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CANCER, CARCINOGENS AND DISPERSAL: A DISCIPLINARY DYSFUNCTION

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ABSTRACT

This article compares the paradigms (shared goals, objectives, methods, and assumptions) of toxicology and environmental engineering. With respect to carcinogens, the different paradigms appear to be inconsistent with each other. Environmental engineers implicitly assume nonlinear (threshold) dose-response relationships while toxicologists tend to employ a linear dose-response relationship for carcinogens in the low-dose range. This difference becomes significant when one considers the dispersal of carcinogens to reduce maximum concentrations. Environmental engineers tend to assume that dispersal is desirable though the assumption is often implicit. Toxicologists, in general, do not examine dispersal but much of their work suggests that dispersal is not desirable. The experimental and theoretical research of both disciplines as traditionally practiced is not likely to resolve this inconsistency. An experimental approach is outlined that could address these inconsistencies.

Many disciplines are involved in the assessment and management of carcinogens. Two broad disciplinary groups will be discussed herein: toxicologists and environmental engineers (including many applied scientists and managers). Each of these groups can be characterized by a dominant paradigm [1] which can be described as a constellation of shared expectations, goals, objectives, methods, and assumptions. Such paradigms provide the basis for professional action, discipline, and problem identification within each group. At the same time, these paradigms can insulate each of these groups from important problems. Moreover,

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differences in paradigms can make cross-disciplinary dialogue difficult and thus inconsistencies between them may not be exposed and resolved [2].

This article will provide a partial characterization of the paradigm differences between toxicology and environmental engineering by comparing certain goals, objectives, methods, and assumptions. It will be reasoned that these paradigm differences reveal inconsistencies and unresolved problems with respect to the assessment and management of carcinogens.

A DISCIPLINARY DYSFUNCTION

Toxicologists and environmental engineers share the following common goal:

> *Common Goal:* To provide professional services so as to reduce the total risk to human health from exposure to environmental pollutants.

Each of these disciplinary areas approaches this goal from different paradigms involving different objectives, tasks, and methods. Important (though not complete) objective statements for each of these areas are as follows:

> *Toxicological Objective:* To determine dose-response relationships for different chemicals (including carcinogens) so that environmental standards (typically expressed as maximum acceptable concentrations or doses) can be more appropriately established.

> *Environmental Engineering Objective:* To employ treatment and disposal practices that keep pollutant concentrations (in air, water, sediments, food, and tissue) below some maximum acceptable concentration (standard).

Both objectives are pursued within a social context involving political and economic concerns and regulations.

For the purpose of this discussion, a general method (one of many) to meet the objectives of each disciplinary area is identified.

> *Toxicological Method:* To expose test organisms to high doses (concentrations) of potential carcinogens, observe responses, and extrapolate results to low doses (concentrations) where responses are likely to be sufficiently low so that standards for human exposures can be established.

The methods of environmental engineers are largely directed toward reducing concentrations of pollutants below some specified level. Methods employed involve removal, treatment, and dispersal of pollutants through a variety of means. This discussion will focus upon dispersal as a general method.

> *Environmental Engineering Method:* To disperse pollutants so as to reduce pollutant concentrations below some specified level (standard).

Dispersal usually refers to the spatial distribution of a pollutant. However, given a human or nonhuman population distributed within space, dispersal can also refer to the distribution of exposures within this population. For the purpose of this discussion, dispersal will refer to the degree to which a given mass of a carcinogen is distributed throughout a population. A high dispersal means that the mass is more evenly distributed and each individual receives a relatively equal exposure. A low dispersal means that the mass is concentrated within the population and thus a few individuals receive a high exposure while the majority receive a much lower exposure.

The methods of each disciplinary area are based upon dominant assumptions. Within each disciplinary area, certain assumptions tend to be put to practice.

> *General Toxicological Assumption:* A linear dose-response (concentration-risk) relationship is widely employed for carcinogens in the low dose region [3].

This assumption is employed to extrapolate high dose experimental results to lower levels appropriate to human exposure. This assumption has caused controversy among toxicologists and alternative models have been advocated [4-6]. Resolution of this conflict, however, involves many complex problems for which answers are not now available. In general, however, the linear assumption has prevailed in practice for a variety of reasons including practical considerations, regulatory requirements, and a means to provide a stochastic upper (cautionary) bound on more complex relationships. Although more complex models have been developed [7], some of these models approach a linear relationship under certain conditions [5]. Crump, *et al.* demonstrate that many nonlinear models lead to a linear relationship at low doses when a background of similar carcinogens is present [8]. Thus, even if a nonlinear relationship were demonstrated for a particular pollutant, a linear relationship might still be appropriate at low dose levels for conditions under which exposure to multiple carcinogens occurs. Multiple exposure is in fact the normal condition of human exposure [9]. However, the common dose-response models for cancer have not addressed the subject of exposure to multiple carcinogens.

The paradigms of environmental engineering are, in general, based upon the assumption that dispersal is desirable. Much of the professional literature has been devoted to various forms of dispersal. This assumption is most obvious in the technological efforts to deliberately increase dispersal (i.e., ocean outfalls, diffusers, etc.). Less obvious, but more significant, is the practice of defining environmental objectives (standards) in terms of the environmental concentrations of pollutants (usually mass per unit mass or volume). It is commonly assumed that acceptable risk may be attained by keeping the concentrations of pollutants below some particular level. Under this assumption, a problem is identified when a concentration exceeds some prescribed level. Risks are managed by defining standards for maximum permissible concentrations (exposures, doses). All of these notions implicitly assume that high dispersal is good because it leads to a reduction of maximum concentrations.

> *Environmental Engineering Assumption:* It is desirable to disperse pollutants so as to reduce maximum concentrations below a specified acceptable level (standard).

Environmental Engineers will often confine toxic wastes so that they can be isolated and exposures can be reduced. However, for pollutants not isolated, dispersal is normally assumed to be desirable as described above. Such an assumption is implicit in much of environmental assessment and management. We suggest that the shape of the dose-response curve is relevant to this assumption. However, the shapes of dose-response curves have not been significant concerns of environmental engineers. Discussion of such relationships rarely occurs within their literature.

Environmental engineers have generally been content to accept the standards for carcinogens (expressed as maximum allowable concentrations) established through toxicological studies and, in practice, they have assumed that acceptable standards must be determined by toxicologists. Moreover, environmental engineers have seldom made a distinction between carcinogens and other pollutants. This distinction, however, has been important to toxicologists, particularly within the debates over dose-response relationships. Nevertheless, the use of dispersal as an environmental engineering method and the assumed desirability of dispersal does in fact presume a certain kind of dose-response relationship as demonstrated in Figure 1.

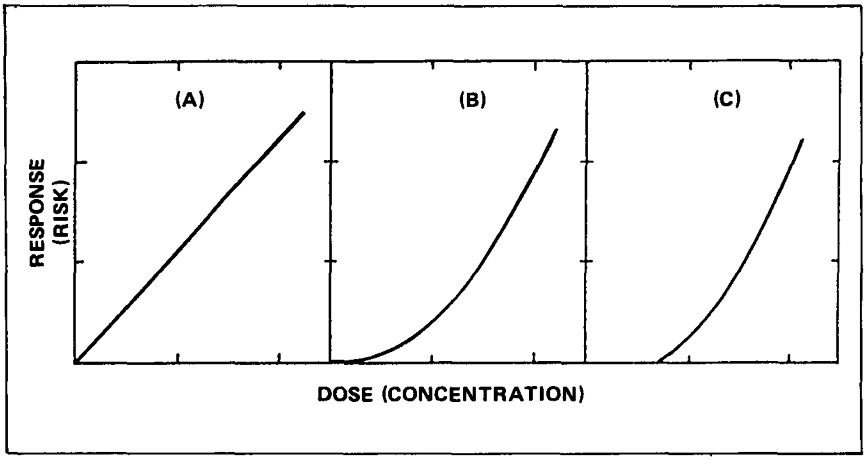

Figure 1. General dose-response relationships for low dose regions: (A) linear, (B) nonlinear, and (C) threshold.

To illustrate the connection between dose-response relationships and dispersal, consider the following illustration. Three general dose-response concentration-risk) relationships are shown in Figure 1. Assume that a pollutant is evenly spread over a given area. Then, assume that dispersal results in the pollutant being distributed over twice that area. As a consequence of such dispersal, the concentration (dose) for exposed populations is reduced by half. If one assumes that the population is evenly distributed within the area, the exposed population will be doubled through such a dispersal. For a linear relationship (curve A), the risk (response) for an exposed organism is reduced by half, but, because the exposed population has been doubled, the total response added (integrated) over the entire population remains the same. For the nonlinear and threshold relationships (Curves B and C), however, reducing the concentration by one-half through dispersal leads to a reduction of risk by more than one-half. Thus, even though the exposed population is doubled, the total response added (integrated) over the entire population will be less. For the threshold relationship (Curve C), the total response will be reduced to zero if dispersal reduces concentrations below the threshold level.

This simple example illustrates a general presumption held in environmental engineering. If a linear assumption (Curve A) is made, the incidence of cancer within the total population is unaffected by dispersal. Dispersal evens out exposure within a population and thus decreases the higher exposures. But, if individual risk is linearly proportional to exposure (concentration, dose), the total risk over the entire population is unchanged. The assumed desirability of dispersal thus presumes a nonlinear dose-response relationship (Curves B and C) at low dose levels. The notion of a threshold concentration (a special case of nonlinearity) below which risk is zero is often presumed by environmental engineers. Under such a presumption, dispersal is desirable, particularly if maximum concentrations are reduced below threshold levels. A linear relationship (Curve A) does not yield such a threshold. By accepting dispersal as beneficial (relative to the *common goal*), environmental engineers presume a nonlinear dose-response (concentration-risk) relationship.

> *Environmental Engineering Presumption:* **In practice, a nonlinear dose-response relationship at low doses is presumed for all pollutants including carcinogens.**

Thus, the *environmental engineering presumption* conflicts with the *general toxicological assumption*. But this conflict is hidden and ignored because of the traditional ways that *objectives* and *methods* have been established within each of these two disciplinary areas. The toxicological effects of dispersal are concerns that do not fall within the purview of the *objectives* and *methods* of either disciplinary area. Toxicologists have not been directly concerned with dispersal. As an example, the literature in toxicology does not contain the mathematical models of disperson common to the environmental engineering literature. Environmental engineers, however, have not been directly concerned with the particular methods that toxicologists employ for carcinogens. As an example, the environmental engineering literature does not contain the mathematical models of dose-response relationships that are common to the toxicological literature. The topic, "toxicity and dispersal" is not common to either disciplinary area despite the fact that the topic is important to the *common goal* of both.

The paradigms of each disciplinary area (as illustrated in *objectives* and *methods*) have acted as blinders to a problem of mutual concern. This may be defined as disciplinary dysfunction.

> *A disciplinary dysfunction* occurs when the paradigms of different disciplines are so arranged as to enable conflicting assumptions and problems of mutual concern to persist without receiving the attention of either disciplinary area.

Toxicologists are very much concerned with the dose-response relationships of carcinogens. Much controversy exists over the nature of such relationships. The theoretical models and experimental approaches that one observes within the mainstream literature, however, are not directed toward the effects of dispersal. That is, despite much controversy, the literature reflects agreement over what the critical questions are. Based upon our own review of the literature, these critical questions do not involve dispersal. It is not even clear from the literature that toxicologists who support a nonlinear dose-response relationship would in turn support a strategy to maximize dispersal. Thus, at the very least, the toxicological literature does not convey to these environmental engineers a concern for the toxicological effects of dispersal nor does this literature indicate that such a concern has been transmitted from enviornmental engineers to toxicologists. Thus, it does appear that, whatever efforts have been made in this regard, a disciplinary dysfunction does indeed exist.

A SUGGESTION

Debate among toxicologists and regulators over dose-response relationships for carcinogens has focused upon the practical problem of extrapolating risk estimation to low doses. The experimental approaches commonly employed are not well suited to a better understanding of dispersal. Dispersal involves more than dilution. The dispersal of carcinogens promotes the mixing of different carcinogens, including initiators and promoters [10], and thus influences the extent of antagonistic, additive, and synergistic interactions. Toxicological methods and models typically employ single carcinogens and thus they seldom accommodate such interactions. An outline of an alternative approach is presented below.

The approach employs:

1. A near equitoxic (equicarcinogenic) dose, D, for each of N different chemicals.
2. N different and separate test environments (containers) containing equal numbers of test organisms.

Two test runs would be compared.

Test run 1: Each environment would receive a dose D of one and only one different chemical.

Test run 2: Each environment would receive a dose D/N of each and every chemical.

The total incidence of tumor in the entire population of test organisms would be measured for each test run. If the total incidence of test run 1 was greater than test run 2, an inverse relationship between total incidence and dispersal would be implied and the environmental engineering assumption would be supported. Contrary results would imply a direct relationship between total incidence and dispersal and the environmental engineering assumption would not be supported. As N is increased, the total number of organisms would be kept constant (the number per separate environment would decrease). At higher levels of N, some tendencies might emerge that would indicate a general relationship between total incidence and dispersal. Dispersal in this approach would be given by N (the number of equal volumes over which each chemical is dispersed). Variations of this approach could allow for intermediate levels of dispersal among the N containers. The general approach might also be employed to test for mutagenicity and the influence of dispersal.

The results of such experiments could address the disciplinary dysfunction described herein and thus might promote an alteration of the paradigms of toxicology and environmental engineering. As an example, if evidence indicates that dispersal is not desirable (relative to the *common goal*), then efforts to reduce total exposure might become more important in comparison to the present approach that seeks to keep concentrations of individual pollutants below a prescribed level. Theoretical models which deal with dose-response relationships of single carcinogens would appear as less useful and fundamentally different models would be called for.

REFERENCES

1. T. S. Kuhn, *The Structure of Scientific Revolution*, The University of Chicago Press, Chicago, 1962.
2. D. A. Bella and K. J. Williamson, Conflicts of Interdisciplinary Research, *Journal of Environmental Systems*, *6*, pp. 105-124, 1976-77.

3. U.S. Office of Science and Technology Policy, Chemical Carcinogens: Notice of Review of the Science and Its Associated Principles, *Federal Register*, *49*:100, pp. 21594-21661, May 22, 1984.
4. B. Altshuler, Modeling of Dose Response Relationships, *Environmental Health Perspectives*, *42*, pp. 23-27, 1981.
5. T. Tabesh, Analysis of Dichotomous Response Models for Low-Dose Carcinogenic Risk Estimation, Masters thesis, Oregon State University, Department of Civil Engineering, Corvallis, OR, 1984.
6. D. Krewski and C. Brown, Carcinogenic Risk Assessment: A Guide to the Literature, *Biometrics*, *37*:2, pp. 353-366, June 1981.
7. D. G. Hoel, H. L. Kaplan, and M. W. Anderson, Implication of Non-linear Kinetics on Risk Estimation in Carcinogenesis, *Science*, *219*, pp. 1032-1037, 1983.
8. K. S. Crump, D. G. Hoel, C. H. Langley, and R. Petro, Fundamental Carcinogenic Processes and Their Implications for Low Dose Risk Assessment, *Cancer Research*, *36*, pp. 2973-2979, September 1976.
9. D. P. Rall, Thresholds? *Environmental Health Perspectives*, *22*, pp. 163-165, 1978.
10. S. H. Moolgavkar, Model for Human Carcinogenesis: Action of Environmental Agents, *Environmental Health Perspectives*, *50*, pp. 285-291, 1983.

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