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RISK ASPECTS AND DECISION-MAKING FOR CONTAMINATED SITE REMEDIATION

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INTRODUCTION

Extensive societal pressures are being exerted in North America, in an effort to decrease the risks to which people are exposed. Although these risk-reduction initiatives are being experienced in many aspects of modern-day society, they are particularly relevant in relation to hazardous wastes. A number of reasons explain the focus toward risk reduction associated with hazardous wastes including: (i) people don't understand many of the characteristics of hazardous wastes and there is a fear of the unknown, (ii) there are acknowledged historical incidents or "horror stories" such as the Love Canal in which large quantities of chemical wastes were poorly disposed of, and (iii) the knowledge that somebody else will pay the economic costs associated with contaminated site remediation quickly persuades many people that no expense for risk reduction is too large. The result is that there is extensive pressure being brought about by governmental regulators in North America to have the risks associated with hazardous wastes decreased to very small magnitudes. On the other hand, as members of modern society, people are exposed to a variety of risks on a daily basis; when the risks are voluntary and, at least to some extent they understand the risks, the risks are accepted (e.g. the smoking of cigarettes and the taking of airplane flights). Thus, there are differences in attitude and acceptance as a function of the source of the exposure risk.

In addressing risk considerations associated with hazardous wastes, an important area of necessary research relates to the need to improve the methods utilized for characterizing the risks and ultimately, for making decisions on the remediation of contaminated sites. Risk assessment in relation to environmental phenomena is a process that seeks to estimate the likelihood of occurrence of adverse effects due to exposures to chemical, physical and/or biological agents in humans and ecological impacts within an ecosystem. The goal of risk management is then to select between available remediation options that balance the benefits of an activity against a real or perceived risk, with the costs of eliminating that risk. In utilizing the available tools for risk management for contaminated site remediation, we have two major considerations:

(i) it is inappropriate to try to decrease the risk to too small a magnitude. As a compromise, risk management for contaminated site remediation is often now being interpreted as decreasing the risk to one in a million. For example, the chance of being struck by lightning in North America is approximately one in a million. In the legal profession, that is called a "deminimus risk" or negligible risk. Some examples of risks that increase the chances of death by one in a million are summarized in **Table 1**.

The acceptance of a risk of one in a million associated with contaminated site remediation thus reflects an attempt to decrease the risk associated with site remediation to a magnitude similar to the other risks to which members of modern society are exposed;

(ii) a difficulty associated with assessments of many environmental problems is the availability of only minimal data. For example, only limited knowledge typically exists regarding the quantities and specifics of contents of solid wastes disposed of at a site needing remediation. Thus, it is difficult to establish the exposure risks for nearby residents and/or onsite construction workers that may be encountered during site remediation. As a result, one response that is frequently adopted is to utilize a succession of worst-case assumptions. For example, we may know only that organic chemicals were disposed of at the site but to be conservative we will assume that all of the organics were benzene, a highly volatile chemical. As well, since the wind direction for a particular time period during site

Table 1 Risks Which Increase Chance of Death by One in a Million

Smoking 1.4 cigarettes
Drinking 1/2 liter of wine
Spending 1 hour in a coal mine
Travelling 6 minutes by canoe
Travelling 10 miles by bicycle
Flying 1000 miles by jet
Drinking City of Miami drinking water for 1 year
Eating 40 tablespoons of peanut butter
Eating 100 charcoal broiled steaks

Ref. Wilson (1990)

remediation cannot be predicted definitively, the assumption may be made that the direction is such as to maximize exposure of the residential population-at-risk. Neither of the above assumptions are likely correct but such an approach can be utilized to estimate the maximum feasible exposure risk.

An alternative type of data problem is related to the uncertainty of any risk estimate. For example, our best estimate might entail calculatioins which indicate acceptable slope-stability conditions during site excavations to remove contaminated soil. However, as an example of uncertainty, conditions other than those expected may occur and slope instability may initiate much higher exposure levels. Any derivation then of expected value or best estimate of the exposure risk must be considered only that, the best estimate, and uncertainty exists in these estimates. This type of finding then must be reported as, our best estimate is 'x', but in reality the exposure risk could be as high as 'y' where y>x, some measure of the upper bound of the exposure risk.

These two data-related examples demonstrate two very important aspects of risk assessment problems in relation to contaminated site remediation-the risk values are probably conservatively high (because of the use of one or more worst-case assumptions) and the estimated exposure risks may have considerable uncertainty associated with them.

Subset (ii) above is worthy of significant additional research. Site cleanup costs are substantial. For example, in the United States, the records of decision for cleanup of contaminated superfund sites in the U. S. indicate an average of thirty million dollars per site (Dienemann et al, 1992). Since the number of such sites in the U.S. could be 10,000 or more, the cleanup costs might eventually require 300 to 700 billion dollars. For the reasons indicated in the previous paragraph, there are probably monies being expended on site remediation that are unnecessary and the magnitudes of expenditure are substantial which results in less money being available for alternative uses. This author feels the potential exists for overexpenditure when attempts are made to make the exposure risks inordinately small. Some guidance as to how improvements in analysis may be made are detailed in the following paragraphs.

BACKGROUND TO A RISK ASSESSMENT

In a typical scenario in which there is an exposure, contaminants may be transported via one or more media (including air, soils/sediments, surface water and ground water) to potential receptors (through, for example, inhalation, dermal contact and ingestion). The exposure assessment aspect of the risk assessment must then involve the characterization of the physical and exposure setting, including contaminant distributions leading from sources at a hazardous site to the points of exposure, the identification of significant migration and exposure pathways, the identification of chemical intakes for all potential receptors and significant pathways of concern. The exposure and risk assessment must then be completed for each remediation alternative to allow a comparison between the different alternatives.

A part of the challenge in the development of the risk assessment arises in that there is uncertainty in the data assignments used in the models, and there is uncertainty in the impact of different exposure levels. To demonstrate these concerns further, assume for purposes of discussion that one remediation alternative involves the excavation of contaminated soils. The resulting uncertainties in the data assignments include such features as (i) the meteorological conditions to be experienced during the excavation are known only to the extent to which historical data can be used to identify the probabilities of alternative meteorological conditions; (ii) the locations, quantities and form of containment of buried wastes to be excavated are known only to a limited extent; and (iii) the resulting effectiveness of a specific remedial action is uncertain until after it has been attempted (e.g. will bioremediation of soils cleanse the soils to acceptable levels?). In addition, there is uncertainty as to what exposure level to a chemical is sufficient to initiate cancer. In relation to these problems, a frequent practice is to be very conservative in the assignment of the parameters.

As another example of the degree of conservativeness sometimes adopted, the current knowledge may indicate that there is a one-in-a-million chance of contracting cancer associated with exposure to a chemical at a specified concentration for an individual who consumes 2 liters of water per day contaminated at the specified concentration, over a period of seventy years. However, regulators have utilized this same specified concentration, or environmental standard, in assimilative capacity calculations for downstream users of a surface waterbody as a source of water supply. In this situation, the allowable discharges to the waterbody have been determined on the basis of not exceeding the environmental standard in the waterbody during low flow conditions. Specifically, stipulations on allowable discharges to the waterbody allow the magnitude of the dilution effect provided by the waterbody only to the seven-day (weekly) average low flow level that is exceeded once on average, in twenty years (i.e. a very low flow level). The result is the risk associated with an environmental standard that is premised upon continuous, lifelong consumption of water at a specified concentration of a chemical is made dramatically more conservative by associating with it, a very low level of streamflow. Most of the time (i.e. $1-1/[(20 \text{ years})(52 \text{ weeks/year})]=1-1/1040=.999$, or 99.9% of the time the chemical concentration will be lower than the environmental standard because the instream dilution flow is higher)-the result is a very conservative exposure scenario.

The above comments associated with the remediation of contaminated sites are indicative of at least two major concerns. The estimates of risk are uncertain in magnitude, and calculated risks may be much larger than real risks. In addition to these considerations, the temporal variability of risks associated with contaminated site remediation may be huge. As an indication of this, consider that at one time during site remediation, the environmental risks are relatively small whereas at other times, the risks are perhaps five orders-of-magnitude higher. Enormous variations in temporal exposure risk frequently occur during contaminated site remediation. Incorporating the temporal variations in exposure risk with considerable uncertainty that exists in many current estimation procedures makes the problem of selection between alternative site-remediation schemes a considerable challenge.

In order to explore how some of these difficulties with risk assessment might be addressed, a useful element of the analysis involves the use of risk-time curves, a concept described in McBean and Rovers (1994).

BASIS OF RISK-TIME CURVES

The use of cost-times in the selection between remediation alternatives has been standard practice for many years. Typically, the curves themselves have only been considered peripherally since, using a discount rate, the temporal variability of the costs is modified to a present value and/or translated into an equivalent annual cost. The equivalencing concept is utilized to allow comparisons between alternatives by removing the individual temporal variations, placing the comparisons between the alternatives onto an equal basis.

Risk-time curves are of a similar nature, except that the curves indicate the temporal changing levels in terms of risk, as a function of time, for each of the remedial alternatives. The flexibility and easy comprehensibility of the results to a non-technical audience, have made the approach a useful one.

As an example of risk-time curves, consider the remediation of ground water contaminated with solvents. In this example, the contamination is the result of improper disposal where solvents were simply dumped into lagoons which in turn leaked into the soil profile for a number of years. The contamination exists over considerable depths of soil profile (50 m to bedrock and also into the fractures within the bedrock itself). In considering the potential remediation options, at least the following two possibilities exist, namely:

(1) Option 1-Excavation and Disposal

Excavation of the contaminated soil, temporary stockpiling on site, with eventual removal and disposal in a secure landfill site. The impacts in terms of risk include volatile emissions during excavation and from the stockpiles of soil, and the potential for backfill recontamination from upwelling of contaminants from the bedrock. The excavation, soil stockpiling, and removal of the soils at the site can pose significant risks to on-site workers resulting from accidental chemical exposures, physical hazards, heat stress, or other conditions commonly encountered during excavation. An indication of the resulting risk-time curve is as indicated in **Fig. 1**, in which the curve shows the best estimate of the cancer risk with time. The 'status-quo' or do-nothing option indicates the risk versus time for the do-nothing approach. The status quo curve illustrates a continuing gradual increase in risk as the contamination continues to migrate over time. Significant temporal variation of risk versus time in the excavation and disposal option is apparent. The period of elevated risk is lengthy (5 to 10 years) since the excavation and removal of large quantities of soil will take a lengthy period of time.

(2) Option 2-Inplace Containment

Placement of an engineered cap over the contaminated soils, and combining this with a passive

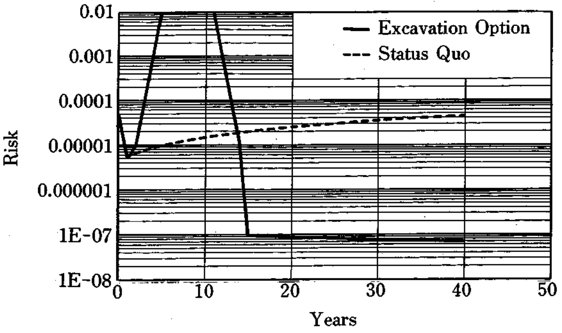

Fig. 1 Risk-Time Curve for Option 1

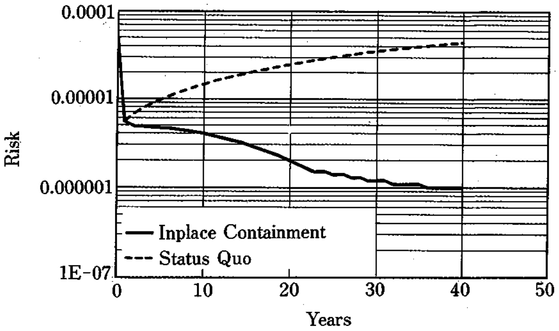

Fig. 2 Risk-Time Curve for Option 2

gas collection system. These two actions (capping and gas collection) encompassing the inplace containment approach would effectively contain the volatile organic chemical emissions. The implementation of a comprehensive monitoring program would be required to ensure that the inplace containment system continued to function as designed, but the inplace containment option would involve a small fraction of the costs implied in Option 1. The resulting best estimate, or expected value, of the risk-time curve is depicted in **Fig. 2**. Again, the status-quo curve has been included in **Fig. 2** for purposes of showing relative comparisons.

A comparison of the risk-time curves and related information for Options 1 and 2, and the implications of the two approaches, demonstrate several relevant features:

(i) the economic costs associated with Option 1 are substantial, in comparison with those of Option 2. However, the inplace containment option involves "writing off" the value of the contaminated groundwater resource and soil environs. The economic opportunities foregone by allowing the contaminated soil to remain contaminated essentially in perpetuity, must be evaluated in economic terms to complete the economic analyses.

(ii) The inplace containment approach of Option 2 involves significantly less exposure risk, in comparison with that of Option 1. There is no disturbance of the soil and thus by placement of the cap, there is no increase in exposure pathways for the chemicals in the ground. The risk-time curves are useful in indicating to both technical and nontechnical individuals alike, the temporal variability of the expected risks.

(iii) The construction activities involved in Option 2, with placement of a gas collection system and an engineered cap are understood, and thus the uncertainty of risk-time predictions is likely very small. Alternatively, the excavation of a 50 m deep pit to remove the soils may result in problems such as slope instability and/or the excavation of previously-unexpected chemicals. The result is that an upper-bound risk-time curve reflecting uncertainty could well entail a curve that is several orders of magnitude higher than that depicted in **Fig. 2**.

In all likelihood, the best option for the hypothetical site as briefly described in the example above, involves inplace containment. The advantages of inplace containment over excavation and removal of the contaminated soil include lower costs, lower risk and less uncertainty of the risks. These advantages must be compared with the opportunities foregone as a result of leaving the aquifer contaminated virtually in perpetuity. The uncertainty of the risks associated with the excavation option, with a nonzero probability of a very large exposure risk, also argue strongly in support of inplace containment as the most appropriate contaminant remediation option for the site described herein.

THE GENERALITY OF CONCERNS ASSOCIATED WITH RISK ASSESSMENT AND MANAGEMENT

The principles and concerns associated with risk assessment and management, as detailed in the context of contaminated site remediation, are general and have merit in application to a wide range of environmental and water-related issues. There remains the need for extensive methodological development and technical analyses to resolve the questions regarding the appropriateness of worst-case assumptions and the most effective way of dealing with uncertainty in risk assessments and risk management. The use of risk-time curve methodology is but one of a number of methodologies which has merit in providing insights into problems of selection between a number of potential remediation alternatives.

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