Development of Risk-Based Remediation Strategies

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Abstract: Risk assessment can be applied throughout the site evaluation process to help identify remedies that are both environmentally sound and cost-effective. For example, risk assessment is often used for calculating cleanup goals for soil and ground water, and as a tool to help to determine the most appropriate corrective actions. Risk assessment can also be used to focus site characterization activities, establish remedial action objectives, compare alternative remedies for achieving those objectives, and develop postremediation monitoring plans. This paper provides a brief overview of the basic principles of risk assessment and of how those principles are applied to hazardous waste sites and industrial facilities. It also identifies assumptions made during the risk assessment process that can have a significant effect on remediation decisions, and discusses the use of risk assessment in selecting an appropriate remedy. Case histories are also presented to illustrate important applications of risk assessment, including its use in updating remedy decisions and evaluating the safety of remedy implementation.

INTRODUCTION

Environmental statutes and regulations in the United States commonly require remedial action at hazardous waste sites and industrial facilities that are shown to pose an ‘‘unacceptable’’ risk to human health or the environment. For example, the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), which governs Superfund, calls for remedies at sites demonstrated to represent ‘‘a substantial endangerment to public health or welfare or the environment’’ [CERCLA Section 104(a)]. Selecting the appropriate remedy at such a site usually also involves a consideration of current and future risk, as well as numerous additional factors including cost, technical feasibility, and local and state regulations. Public acceptance can also play an important role.

For over two decades, the process of risk assessment has been used and accepted by U.S. regulatory agencies as an objective means of identifying sites in possible need of remediation, and as a tool helping to determine the most appropriate remedial action. For example, risk assessment can be used to help estimate the risk posed by a site in the absence of remedial action; focus site-characterization activities on the exposure pathways, media, and chemicals that pose the greatest risk; establish cleanup or treatment goals; compare alternatives for most cost-effectively achieving the cleanup goals and other remedial action objectives; and develop postremediation monitoring plans.

Risk-based strategies allow for identification of remedies that can be demonstrated to be protective of human health and the environment, but which are also cost-effective. The return of industrial or waste management sites to ‘‘pristine’’ or ‘‘natural background’’ is usually prohibitively expensive, and often technically impracticable. Risk assessment, when properly applied, can be used to define chemical concentrations that may exceed ‘‘natural background’’ but do not pose a significant threat given the intended future use of the site. It can also be used to objectively evaluate the relative risk reduction associated with alternative remedial actions. In many instances, relatively inexpensive remedies (such as natural attenuation or institutional controls) may represent a protective, cost-effective alternative to removal or treatment in reducing potential site-related risks. In fact, the risks of implementing a removal remedy can sometimes more than offset any potential long-term risk reduction.

The potentially high cost of remediation has been cited as one cause for the slow redevelopment of so-called ‘‘brownfield’’ sites. These sites, which are often located in areas where economic revitalization is most needed, are typically former industrial or manufacturing facilities with varying levels of chemical contamination in soil and/or ground water. Risk assessment has emerged as an important tool in determining the level of remediation necessary to return such sites to productive use, without requiring cleanups that make the property unattractive to investors.

Of course, not all sites warrant consideration of an expensive cleanup or a sophisticated, site-specific risk assessment. At some sites, particularly if they are small and exhibit relatively low levels of contamination, it may be relatively easy to identify a remedy that is both cost-effective and provides sufficient risk reduction. For this reason, many state and federal programs are moving toward a ‘‘tiered’’ framework for integrating risk assessment into the site remediation process. In general, using this approach, the first tier requires the least site-specific evaluation, but results in more stringent cleanup requirements (e.g., reduce concentrations to ‘‘background,’’ or levels consistent with unrestricted future land use.) Higher tiers usually require the collection of more site-specific information and a more sophisticated risk assessment, but allow for greater flexibility in cleanup goals.

One example of the tiered approach to site remediation is the ASTM risk-based corrective action (RBCA) standard for petroleum hydrocarbon sites (ASTM Standard E-1739). ASTM RBCA incorporates a three-tier framework, progressing from Tier 1 (risk-based screening levels) to Tier 2 (simple site-specific screening levels, typically based on the same risk assessment methodologies as those used in Tier 1) to Tier 3 (complex site-specific screening levels, usually based on more sophisticated risk assessment methodologies). The ASTM RBCA tiered framework has been adopted by a number of state environmental agencies, including those of Texas and Michigan. Experience in these and other states suggests that the majority of petroleum hydrocarbon sites, such as gasoline stations, can be successfully addressed under Tiers 1 or 2 without needing the more complicated evaluation under Tier 3 to identify a cost-effective remedy. A similar provisional guide for RBCA at chemical release sites was issued by ASTM in July 1998, with adoption anticipated by July 2000.

Compared with most petroleum hydrocarbon sites, cleanups at Superfund, RCRA, and other chemical release sites typically consider a wider range of constituents and a number of source

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areas, and can be much more expensive to remediate. Thus, sophisticated risk assessment methodologies, including probabilistic techniques (e.g., Monte Carlo) have evolved over the past decade to allow for a refined evaluation of cleanup requirements where remediation costs are high and screening-level evaluations indicate a potentially significant risk to human health or the environment.

KEY CONCEPTS IN RISK ASSESSMENT

Both the National Academy of Sciences (NAS) and the U.S. Environmental Protection Agency (USEPA) have established guidelines for performing risk assessments. According to these guidelines, a quantitative risk assessment typically includes three steps: hazard evaluation, exposure assessment, and risk characterization (NAS 1983; USEPA 1989).

During hazard evaluation, the chemicals present at a site are identified and their concentrations and locations in various site media are characterized. Information regarding the toxicity of site-related chemicals (e.g., the types of health effects associated with each chemical, and the relationship between dose and response) is gathered and summarized. Two broad categories of health effects are generally reported—cancer and noncancer effects. Cancer potency is typically expressed as a slope factor, in inverse units of milligrams of chemical per kilogram body weight per day of exposure $(mg/kg/day)^{-1}$, which is the projected slope of the dose-response curve, and incorporates the Environmental Protection Agency's (EPA) typical default assumption that any level of exposure to a cancer-causing agent has the potential to cause cancer (Fig. 1). This is known as the ''no threshold'' assumption, and may not be appropriate for all carcinogens (chemicals believed to have the potential to cause cancer). The slope factor and degree of confidence in the data regarding the chemical's cancer-causing potential are reported in the hazard evaluation portion of the risk assessment. For noncarcinogens (chemicals believed to have the potential to cause health effects other than cancer), exposure thresholds are assumed to exist; below such a threshold, noncancer health effects would not be expected to occur (Fig. 2). Reporting of toxicity for noncancer effects includes a numerical estimate of the threshold dose or concentration, an estimate of the uncertainty in the threshold dose, and an identification of the primary organs targeted by, or types of health effects caused by, the chemical. EPA's noncancer toxicity criterion is commonly the Reference Dose (RfD), and is expressed in units of milligrams of chemical per kilogram body weight per day of exposure (mg/kg/d). The RfD value for a chemical typically incorporates ''safety'' or ''uncertainty'' factors of between 10 and 1,000, depending on the source and quality of the toxicity data, as well as to account for sensitive individuals in the general population. ''Modifying'' factors between 1 and 10 may also be applied in developing the RfD, depending on the quality of available data.

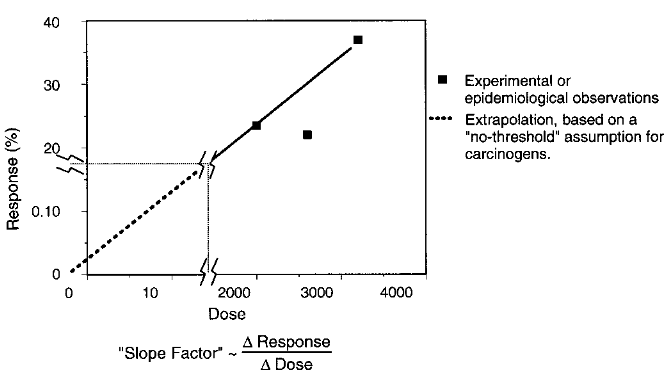

FIG. 1. Assumed Dose-Response: Cancer Effects (No-Threshold Model)

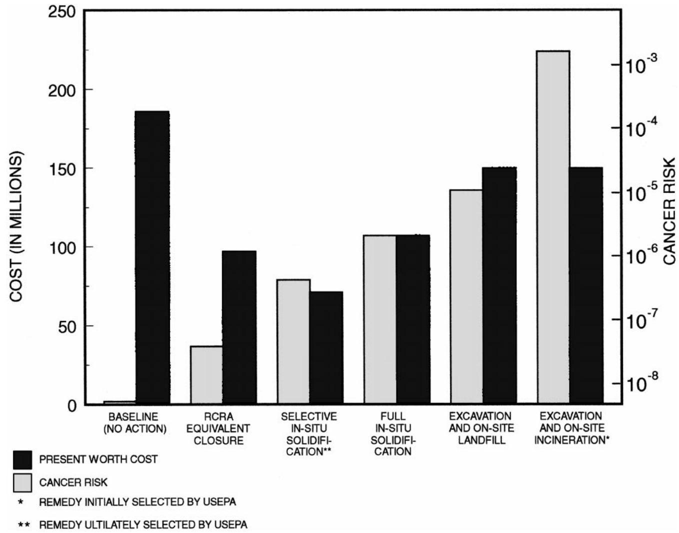

FIG. 2. Assumed Dose-Response: Non-Cancer Effects (Threshold Model)

The exposure assessment of a risk analysis quantifies the dose of site-related chemicals that individuals are likely to receive. The exposure assessment involves identifying potential sources of chemical release into the environment, actual or hypothetically exposed populations (i.e., receptors), and pathways for the chemicals to migrate from the source to the receptor. A critical element of this first portion of the exposure assessment is a characterization of current and reasonable future land ground-water use. The exposure assessment also involves the use of information regarding behavior patterns and characteristics of individuals in the receptor population to estimate the chemical dose received through the identified exposure pathways. Constituent concentrations to which receptors could be exposed should be estimated using techniques consistent with the type and duration of exposure. For example, because a receptor is not likely to be exposed to the maximum concentration at a site continuously over several years, long-term exposures are usually based on a conservative measure of the average concentration.

The risk characterization step of the risk assessment includes calculation of the risk using results from the hazard evaluation and exposure assessment, and evaluation of the uncertainty associated with the risk estimates. As noted previously, agencies are placing greater emphasis on the risk characterization portion of risk assessments. The risk characterization should ''convey the range of information considered and used in developing the assessment . . . including a statement of confidence about data and methods used'' (USEPA 1992a).

Assumptions made during the risk assessment may affect later decisions regarding the need for, the extent of, and the type of remediation. One such assumption relates to future land use. According to USEPA guidance under Superfund, ''the potential land use associated with the highest level of exposure and risk that can reasonably be expected to occur should be addressed in the baseline risk assessment . . . [and] should be used in developing remediation goals'' (USEPA 1991a). Residential land use is often associated with the highest level of exposure and risk, and is often assumed in a risk assessment unless an alternate future land use can be supported by site-specific information. The additional effort to perform a detailed land use evaluation can be worthwhile because ''different land uses result in different human exposure pathways as well as different exposure durations, thus varying remediation standards that may be appropriate based upon land use'' (NJDEP 1994).

Assumptions about the toxicity of chemicals in a mixture can also affect later decisions regarding the extent of remediation. In the risk assessment, the summation of cancer risks and noncancer effects for multiple constituents is based on dose additivity, which assumes that there are no synergistic or antagonistic interactions among the constituents in a mixture and that each constituent has the same mode of action and elicits the same health effects. In subsequent risk management decisions, one target cancer risk level may be established for the individual constituents, at say 10^{-6}, while a separate cumulative risk limit may be set for the mixture. If the cumulative risk is set at 10^{-5}, as in Wisconsin's soil cleanup standards (Wisconsin Chapter NR 720), then the assumption of dose additivity can lead to cleanup levels for individual chemicals that are well below 10^{-6} when numerous chemicals are present at a site.

APPLICATION OF RISK ASSESSMENT TO REMEDIATION

Developing Site Characterization Plans

Site characterization serves a number of different purposes. Data are collected to determine physical characteristics of the site (e.g., soil characteristics and ground-water movement), identify the nature and extent of contamination, and support the design of remedial alternatives, in addition to supporting the needs of the risk assessment. However, sampling designed specifically to characterize the extent of contamination may not be adequate for estimating exposure concentrations in the risk assessment. By the same token, sampling efforts can often be reduced in scope if they are tailored to an overall risk-based remediation strategy.

Preliminary identification of exposure routes and exposure points when the site characterization plan is developed can be used to identify the appropriate number, type, and location of samples needed to assess exposure. If preliminary sampling results are available, risk-based screening methodologies—such as the EPA's Soil Screening Guidance (USEPA 1996)—can be used to focus subsequent investigation on areas of the site more likely to be of concern. Quantitation limits should also be considered prior to site characterization, since these are used in the risk assessment to estimate concentrations of site-related chemicals in ''nondetect'' samples. It may also be important to collect information on key properties of soil, ground water, and other media at the site to allow for use of site-specific data (rather than generic defaults) as inputs to fate and transport modeling conduct as part of the risk assessment.

Determining Whether Corrective Action Is Necessary

Although any contaminated site can pose some level of risk to human health and the environment, not all sites with contamination require remediation. The need for remediation and the extent of remediation required depend on the chemicals present, their concentrations in the various environmental media—including soil, ground water, surface water, and air—and the extent of potential exposure to these media (e.g., greater potential for exposure to surface soil than subsurface soil). Risk assessment techniques are commonly used to identify those sites that may pose unacceptably high risks to human health or the environment, and thus require some type of corrective action.

Typically, the first step in the site remediation process is an initial assessment of potential risks to determine whether or not any portion of the site may require cleanup. Under Superfund and RCRA, this initial assessment is typically referred to as a baseline risk assessment. The baseline risk assessment examines the current and future risks posed by a site in the absence of remediation, taking into account expected land use in the area and usually using assumptions and inputs that are believed to be conservative (i.e., more likely to overestimate rather than underestimate potential human health and environmental risks). The results of a baseline risk assessment are often used as the basis for determining whether remediation should be considered to reduce the risks posed by contamination at a site.

For carcinogens, an excess lifetime cancer risk greater than 1 in 1,000,000 (10^{-6}) has traditionally been used as one benchmark for determining whether a site poses potentially significant risks to human populations. The 1990 National Contingency Plan (NCP) requires that a 10^{-6} level be used as a ''point of departure'' in determining the need for remediation. If risks are below 1×10^{-6}, a cleanup is rarely if ever required. In fact, according to subsequent guidance from the USEPA, remediation at Superfund sites is generally not warranted unless excess cancer risks exceed 1 in 10,000 (1×10^{-4}) (USEPA 1991a). In evaluating noncancer health effects, the point of departure is usually taken to be a ''no-adverse-effect'' levels, taking into account safety factors as appropriate. If conditions at a site are such that exposures would be expected to produce adverse noncancer effects, i.e., if the dose is significantly higher than the RfD, remediation is typically required.

Selecting among Potential Remedial Alternatives

The appropriate remedy for a particular site can range from ''not action required'' to complete removal of contaminated materials with off-site treatment and disposal. An initial step in the selection of remedial alternatives is to determine whether treatment or containment is the primary objective. For example, EPA expectations for remedy selection under RCRA corrective action include the use of ''treatment to address the principal threats posed by a site, wherever practicable and cost effective'' (61 FR 19432 at 19448, May 1, 1996). Subsequent EPA guidance clarifies the role of risk assessment in helping to identify principal threats, which are defined in part as materials ''with toxicity and mobility characteristics that combine to pose a potential risk several orders of magnitude greater than the risk level that is acceptable for the current or reasonably expected future land use, given realistic exposure scenarios'' (USEPA 1997). Containment remedies, such as the capping of contaminated soils, may be appropriate for materials that do not warrant treatment, but still pose an unacceptable risk to human health or the environment. Consideration of institutional controls may also be appropriate under certain site conditions. For example, land use restrictions could be considered when levels of contamination might pose a potentially significant risk under residential land use, but not under commercial/industrial land use.

Beyond identification of principal threats, selecting the most appropriate remedy involves the consideration and balancing of a number of important factors. The two threshold criteria that all alternatives must achieve for consideration under the Superfund program are the overall protection of human health and the environment, and compliance with Applicable or Relevant and Appropriate Requirements (ARARs). Once those criteria are satisfied, the 1990 NCP identifies five primary balancing criteria for consideration: long-term effectiveness; short-term effectiveness; implementability; cost; and reduction of toxicity, mobility, or volume through treatment. Risk assessment often plays an important role in evaluating both long-term and short-term effectiveness. Long-term effectiveness is most frequently based on an evaluation of the residual risk posed by a site after remediation is complete. Short-term effectiveness often includes an assessment of the risks of implementing a remedy, such risks as vapor emissions during excavation of waste materials. Finally, the 1990 NCP identifies two modifying criteria: public acceptance and state acceptance.

Developing Cleanup Criteria

If remediation at a site is deemed necessary, cleanup criteria must be identified that represent an ''acceptable'' level of residual concentrations in the affected environmental media. Cleanup levels may be established by (1) relying on environmental quality standards from applicable or relevant statutes, such as maximum contaminant levels (MCLs) in drinking water; (2) setting levels equal to local background concentrations or analytical detection limits; or (3) using risk assessment methods to determine concentrations that are protective of human health and the environment, given reasonably expected land use or institutional controls that might be considered.

Risk-based cleanup levels are usually developed using the basic methodologies and assumptions applied in the baseline risk assessment. Often, cleanup levels are ''back-calculated'' to correspond to an overall risk goal for a site. This is achieved by setting chemical-specific cleanup levels equal to chemical concentration believed to have no adverse effect on human health or the environment, and which pose an ''acceptable'' or ''insignificant'' cancer risk.

There are several advantages to a risk-based approach for establishing cleanup target levels. First, risk assessment provides a scientifically defensible and increasingly standardized method for establishing cleanup levels that are protective of human health and the environment. In contrast, the use of standards from relevant statutes may yield cleanup levels that are either not sufficiently protective or are overly stringent and wasteful of limited resources. While the uncertainties of the risk assessment process can be considerable, it provides a rational basis for setting consistent cleanup goals.

Furthermore, the risk assessment approach permits establishment of target cleanup levels appropriate to the actual current or anticipated future use of a site. A site that is expected to remain in industrial use and is located in a heavily industrial area need not be cleaned to the stringent levels appropriate for a residential area. Such distinctions allow for available resources to focus on conditions posing the greatest public health risk.

In developing risk-based cleanup levels, appropriate concepts of areal and temporal averaging can often be incorporated. As exposure to soils over a period of time would be expected to occur over an area rather than at one particular point location, it is usually appropriate to expect cleanup levels to be met over an exposure area, rather than at every point in the area. Similarly for ground water, because exposure would occur through a well and a well draws ground water from an area rather than a single point in an aquifer, it is typically appropriate for the average ground-water concentration over the well's recharge area to meet the cleanup levels, rather than to require that the cleanup levels necessarily be met at each point in the aquifer.

Evaluating Safety of Remediation Implementation

The risks potentially posed by the implementation of alternative remedies for a site should be considered when evaluating the short-term effectiveness criterion. The risks created by remedy implementation at a site may include exposures to toxic chemicals, accidents associated with use of heavy equipment, heat stress caused by impermeable protective coveralls and use of respirators, and accidents or spills during off-site transportation of hazardous materials. The populations potentially at risk during implementation include on-site workers during site investigations and cleanup; off-site residents and workers in nearby areas; and crops, livestock, and wildlife in the vicinity of the site. In some cases, implementation risks may exceed the long-term risks associated with a no-action remedy.

The NCP and RCRA Subpart S regulations both require consideration of implementation risks in remedy selection at hazardous waste sites. EPA guidance explicitly states that ''alternatives should be evaluated with respect to their effects on human health and the environment during implementation of the remedial action'' (USEPA 1988). The evaluation should include ''any risk that results from implementation of the proposed remedial action such as dust from excavation . . . that may affect human health . . . [and] threats that may be posed to workers'' (USEPA 1988).

Failure to adequately evaluate implementation risks during the remedy selection process can result in unanticipated chemical exposures for workers and nearby residents during cleanup, or in costly delays or abandonment of an incomplete remedy. For example, at a Superfund site in Baton Rouge, Louisiana, excavation of soil containing a variety of volatile organic compounds (VOCs) was abandoned because the associated release of vapors was deemed unacceptable. An in situ remedy that minimized volatile releases was ultimately selected as a more appropriate remedy.

Despite the clear intent of the NCP and the potential importance of remedy implementation risks, many assessments address the risks created by site cleanups only qualitatively, if at all. Implementation risk assessments are beginning to figure more prominently in remedy selection, however. At the Tyson's Lagoon Superfund site in Pennsylvania, the EPA reevaluated its initial Record of Decision (ROD), which specified excavation of contaminated materials. Due in part to the public health risks created by excavation, the EPA issued a revised ROD, which selected a nonintrusive remedy, in situ vacuum extraction. At the Hardage Superfund site in Oklahoma, an evaluation of potential on-site worker and off-site community health risks during remediation weighed heavily in a judge's decision to overturn an EPA ROD based on excavation in favor of a more nonintrusive containment remedy. Risks to workers involving explosions, heat stress, and accidents during excavation were of particular significance in the decision. Implementation risks were also cited as a critical factor by the EPA in selecting a nonintrusive remedy at the McColl Superfund site in California. In fact, it was estimated that the risks created by the EPA's original preferred remedy (excavation and on-site incineration) more than offset any risk reduction offered by that remedy. Thus an in situ, partial solidification remedy was ultimately selected.

Development of Postremediation Monitoring Plans

The nature of risks posed by a site should also be considered during development of postremediation monitoring plans. A ground-water monitoring plan developed in response to short-term risks from fluctuation of concentrations above a certain threshold is likely to require more frequent samples for specific contaminants than one driven by cumulative risk from many years of exposure. Additional risk-related factors to consider when identifying the sampling frequency requirements in a ground-water monitoring program include proximity to downgradient receptors, the rate of flow in the aquifer, and whether large seasonal changes occur in the ground-water system (USEPA 1996b). Risk assessment can also narrow the scope of each sampling event so that analyses are more cost-effective, i.e., are focused on those contaminants that contribute the most to risk.

CASE STUDIES

Use of Risk Assessment to Update Remedy Decisions

For a Superfund site located in the northwest, a Remedial Investigation including a baseline risk assessment and a Feasibility Study were completed in the early 1990s. Historical activities at the site included operation of a chemical plant and landfilling. The site is currently zoned for industrial use, and an active manufacturing facility is located on a portion of the property. Following the Feasibility Study, the EPA issued an ROD specifying numerical cleanup standards, for site chemicals in soil and ground water, that were based directly on risk estimates from the baseline risk assessment. Several assumptions made during the risk assessment process (including assumed future residential development of the entire site) contributed directly to the extremely low cleanup standards identified in the ROD. Concerns regarding the technical practicability of achieving (or even measuring) the selected cleanup levels have been raised, and an ROD amendment may be required.

In the time since the ROD was issued, a substantial amount of new characterization data have been collected at the site. The EPA has also updated toxicity values and physical/chemical property data for many chemicals, and issued major new guidance documents, particularly in the areas of exposure assessment and risk characterization. As a result the risk estimates presented in the baseline risk assessment, and the cleanup goals based on that assessment, are no longer consistent with current understanding of site conditions, or with current risk assessment science and policy. At the EPA's request, a revised baseline risk assessment was prepared with the intent to reevaluate the remedy decision and cleanup targets for the site.

One of the key differences between the original baseline risk assessment and the revised assessment is the assumed future land use at the site. The earlier assessment was based on the conservative assumption that future land use would be residential, and accordingly estimated risks for children and adults living on the property and using the ground water as drinking water. Using the EPA's guidance regarding land use assumptions (USEPA 1995), a detailed evaluation of future land use was performed as part of the revised baseline risk assessment. This evaluation, which was accepted by the EPA, supported a conclusion that future land use at the site would remain industrial. The revised assessment therefore evaluates on-site chemical concentrations in the context of worker exposures rather than residential exposures, and estimates lower site-related risks.

The relative contribution of individual chemicals to risk estimates has changed significantly, due in part to additional sampling data, but also due to the use of refined toxicity information. For example, polycyclic aromatic hydrocarbons (PAHs) were key risk drivers in the original risk assessment (that is, they comprised a majority of the total risk estimate for certain exposure pathways). Specific toxicity criteria have not been developed by the EPA for many of the individual PAHs. This data gap was resolved in the original assessment by assuming that all PAHs had the same toxicity as benzo(a)pyrene, the most toxic form of PAH at the site. Subsequent USEPA guidance (USEPA 1993) has estimated the potencies of several PAHs to be 10 to 1,000 times lower than that of benzo(a)pyrene; by using these toxicity data, the calculated risks from PAHs dropped dramatically.

The relative contribution of exposure pathways to total risk estimates has also changed significantly. In the original assessment, risks from dermal exposure to soil and ground water comprised 75% of the total cancer risk, as compared with 19% from ingestion or 5% from inhalation. All chemicals in the original risk assessment were assumed to be 30% absorbed from soil, and most were assumed to have a permeability (Kp) of 1.0 cm/h. Subsequent EPA guidance (1992b) has identified chemical-specific Kp values that are often lower by up to several orders of magnitude. The same guidance identifies a dermal absorption fraction from soil of 6% for PCBs, another risk driver at the site. In the revised risk assessment, the dermal exposure pathways are estimated to represent only 20% of the total risk.

Overall, revised risk estimates are five to over 1,000 times lower than were previously estimated. These reduced risk estimates, along with the assumption of future industrial land use, allow for the development of more achievable cleanup targets that are still protective of human health and the environment.

USE OF RISK ASSESSMENT IN EVALUATING REMEDY IMPLEMENTATION RISKS

The remedy originally selected by the EPA for a Superfund site located in the western United States incorporated the following components: (1) Excavation of between 97,000 and 266,000 cubic yards of waste and soil; (2) on-site incineration of all excavated material; and (3) on-site or off-site disposal of solid residues from the incinerator. This remedy was initially selected by USEPA largely because it included significant treatment of contaminated materials. However, the short-term risks of excavating, incinerating, and transporting the waste and soil were not quantified by the EPA in selecting the original remedy.

An evaluation of the remedy alternatives, comparing costs, off-site community risks, and risks to workers implementing each remedy was eventually undertaken by the Potentially Responsible Parties (PRPs) at the site. The types of worker risks evaluated included exposure to toxic chemicals; heat stress and heat stroke; direct physical injuries and fatalities in construction-related accidents; exposure to high levels of noise; and fire, explosion, and electrical hazards.

Off-site community risks were calculated by summing estimated chemical exposures during remediation, with potential postremediation exposures. When costs for each remedy were graphed alongside the total off-site community risks (Fig. 3), it was apparent that the original remedy was significantly more expensive than the other alternatives but did not provide significant benefits in risk reduction. In fact, not only was the original remedy the most expensive considered, it also posed greater overall risks than any of the alternatives except ''No Action.'' The original excavation/incineration remedy was subsequently withdrawn by the EPA, largely due to the potential community and worker risks. The EPA ultimately selected

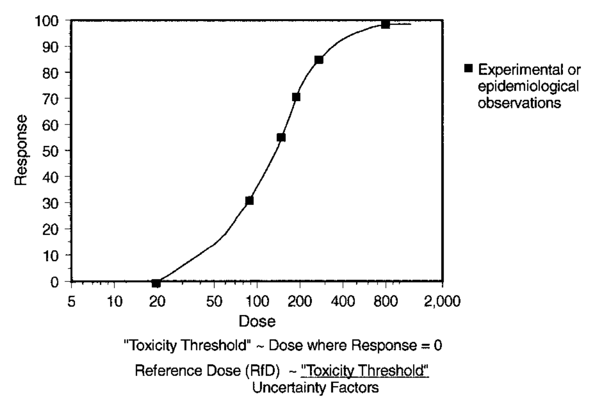

FIG. 3. Estimate of Costs and Off-Site Community Risks

an in situ partial solidification remedy, with a cost reduction of over $140,000,000.

APPENDIX. REFERENCES

National Academy of Sciences. (1983). *Risk assessment in the Federal Government: Managing the process*. National Academy Press, Washington, D.C.

NJDEP. (1994). ''Future land use: A key consideration in remedy selection.'' *Site Remediation News*, 6(4), 1–2.

''Standard guide for risk-based corrective action applied at petroleum release sites.'' (1995). *E 1739-95*, ASTM, West Conshohocken, Pa.

USEPA. (1988). ''Guidance for conducting remedial investigations and feasibility studies under CERCLA.'' *OSWER Directive 9355.3-01. EPA/540/G-89/004*, Environmental Protection Agency, Washington, D.C.

USEPA. (1989). ''Risk assessment guidance for Superfund, volume 1: Human health evaluation manual (part A). ''*Interim Final. EPA/540/1-89/002*, Environmental Protection Agency, Washington, D.C.

USEPA. (1990). ''National oil and hazardous substances pollution contingency plan. ''*Final Rule, Fed. Reg., 55(46), 8666–8865*, Environmental Protection Agency, Washington, D.C.

USEPA. (1991a). ''Role of the baseline risk assessment in Superfund remedy selection decisions.'' *OSWER Directive 9355.0-30*, Environmental Protection Agency, Washington, D.C.

USEPA. (1991b). ''A guide to principal threat and low level threat wastes.'' *Superfund Publication: 9380.3-06FS*, Office of Solid Waste and Emergency Response, Environmental Protection Agency, Washington, D.C.

USEPA. (1992a). ''Guidance on risk characterization for risk managers and risk assessors.'' *Memorandum from F. Henry Habicht II (Deputy Administrator) to Assistant Administrators and Regional Administrators*, Environmental Protection Agency, Washington, D.C.

USEPA. (1992b). ''Dermal exposure assessment: Principles and applications.'' *Interim Report*, Environmental Protection Agency, Washington, D.C.

USEPA. (1993a). ''Risk assessment: Selecting exposure routes and contaminants of concern by risk-based screening.'' *Region III technical guidance manual*, Environmental Protection Agency, Washington, D.C.

USEPA. (1993b). ''Provisional guidance for quantitative risk assessment of polycyclic aromatic hydrocarbons.'' *EPA/600/R-93/089*, Office of Research and Development, Environmental Protection Agency, Washington, D.C.

USEPA. (1995). ''Land use in the CERCLA remedy selection process.'' *OSWER Directive No. 9355.7-04*, Environmental Protection Agency, Washington, D.C.

USEPA. (1996a). ''Soil screening guidance: User's guide.'' *EPA/540/R-96/018*, Environmental Protection Agency, Washington, D.C.

USEPA. (1996b). ''Superfund reforms: Updating remedy decisions.'' *EPA540/F-96/026*, Environmental Protection Agency, Washington, D.C.

USEPA. (1997). Rules of thumb for Superfund Remedy Selection. *EPA 540-R-97-013. OSWER 9355.0-69*, Office of Solid Waste and Emergency Response, Environmental Protection Agency, Washington, D.C.