobic and strongly sorbs to available organic matter. The concentrations of both sorbed and dissolved dioxin in an effluent and receiving waterbody can be calculated. Such calculations demonstrate that the amount of dioxin associated with organic matter far exceeds that found dissolved in the aqueous environment. Therefore, in the water column, dioxin exists almost exclusively in the sorbed state. Since sorbed dioxin is too large to enter the gills of aquatic organisms, an alternative to the BCF and is required in determining dioxin WQC.

An essential function of the water quality criterion equation is to correlate contaminant concentrations from effluent to fish to humans. The equation is used as a predictor of contaminant uptake by aquatic organisms from water, and by humans from aquatic organisms. The device used to delineate the first part of the chain of uptake is the BCF; in other words, the BCF is used to predict aquatic organism contaminant accumulation by bioconcentration. Since bioconcentration is not the primary route of uptake of hydrophobic compounds, the BCF cannot predict fish tissue contamination levels for hydrophobic substances, and the resultant water quality criterion does not address the primary route by which humans are exposed to these substances.

Raising the Dioxin BCF

Recent scientific evidence suggests that the value of the bioconcentration factor (BCF = 5,000) currently used by EPA and most states in the U.S. should be raised to significantly higher levels. Since virtually all of the dioxin present in the aquatic environment exists sorbed to solids, a higher BCF and associated criterion will still not address more than 99% of the dioxin in the aquatic environment. Given the current level of understanding of the environmental fate of dioxin, it is clear that the use of a factor that describes dissolved dioxin uptake (BCF) to predict fish tissue contaminant levels is inappropriate.

Ingestion Uptake Route

Sorbed dioxin enters aquatic organisms primarily via the ingestion route. However, in evaluating the effects of dioxin on aquatic life or human health, the different routes of exposure for aquatic organisms are not considered in Equation 1. Differentiating between uptake routes is not merely an academic exercise. Depending on the route of uptake, the degree of accumulation of a contaminant in an organism will be vastly different. For example, aquatic organisms can bioconcentrate dissolved dioxin by 5,000-100,000 or more times the dissolved dioxin concentration. However, laboratory research has shown that aquatic organisms accumulate sorbed dioxin (through ingestion) on the order of 0.1-5 times the sorbed dioxin concentration (Figure 1 and references within).

The ingestion route could be effectively regulated by setting risk-based limits for contaminated solids in an effluent. To do this, a factor other than the BCF must be incorporated into the risk assessment equation. The BCF should be replaced by a factor which more realistically describes the transfer of dioxin from the water column (i.e., dioxin sorbed to organic material) to aquatic organisms. One such factor, the Bioavailability Index (BI) (6), is the ratio of dioxin in fish lipid to dioxin in sediment organic carbon. BIs for 2,3,7,8-TCDD have been determined and are shown in Figure 1. The replacement of a BCF with a BI would have a dramatic effect on the value of the final criterion, raising it by 3-4 orders of magnitude.

It is interesting to note that while existing dioxin water quality criteria appear to be extremely conservative and protective (e.g., 0.013 ppq), the criteria apply to the extremely low levels of dissolved dioxin and many sources may, therefore, be in compliance. This is clearly not the intent of federal and state regulators, but is a situation that has resulted from not incorporating new scientific evidence into the regulatory decision-making process.

Conclusion

EPA and other environmental regulatory agencies should explore alternative equations which would more accurately predict fish contaminant uptake. Attempting to develop new methods for regulating pollutants poses great difficulties. By convention or tradition, regulating through the standard permitting process has not involved separating solids and dissolved fractions. However, convention should not dictate the continued use of a methodology that is scientifically indefensible.

To summarize, the use of a BCF in the equation used to calculate a water quality criteria for dioxin effectively ignores virtually all of the dioxin that enters aquatic organisms and ultimately, man (1). A regulatory approach should be developed which considers the ingestion route by utilizing an alternative factor, such as a BI. A new term should be coined for the related criterion; we suggest "environmental quality criterion".

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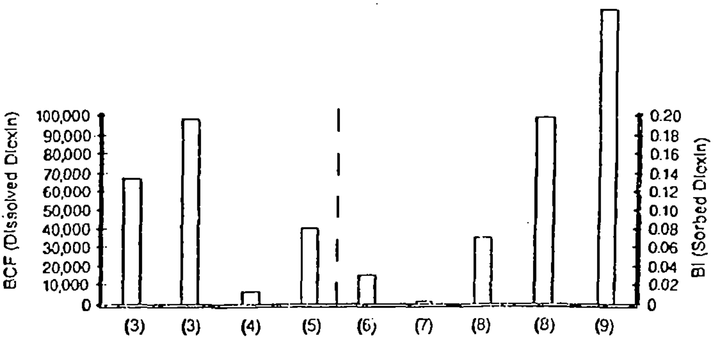

Figure 1: Bar graph illustrating significant differences between factors describing aquatic organism uptake of dissolved (BCF) vs. sorbed (BI) dioxin. (The numbers along the bottom axis refer to references at end of text.)