ENVIRONMENTAL CLEANUP OBJECTIVES FOR PCBs

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Summary

1. Environmental cleanup objectives are the result of tracing the acceptable burden of the contaminants from the endangered resources back to the contaminated environmental compartments via the exposure pathways. The relevant criteria as well as the exposure routes are determined by the planned use of a site following the remedial activities. Therefore, the proposed Environmental Cleanup Objectives Standard Procedure (ECOSP) can only be applied on a case by case basis. 2. With PCBs both human cancer risk assessment as well as ecotoxicological criteria lead to a cleanup objective for surface water in the low (1 - 4.5) nanogram per liter range.

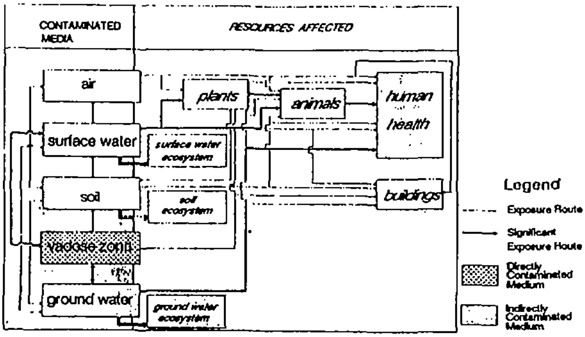
1. The Environmental Cleanup Objectives Standard Procedure (ECOSP)

Cleanup objectives for contaminated sites are determined by using the acceptable burden for the endangered resources and by taking into account the efficiency of transfer of the contaminants via the relevant routes of exposure.

The acceptable burden results from the quality and potency of the toxic effects of the contaminants present. 'Acceptable' means protective; the acceptable burden should no longer pose a threat for the concerned resources. Thus the acceptable burden depends on the properties of both the objects to be protected such as living organisms or ecosystems as well as of the contaminants exerting the toxic effects.

A toxic effect depending on a chemical substance cannot occur without exposure towards that substance (fig. 1). The route of exposure consists of various steps of dilution, ccumulation, transformation, and elimination. In going through these processes the concentration of the contaminant changes with time and position. These changes of concentration are described by mathematical models of environmental transport and by pharmacokinetic equations. The simplest approximations of such transport models are transfer coefficients which can be calculated as the ratio of the effective concentration in the resource to be protected divided by the original concentration in

Fig. 1: Exposure Routes Originating From Problem Sites



the contaminated medium or compartment. Transfer coefficients only hold for constant environmental circumstances such as time, place, species, etc..

Thus, a cleanup objective results from tracing the acceptable burden of a contaminant back to the contaminated environmental compartment via the exposure pathways. The procedure how it is determined ("Environmental Cleanup Objectives Standard Procedure" = ECOSP) involves connecting chemical properties, criteria for the sensitivity of the resource, and routes of exposure. These categories can be thought of as the axes of a 3-dimensional matrix (substances, criteria, exposure; fig. 2).

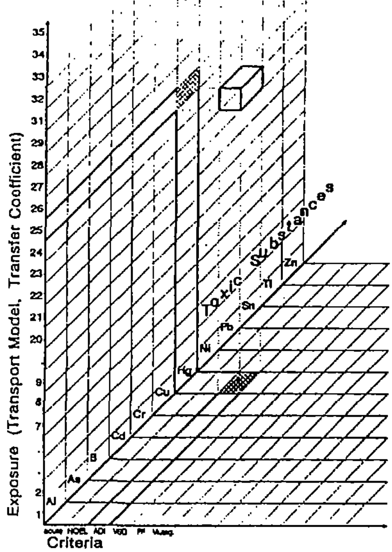
The substances are environmental contaminants that may be released by problem sites or accidental spills. Their properties must be known and stored as numerical data starting with the most notorious environmental toxicants.

The criteria depend on the resources at risk. Primary resources are human health and natural ecosystems. Consequently, cleanup objectives are established according to toxicological and ecotoxicological criteria. Toxicological criteria are mainly derived from experiments with laboratory mammals and less frequently from observations of accidental or voluntary human exposure (epidemiological studies, case histories). Irreversible effects such as chemical carcinogenesis, teratogenesis, or mutagenesis are weighted more heavily than purely acute toxicity whose symptoms disappear after terminating the exposure. The field of ecotoxicology is still at a childhood stage. Mainly aquatic organisms as well as some terrestrial plant species are used as models to probe for noxious effects of chemicals on ecosystems.

The storage of data with regard to exposure routes is most difficult because the environmental influences on the fate of chemicals are manifold. Only in simple cases can a transfer coefficient substitute for a mathematical transport model, and even transport equations can only be solved for known circumstances.

Finally, it is to be emphasized that the ECOSP described here can only be applied on a case by case basis because the use of a site following cleanup must be the result of a

Fig. 2: Cleanup Objectives Matrix



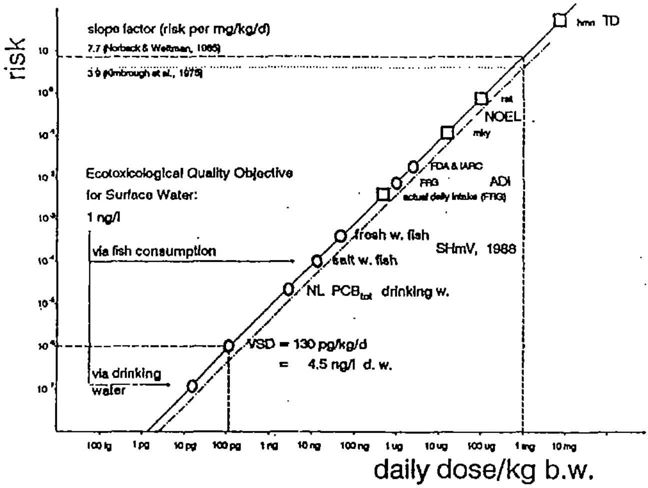
political decision that has to be made for each site individually. The use determines the relevant criteria as well as the exposure pathways which lead to the resources chosen to be protected. The desired use and the actual site-specific circumstances activate certain elements of the cleanup objectives matrix (COM) which are composed of parameter values for the toxic substances and of kinetic equations and finally yield the cleanup objectives as site-specific solutions for these equations.

2. The PCB Example

Human Health Criteria

PCBs are regarded as carcinogens. Based on human exposure alone the evidence is inadequate yet suggestive. But various animal experiments under more controlled conditions yielded sufficient evidence to classify this class of compounds as liver carcinogens in rats and mice. The application of a low-dose extrapolation procedure to the most conclusive one of these experiments (Norback and Weltman, 1985) results in a so-called slope factor of 7.7 per mg/kg/d. Another experiment leads to a slope factor of 3.9 per mg/kg/d (Kimbrough et al., 1975). These slope factors designate the risk that is attached to a chronic-dose of one mg/kg/d of a carcinogen and fix the position of two straight lines in a bilogarithmic dose-response diagram (fig. 3). Such a line is used to extrapolate the measured dose-response curve down to low risks such as 10^{-6} which are regarded as acceptable.

Fig. 3: Dose-Response Curve (Extrapolated) for Arochlor 1260



Exposure Conditions

The corresponding low dose can be converted to an environmental concentration under certain reasonable exposure assumptions and can thus serve as a cleanup objective. In this case an acceptable risk of 10^{-6} corresponds to a chronic dose of 129 pg/kg/d or a concentration of 4.5 ng PCB/l drinking water if this were the only source of human PCB-intake (an exposure factor of 35 results from 70 kg body weight divided by 2 l drinking water consumption per day).

The German "Schadstoff-Höchstmengenverordnung" (SHmV) sets the upper limit for PCBs (138 and 153) in fresh water fish at 0.3 mg/kg and in salt water fish at 0.1 mg/kg. Assuming an average consumption of 10 g of fish per day by a 70 kg person (BLAK QZ, 1989) and 100% gastro-intestinal absorption one obtains an exposure factor from fish to man of 0.000 143/d and arrives at a daily dose of 43 ng/kg/d from fresh water fish and 14.3 ng/kg/d from salt water fish. This translates into a risk of 3 or 1 x 10^{-4} from fresh or salt water fish respectively, each containing the maximum allowable amount of PCBs.

The extrapolated dose-response curve thus serves to visualize quality objectives that were derived from different exposure situations and to compare them with each other in terms of quantitative risk. This procedure can be carried further:

A surface water quality that leads to the above limit values in fish can be estimated by dividing these values by the approximate BCF of 50 000. The resulting cleanup objectives of 6 and 2 ng/l for fresh and salt water, respectively, are in the same order of magnitude as the drinking water standard of 4.5 ng/l. But since the surface water cleanup objectives are associated with a much higher risk, one can see that the human exposure via the food chain is more critical than via drinking water. A reduction of the limit values for fish that would be necessary in order to reduce the risk to an acceptable level (10^{-6}) does not seem feasible at this time.

Other Toxicological Criteria

The relatively high risk due to the consumption of fish that are contaminated with PCBs up to the maximum allowed concentration is exceeded still by the actual daily intake in the FRG of 500 ng/kg/d via all foodstuffs and all exposure routes taken together (risk = 4×10^{-3}). From the dose response curve it is further obvious that the ADI values recommended by the Commission for the Assessment of Residues in Food of the DFG of 1 ug/kg/d and by both the US-FDA and the IARC of 2.5 ug/kg/d with an associated life time cancer risk of 8×10^{-3} and 2×10^{-2}, respectively, do not offer sufficient protection. The ADI concept of dividing the NOEL by a safety factor is not applicable in the case of PCBs which are proven animal carcinogens. For reasons of comparison the NOELs obtained with monkeys and rats and the respective risks are displayed in figure 3 (mky: 16 ug/kg/d with a 1.2×10^{-1} risk; rat: 100 ug/kg/d with a 7.7×10^{-1} risk). A PCB dose of 7 mg/kg that elicits toxic symptoms in humans would be associated with an exceedingly high projected cancer morbidity of 55 times per person.

Ecotoxicological Criteria

Several plankton organisms, invertebrates, and juvenile fishes display an effect threshold for PCBs of 100 ng/l surrounding water. Juvenile fish which have been exposed to PCBs as spawn suffer teratogenic effects and reduced survival. The range of the effect threshold for spawn is from 0.5 to 3 mg/kg wet weight. Division of 0.5 mg/kg by the BCF of 50 000 l/kg leads to an ecotoxicological cleanup objective of 10 ng/l.

Marine mammals being at the top of the food chain accumulate PCBs 10- to 100-fold (on a fat basis). Fish bioconcentrate up to 10^5-fold from the surrounding water. The resulting overall BCF for marine mammals is 10^7. Consequently, a water level of 1 ng PCBs/l leads to concentrations of 10 mg PCBs in the body fat of these mammals. These fat concentrations are very problematic in view of laboratory results with monkeys. A mean fat concentration of 16.4 mg Arochlor 1248/kg in the milk of Rhesus monkeys was lethal for some of the young who died after a few months with typical symptoms of PCB intoxication (Lorenz and Neumeier, 1983). These authors therefore propose a surface water quality objective of 1 ng/l based on ecotoxicological considerations. Such a standard does not include a safety factor. Since a standard of 1 ng/l is not achievable technically at this time, the authors plead for a termination of the release of PCBs into the environment. Because of the extraordinarily high BCF encountered with marine mammals these animals require the lowest figure of 1 ng/l for an ecotoxicological cleanup objective.

Conclusion

There are two main possibilities for translating this ecotoxicological cleanup objective into a hypothetical human cancer risk for comparison with other cleanup objectives. The first is via the food chain. Because of its high exposure factor this route leads to an intake of 14.3 ng/kg/d and a corresponding risk of 1×10^{-4}. The other possibility is via drinking water which entails a daily intake of 28.6 pg/kg/d and a 2.2×10^{-7} risk.

Interestingly, this latter value compares very well with the human health based virtually safe dose of 130 pg/kg/d at a 10^{-6} risk. This result gives strong support for a surface water cleanup objective in the low ng/l range, preferably at 1 ng/l, since such a value is required by both, human health and ecotoxicological criteria.

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