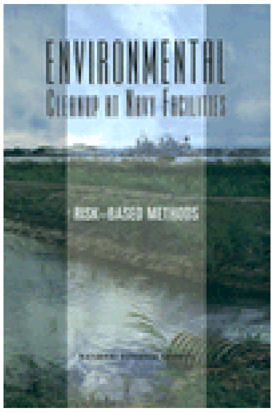

Environmental Cleanup at Navy Facilities: Risk-Based Methods

Committee on Environmental Remediation at Naval Facilities, National Research Council

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THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

ENVIRONMENTAL
CLEANUP AT NAVY FACILITIES

Risk-Based Methods

Committee on Environmental Remediation at Naval Facilities

Water Science and Technology Board

Commission on Geosciences, Environment, and Resources

National Research Council

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Preface

> *"I have yet to see any problem, however complicated, which, when you looked at it in the right way, did not become still more complicated."*
>
> *Poul Anderson, New Scientist (London, Sept. 25, 1969)*

Under the auspices of the Water Science and Technology Board (WSTB), the National Research Council (NRC) established the Committee on Environmental Remediation at Naval Facilities in 1997. The NRC chose 15 experts to serve on the committee for the purpose of studying issues associated with the remediation of contaminated soil, sediment, and ground water at Navy facilities. The committee was initially established to provide guidance on the following three main areas pertinent to characterization and remediation of Navy facilities:

1. *Risk-Based Methodologies.* What are the strengths and weaknesses of risk-based methodologies for cleaning up contaminated sites, including (but not limited to) the Risk-Based Corrective Action standard (RBCA) devised by the American Society for Testing and Materials? How should such a methodology be implemented at Navy facilities?
2. *Innovative Technologies.* What innovative technologies are appropriate to assist the cleanup efforts at Navy facilities?
3. *Long-Term Monitoring.* For Navy facilities that will not be able to meet regulatory standards for cleanup in the near future, what guidance can be given for establishing and maintaining long-term monitoring at such sites?

The project was supported by the U.S. Navy with the stipulation that the three study topics listed above would be funded incrementally. This report reflects the outcome of the first year of committee deliberations that addressed risk-based methodologies (Task 1 above). The committee saw as its goals to provide a review of existing risk-based methodologies, a description of their strengths and weaknesses, and a set of recommendations on how the Navy should proceed.

The Navy did not ask the committee to review methods they are currently using to comply with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The committee was also not asked to review the Relative Risk Site Evaluation Framework, which is a risk-based framework for requesting and distributing cleanup funds in the military. Consequently, the committee did not view as its role the task of suggesting improvements to the approach the Navy is currently using and did not deliberate on how to improve the CERCLA process. The committee discussions focused on risk-based methods not currently being used by the Navy that may offer cost and time savings. Navy personnel indicated that they were interested in a methodology that could encompass all of their sites, from petroleum underground storage tanks to more recalcitrant types of contamination.

The committee undertook a thorough evaluation of the use of risk-based methodologies for managing current soil and ground water cleanup efforts. During four meetings held over nine months, the committee gathered information from expert presentations to the committee, field trips to three Navy facilities, and dialogue with Navy personnel. The committee also relied on the in-depth experience and expertise of the committee members, who are recognized leaders in environmental engineering, hydrogeology, soil science, geochemistry, ground water modeling, statistical sampling of ground water, toxicology, risk assessment, law, public health, and public participation/stakeholder involvement. Although the committee members represented a diversity of opinions and backgrounds, we were able to reach a consensus on almost all issues. The quote from Poul Anderson above is an accurate reflection of the experiences of this committee. The Navy, like most if not all responsible parties, would like to see a simpler solution to its cleanup problems. However, the committee agreed that site cleanup and maintaining an acceptable risk at a site are both complex and difficult issues. The uncertainties associated with leaving contamination in place and the uncertainties in source, pathway, and receptor characterization led the committee to develop eleven criteria that a risk-based approach must fully satisfy to address Naval hazardous waste sites. The document that follows is the culmination of our initial efforts to help the Navy solve problems in its Environmental Restoration Program. Although the committee discussed the additional time and costs that would be necessary to implement its recommendations, these issues were not quantitatively evaluated.

This report has been reviewed, in accordance with NRC procedures, by individuals chosen for their expertise and broad perspectives on the issues addressed herein. These independent reviews provided candid and critical comments that assisted the authors and the NRC in making the published report as sound as possible, and they ensured that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The content of the review comments and the draft manuscript remain confidential to protect the integrity of the deliberative process. The committee wishes to thank the following individuals for their participation in the review of this report and their many instructive comments: Patrick Atkins, Aluminum Company of America; Anthony Grey, New York State Department of Health; Theodore Henry, Community Health Assessment & Public Participation Center; Michael Kavanaugh, Malcolm Pirnie, Inc.; Paul Kostecki, University of Massachusetts at Amherst; Philip LaMoreaux, P. E. LaMoreaux and Associates, Inc.; Joel Massmann, University of Washington; and William Walsh, Pepper Hamilton LLP. While the individuals listed above have provided many constructive comments and suggestions, responsibility for the final content of this report rests solely with the authoring committee and the NRC.

Special thanks must go to several individuals who contributed to the committee's overall effort in so many ways. First, a great share of appreciation must go to Laura Ehlers, the NRC Staff Officer for this project. Laura put forth a great deal of effort in coordinating the committee meetings, gathering information, preparing copious minutes of the meetings, and reminding the committee members of their duties and responsibilities. Laura actively participated in the committee discussions, offered insightful comments and input, and demonstrated considerable editing skills in preparing and extensively rewriting significant sections of the report. We owe much of the credit for the success of this report to Laura. Second, much appreciation also goes to Jackie MacDonald. Jackie is the associate director of the WSTB and assisted the committee with this project by actively participating in the meetings, providing background details on the evolution of the study, and writing sections of the report. Jackie's positive feedback of the committee's progress during these past nine months is appreciated. Third, the committee extends its appreciation to Kim Swartz who, as project assistant, provided the essential administrative support associated with the committee effort. Fourth, the committee thanks Steve Eikenberry, director of the Environmental Restoration Division of the Naval Facilities Engineering Service Center, for his role as the Navy liaison. The committee benefited from Steve's insight into the problems and needs of the Navy with respect to environmental remediation. Fifth, I thank Gene Parkin who assisted me as vice-chair. Gene's attention to details, timeliness, and positive spirit are much appreciated.

Finally, I would like to thank the committee members, who devoted many long hours to this project. I have enjoyed immensely the opportunity to work with such a talented and articulate group of professionals. They provided a stimulating environment for addressing the study issues. I especially appreciate their willingness to spend time researching, writing, and revising their contributions. I believe the results of their efforts will provide useful guidance for some of the environmental restoration challenges of the Navy, which should also be relevant to a broader universe of sites and facilities.

EDWARD J. BOUWER, *Chair*
Committee on Environmental Remediation of Naval Facilities

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Executive Summary

Activities of the U.S. Navy over the past century have had substantial impact on the environment. Some of the most significant environmental liabilities the Navy is facing are the 4,448 waste sites at Navy installations across the country. At almost every active and closing Navy base, soils, sediment, or ground water have been exposed to chemical contamination to some extent. At large facilities, there may be as many as 100 individual sites requiring remediation. Cleaning up these sites is a major goal of the Navy's Environmental Restoration Program.

Contaminants and site conditions at Naval facilities are highly variable, with such recalcitrant compounds as metals, chlorinated solvents, and hydrophobic organic chemicals being common concerns. Cleanup efforts involving these contaminants can be frustrating, time consuming, and expensive, and sometimes can have limited results in terms of contaminant removal. Thus, the Navy requested the National Research Council (NRC) to examine how the Navy can speed up the pace of cleanup activities and lower the overall cost of the Environmental Restoration Program. This report presents the results of the first phase of the NRC study, which focused on the use of risk-based methodologies for increasing the speed and cost-effectiveness of the Navy's environmental remediation projects.

Approximately 66 percent of the Navy's hazardous waste sites are subject to regulation under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Because the average time for construction of a cleanup remedy is 10.6 years, the CERCLA process is perceived by many as slow and costly. The following problems are partially responsible for this general impression: (1) the way CERCLA is conducted, (2) complex contaminant and site characteristics, (3) unstructured risk management decision making, (4) a lack of technological solutions to address the contamination, and (5) disagreements among responsible parties, regulatory authorities, and surrounding communities. Because the bulk of cleanup time is spent on initial site characterization, the impression of responsible parties, such as the Navy, is that although money is being spent, little actual cleanup is occurring.

Limited financial resources and the inability of remedial technologies to achieve background concentrations have increasingly forced environmental managers to reconsider the concept of resource conservation (that is, restoration of sites to near-natural conditions) as the guiding principle for site restoration. There has been a shift toward considering overall reduction of risk to humans and the environment as the main driver for remediation. At the time of the Navy's request for guidance from the NRC, several studies and other efforts were under way to evaluate the use of risk-based methodologies for cleaning up waste sites. In particular, in 1995 the American Society for Testing and Materials (ASTM) released a risk-based methodology known as Risk-Based Corrective Action (RBCA) Applied at Petroleum Release Sites ("petroleum RBCA"). ASTM RBCA is being rapidly adopted by many states for cleanup of leaking petroleum underground storage tanks. A second ASTM RBCA standard guide, for contaminants other than petroleum hydrocarbons, has also been developed ("chemical RBCA"). Encouraged by RBCA's growing role in cleanup programs, the Navy asked the NRC to evaluate ASTM's standard guides and suggest whether those methodologies, or a similar but simpler approach, could be used to rapidly close out Navy sites. This report examines how risk-based cleanup operates under CERCLA and whether other methodologies can appropriately expedite the cleanup process.

REVIEW OF RISK-BASED METHODOLOGIES

The committee focused its review of risk-based methodologies on the ASTM RBCA standard guides and the CERCLA process (as described in numerous EPA documents) for two reasons: (1) although not the only approaches available, they are the most widely used and (2) most other methodologies investigated did not differ appreciably from those of the EPA and ASTM. Other frameworks considered by the committee included the Air Force's Enhanced Site-Specific Risk Assessment, the EPA Science Advisory Board's Integrated Risk Project, the Lawrence Livermore National Laboratory/University of California methodology, and numerous state variations on the practices and methods of ASTM and the EPA.

EPA Risk-Based Methodologies

Because most Navy sites are regulated under the CERCLA cleanup process, CERCLA is the standard to which all other methodologies should be compared. During the initial phase of CERCLA, a preliminary assessment and a site inspection are conducted to collect data and determine the need for further cleanup action. If contamination is found, a detailed remedial investigation (RI) is conducted, which involves further site characterization and the elucidation of potential exposure pathways. During the RI, human health and ecological risk assessments are conducted, using procedures outlined in the EPA's Risk Assessment Guidance for Superfund (RAGS). Estimates of risk are determined using models of contaminant fate and transport and human and ecological exposure to those contaminants. When the risk estimate is greater than a specified acceptable risk level, RAGS can be used to develop preliminary remediation goals.

For soil contamination only, the EPA has developed the Soil Screening Guidance for closing out low risk sites and arriving at preliminary remediation goals. The Soil Screening Guidance is a tiered approach during which site data are compared to either generic or site-specific screening levels. If concentrations are below the screening levels, the screening process ends, and a site can most likely be closed with no further action. If concentrations are above screening levels, then additional data collection is performed to generate more site-specific cleanup levels.

Information from the RI, including the results of all risk assessments and preliminary remediation goals derived from RAGS or the Soil Screening Guidance, is used to conduct a feasibility study to determine the ultimate remedy. During the feasibility study, alternative remedial measures are identified, evaluated, and compared. Although the EPA does allow for a combination of remedial options, it has a preference for options that focus on removal of contaminant sources. The final stages of the CERCLA process include maintaining engineering and institutional controls and conducting long-term monitoring.

ASTM RBCA Standard Guides

Like the EPA's Soil Screening Guidance, both of ASTM's RBCA standard guides (for petroleum release sites and for sites containing other chemical contaminants) are based on a tiered approach for evaluating the risk of waste sites. However, unlike the Soil Screening Guidance, ASTM RBCA uses the tiered approach for all types of contamination and contaminated media.

The first phase of ASTM RBCA is an initial site assessment to gather information about the chemicals of concern (sources), the migration pathways of the contaminants (pathways), and potential human and ecological receptors (receptors). This information allows an initial classification of the risk posed by the site and can direct emergency response actions.

A tier 1 evaluation then commences, during which the concentrations of contaminants at the site are compared with generic, conservative cleanup levels. If the contaminants are present in amounts greater than the tier 1 cleanup levels, then either the site can be cleaned up to reduce the concentrations of the contaminants to below those levels, or a tier 2 evaluation can commence to better characterize the site and develop site-specific cleanup levels.

At tier 2, additional site characterization is conducted to generate more site-specific and less conservative cleanup goals. These goals are the result of risk assessment calculations that take into account an acceptable risk level, models of fate and transport, and models of human and ecological exposure to contamination. ASTM RBCA recommends use of mathematical models similar to those found in RAGS. Contaminant concentrations are compared to the site-specific cleanup levels, and a choice is made to either close the site, clean the site to the site-specific cleanup levels, or proceed to a tier 3 evaluation. Tier 3 contains an additional layer of complexity as more refined site-specific cleanup levels are generated for comparison to contaminant concentrations.

Throughout ASTM RBCA, the chosen path is determined by comparing the cost of cleaning the site to the cost of data collection necessary for the higher tiers. Tier evaluations are followed by remedial actions, which eventually lead to closure of the site. Under the ASTM RBCA methodology, the remedy may include a combination of removal actions, treatment technologies, engineering controls, and institutional controls.

A committee survey of 20 state regulatory agencies indicated that the use of risk-based methodologies is increasing, primarily for the cleanup of petroleum hydrocarbons but also for more recalcitrant compounds. In many cases, these methodologies are state-customized versions of the petroleum RBCA standard guide. As explained further in Chapter 2, most of the states have started developing the appropriate tools that will enable them to fully implement risk-based approaches. However, the states will require further guidance on issues such as natural attenuation, ecological risk assessment, and the use of institutional controls.

STRENGTHS AND WEAKNESSES OF RISK-BASED METHODOLOGIES

Risk-based approaches to environmental remediation have certain inherent strengths and weaknesses compared to resource conservation and technology-based approaches, which focus on source removal. These strengths and weaknesses, which must be considered prior to the implementation of risk-based approaches, are manifested differently in the EPA and ASTM methodologies. In general, ASTM RBCA focuses less on source removal than CERCLA.

Strengths of Risk-Based Approaches

Risk-based approaches tend to be systematic in order to characterize sites and quantify the risks they pose. This organizational structure is often embodied in a tiered approach. In order to be protective of human health and the environment, risk-based approaches depend on extensive data collection and site characterization. The risk assessment calculations that are part of such approaches are based on scientific descriptions of contaminant transport and human and ecological exposure and can incorporate new information as it becomes available. Risk-based approaches allow prioritization of contaminated sites based on their relative risk, which can, in turn, aid in the allocation of resources. For example, money can be spent on sites that pose the highest risks, or at sites where the greatest risk reduction per dollar is achievable.

Weaknesses of Risk-Based Approaches

Risk-based approaches are more likely than resource conservation or technology-based approaches to result in remedies that leave contamination in place. This can be problematic if there are unidentified, potentially dangerous contaminants remaining on site, or if the behavior of known contaminants is poorly characterized. Remedies that leave contamination in place often rely on institutional controls, which, for both legal and physical reasons, are very difficult to enforce. Risk-based approaches may also discourage the development of innovative technologies for source removal.

The greater potential for leaving contamination in place introduces significant uncertainties into any risk-based approach. Quantifying the sources of contamination, the pathways of contaminant migration, and the potential receptors generates significant uncertainty, much of which cannot be reduced. If recalcitrant contaminants are involved, such as chlorinated solvents and metals, uncertainties increase dramatically, because less is known about the toxicological effects, the bioavailability, and the fate and transport of such contaminants in comparison to petroleum hydrocarbons. There are also inherent uncertainties in the effectiveness of remedial options, including treatment systems, engineering controls, and institutional controls. Technological solutions are often uncertain because of unknowns about how well a particular technology will work at a given site. The effectiveness of institutional controls has also not been well established. Chapter 4 of this report discusses methods for quantifying and reducing uncertainties associated both with risk assessment and risk management.

Comparing the Elements of ASTM RBCA and CERCLA

As part of this study, the committee compared the characteristics of the ASTM RBCA and CERCLA methodologies. For the most part, the two approaches are remarkably similar. One procedural difference is that with the ASTM methodology remedial options are available earlier in the process, and the tiered approach is used for all types of contaminated media. There is a general perception that ASTM RBCA is faster, less costly, and more user friendly than CERCLA. Finally, CERCLA received more public input during its design and requires more public involvement during implementation than is inferred in the ASTM RBCA guidance documents.

Strengths and Weaknesses of ASTM RBCA

The strengths and weaknesses of a generic risk-based methodology are more evident in the ASTM RBCA methodology than in the CERCLA process. The tiered approach of ASTM RBCA is highly systematic and can make a large number of diverse sites more manageable. The prioritization of sites is facilitated in both standard guides by a table that categorizes sites into four initial risk levels. Although there is disagreement over the level of site characterization needed for a tier 1 analysis, extensive data collection is required at tiers 2 and 3.

There are other important strengths of the ASTM standard guides. ASTM RBCA may accelerate the cleanup process and expedite site closure because (1) management options, including remedial options, are available during each tier evaluation, (2) it allows the use of institutional controls, which are perceived as requiring minimal cleanup effort, and (3) the assessment procedures are standardized for all types of contaminated sites. The petroleum RBCA standard guide's streamlined documentation has facilitated its comprehension and adoption by both states and industry professionals.

The ASTM RBCA methodology suffers from the weaknesses inherent in any risk-based approach. Because many remedial options available under ASTM RBCA leave contamination in place, the threat of unidentified compounds posing a risk to receptors remains. Petroleum RBCA does not discuss long-term risk and the need to revisit sites if new sources of contamination are found. Chemical RBCA is generally more cognizant of long-term risks, but it contains a provision that might allow sites to be closed prior to a tier 1 evaluation. The treatment of uncertainty in ASTM RBCA is minimal and inadequate, particularly at tiers 1 and 2. Uncertainty regarding the effectiveness of remedial options is not discussed at all.

Finally, there are weaknesses specific to ASTM RBCA irrespective of risk-based approaches. Insufficient consideration is given to the cumulative effects of multiple contaminants and multiple exposure pathways. There is also significant potential for inappropriate application of the methodology. Although not the intention of its designers, the example risk assessment calculations printed in the standard guide, which are intended to serve only as illustrations, have the potential to be inappropriately used during implementation of ASTM RBCA. Petroleum RBCA does not promote public involvement at an early stage in the cleanup process, although this is somewhat corrected in chemical RBCA. Finally, like other ASTM voluntary standard guides, both ASTM RBCA standard guides were designed and approved by a limited group of stakeholders.

Strengths and Weaknesses of the CERCLA Process

The CERCLA process promotes extensive site characterization and relies on scientifically developed risk assessment calculations. However, CERCLA is not as obviously systematic as ASTM RBCA. The tiered approach, which provides organization for examining large numbers of sites, is available only for certain types of soil contamination. Generic soil and ground water screening levels developed by the states do not necessarily impart greater consistency to the CERCLA process. CERCLA does not provide an easy means for prioritizing sites for further action. The Hazard Ranking System, used to determine whether properties should be placed on the National Priorities List, does not distinguish the relative risk between sites on a property. Thus, to some degree, the CERCLA process manifests fewer of the strengths of a generic risk-based approach than the ASTM methodology.

CERCLA has a long history of use in environmental remediation at federal facilities and is familiar to Navy remedial project managers. Public involvement occurs at explicit stages of the CERCLA process, which is important for ensuring acceptance of the remedial option. Because CERCLA was generated through a legislative process, it is less likely to be tied to any special interest other than environmental protection. Thus, the public may perceive CERCLA as providing the best assurance of long-term commitments, such as the maintenance of long-term monitoring and institutional controls.

As one might expect, CERCLA manifests fewer of the weaknesses of a generic risk-based methodology. This is because CERCLA has a strong preference for removing sources of contamination rather than relying on engineering and institutional controls. Thus, the threat of unknown contamination and contamination remaining in place is considerably lessened at sites using the CERCLA process. The EPA acknowledges the importance of uncertainty during the risk assessment process, although there is still minimal guidance on how to quantitatively incorporate uncertainty into the CERCLA process.

ELEVEN CRITERIA FOR A RISK-BASED METHODOLOGY

The committee's evaluation of CERCLA, ASTM RBCA, and other risk-based methodologies illuminated many important features of risk-based approaches, both positive and negative. After comparing these evaluations to the pressing environmental problems faced by the Navy, the committee identified 11 criteria that it believes should be necessary components of any risk-based approach adopted by the Navy.

1. It should facilitate prioritization of contaminated sites at individual installations. The ability to rank sites according to their relative risk is especially important at facilities that have multiple waste sites, as at Navy installations and other federal facilities. Ranking of sites can help determine which sites pose immediate threats to human health and the environment, which sites should be cleaned up first, and where to allocate funding. Prioritization does not have to occur with the same risk assessment and risk management paradigms that characterize the complete methodology. However, data collected for prioritization should be useful in the larger risk framework.

2. It should provide a consistent mechanism for addressing all types of sites. Because Navy facilities include both simple low risk sites and complex high risk sites, the Navy's risk-based methodology must include a systematic approach for conducting site investigations of differing complexity. In facilitating the evaluation of sites ranging from simple to highly complex, both conservative, generic cleanup goals and less conservative but more site-specific cleanup goals should be allowed. Site-specific cleanup goals should be allowed to replace conservative cleanup goals for well-defined contamination problems. To provide equivalent protection for poorly-defined contamination problems, generic cleanup goals should reflect a level of conservatism consistent with the lack of knowledge about the site.

3. It should provide guidance on data collection needed to support the development of site-specific cleanup goals. Because risk-based approaches are more likely than resource conservation or technology-based approaches to suggest remedies in which contamination is left in place, extensive site characterization and data collection must accompany their use to ensure protection of human health and the environment. A satisfactory risk-based methodology will provide guidance on data collection methods and data quality objectives. It will suggest ways to conduct an initial site assessment that will aid in prioritization of sites, as well as methods of site characterization that can be used to generate site-specific cleanup goals.

4. It should provide for integrated assessment of sites affecting the same human or ecological receptors. At large facilities containing multiple hazardous waste sites, the risk from exposure to contamination may derive from multiple sources. A risk-based methodology must be able to quantitatively assess all sources that are affecting individual human or ecological receptors. This includes cumulative risk assessment, which evaluates the effects on potential target receptors of multiple chemicals and multiple exposure pathways originating from a single waste site, as well as an "integrated assessment" of sites, which is conducted to determine the overall facility-wide risk encountered by potential target receptors.

5. It should encourage early action at sites where the risk to human health and the environment is imminent and for which the risks are demonstrably low and remediation is likely to be more rapid and inexpensive. The risk-based methodology should allow for source removal action and pathway interruption to eliminate risk to potential receptors before the remedial option has been chosen. It should facilitate rapid action at sites that are easy and inexpensive to remediate, as defined by the nature of the contaminants present and the affected subsurface. If all contamination is not removed as a result of these early actions, the methodology should evaluate the long-term consequences of removal actions and pathway interruptions through long-term monitoring and, if necessary, further remedial actions.

6. It should consider relevant uncertainties. There is significant overall uncertainty in risk-based approaches to remediation (e.g., model and data uncertainty, lack of understanding concerning ecological risk, uncertainty in dose-toxicity relationships, and doubt regarding the enforceability of institutional controls). This uncertainty directly translates to uncertainty in risk estimates, associated cleanup levels, and the effectiveness of the proposed solutions. The Navy's risk-based methodology should allow for the explicit consideration of these uncertainties and suggest options for reducing them, using both long-term monitoring and formal uncertainty analyses. Uncertainty analyses within the methodology should use stochastic modeling approaches, such as Monte Carlo analysis, to represent the degree of uncertainty associated with the risk estimates. These approaches may generate significant cost savings if they lead to less overestimation of the risk than do conservative cleanup criteria.

7. It should provide a mechanism for integrating the selection of the remedial option with the establishment of remedial goals. It should also provide quantitative tools for developing risk management strategies. Because there are often no technological solutions capable of reducing contamination to background or health-based concentrations, the process by which cleanup goals are set and remedies are selected must be flexible. The risk-based methodology should use an iterative approach during which the responsible party and oversight agencies cycle back and forth between these issues. In addition, the evaluation of multiple remedial options should take place in a quantitative framework to the greatest extent possible. Because short- and long-term effectiveness of the remedy and cost are amenable to quantitative analyses, the Navy's risk-based methodology should contain the appropriate quantitative tools to balance these criteria.

8. It should have options to revisit sites over the long term. Risk-based approaches to managing sites must provide a convincing argument for controlling future risks, both short term and long term. Thus, a risk-based methodology may call for repeated risk evaluations if site conditions change over time. Long-term considerations of risk will enhance the credibility of risk-based approaches with both the regulatory agencies and the affected public.

9. It should be implemented in a public setting with all stakeholders involved. Implementation of a risk-based methodology should take place in a public forum. The science and assumptions used during the risk assessment process, the proposed remedies, and all relevant value judgments must be presented to and understood by interested stakeholders. To facilitate public scrutiny and debate, the methodology must be explicit and traceable.

10. Its guidance document should undergo both external, independent scientific peer review and public review. Any proposed risk-based methodology must be the product of rigorous, broad, and external scientific peer review. In addition, all interested stakeholders must be allowed to review the approach and supporting policies during a public comment period prior to its implementation.

11. It should comply with relevant state and federal statutory programs for environmental cleanup. Any risk-based methodology must comply with relevant laws and regulations. Thus, it must be flexible enough to incorporate the different regulatory policies of the states and the EPA.

Comparing ASTM RBCA to the Eleven Criteria

The ASTM RBCA methodologies, as strictly interpreted from the guidance documents, minimally satisfy only five of the eleven criteria outlined above. ASTM RBCA is able to prioritize sites by risk and thus meets the first criterion. Ranking of sites takes place during the initial site assessment and leads to site classifications of immediate threat, short-term threat, long-term threat, or no demonstrable threat. The tiered approach of RBCA provides a mechanism for addressing all site types and for replacing conservative cleanup goals with site-specific cleanup goals, and thus this process meets the second criterion. Generic standards are used for tier 1 cleanups, while tiers 2 and 3 require site-specific data. Data collection and site characterization are addressed in the ASTM documents, particularly in the chemical RBCA standard guide. However, guidance on monitoring methods, minimum sample size, and method performance criteria is lacking. Therefore, the ASTM methodology minimally satisfies the third criterion. ASTM RBCA allows for source removal actions and actions to interrupt pathways of contaminant migration, meeting the fifth criterion. Once an early action is completed, the user returns to the main cleanup process. This ensures that early actions do not lead directly to site closure. The seventh criterion is partially satisfied by ASTM RBCA, which allows for flexibility in the setting of cleanup goals and the selection of remedial options. During each tier evaluation, either remedial action can be taken or more site-specific cleanup goals can be generated. The RBCA methodology does not provide a quantitative framework for analyzing the cost and effectiveness of different remedial options.

The ASTM RBCA methodology does not satisfy six of the eleven criteria. Although chemical RBCA calls for cumulative risk assessment during a tier 2 evaluation, it does not require an integrated assessment of all sites affecting individual receptors and consequently does not satisfy the fourth criterion. The ASTM RBCA methodology does not sufficiently consider uncertainty in the data and the modeling used in the risk assessment process, a requirement of the sixth criterion. The ASTM RBCA approach to modeling is inherently deterministic and ignores the uncertainties associated with subsurface and exposure pathway modeling. Monte Carlo analysis, which ASTM RBCA suggests as a part of a tier 3 analysis, should be used for tier 2 sites as well. Finally, none of the uncertainties associated with remedial options are mentioned in ASTM RBCA.

ASTM RBCA's handling of long-term risk varies between the two documents. Petroleum RBCA provides almost no guidance on long-term monitoring, and it does not discuss assessing the long-term risks of a hazardous waste site. Chemical RBCA, on the other hand, clearly states the purpose of long-term monitoring and outlines actions that should be taken if remedial options are ineffective or if there are future changes in land use. However, chemical RBCA contains a provision in its tier 1 evaluation that, depending on its interpretation by the states, might lead to site closure prior to any comparison between site conditions and generic cleanup levels. Thus, neither RBCA standard guide fully satisfies the eighth criterion.

Public involvement is not discussed in the petroleum RBCA standard guide. Chemical RBCA mentions public involvement during the collection of site assessment information, following site classification, and during remedy selection, but public involvement does not appear at explicit points in the RBCA flowchart. The ninth criterion, therefore, is not adequately satisfied by either RBCA standard guide. The ASTM standard guides were created and approved by a limited group of stakeholders consisting of oil and chemical industry representatives, some state regulators, and the EPA (which abstained from voting in favor of chemical RBCA). The RBCA standard guides did not undergo external scientific peer review nor a public review period, and therefore they do not satisfy the committee's tenth criterion. Finally, although the RBCA methodologies outline a framework that encompasses all stages of cleanup, from site discovery to site closure, it is not clear that this framework can be integrated into existing state and federal environmental statutes. Especially for those sites regulated under CERCLA, the use of either RBCA standard guide may present legal and administrative problems for the Navy. Thus, the ASTM RBCA methodology does not satisfy the eleventh and final criterion.

RECOMMENDATIONS

The characteristics of Navy facilities that make them different from other hazardous waste sites include the wide range of activities that generate waste, the large amounts and types of chemicals that have been disposed of, the poor record-keeping associated with hazardous waste disposal, and the rushed time line on which many of the facilities are expected to close. These features of Navy installations require the adoption of a highly flexible, yet protective, risk-based methodology, if one is to be adopted at all. Significant weaknesses of existing risk-based methodologies prevent the committee from fully endorsing their use at Navy facilities unless those weaknesses are corrected.

Use of the ASTM RBCA Standard Guides

The committee does not recommend the adoption of either the ASTM petroleum or chemical RBCA standard guides at Navy facilities unless they are modified to satisfy the 11 criteria outlined above. As currently formulated, the ASTM RBCA methodology does not satisfy all of the 11 criteria listed above as characteristics of an effective risk-based methodology. Second, the perceived time and cost savings associated with the use of ASTM RBCA at petroleum underground storage tanks are less likely to accrue to the Navy because of the complexity of its hazardous waste sites. This is especially true for those sites that would have to be evaluated with a tier 3 evaluation. Navy facility cleanups are overseen by a wide range of federal and state regulatory agencies, often with inconsistent environmental policies. The reopening of Federal Facilities Agreements to incorporate RBCA could present legal difficulties and public opposition, and ultimately delay cleanup.

A Risk-Based Approach for the Navy

The committee recommends that the Navy develop a risk-based methodology to be used specifically for its Environmental Restoration Program that satisfies the 11 criteria listed above. These criteria overcome many of the weaknesses associated with the risk-based methodologies evaluated by the committee. In particular, if a risk-based methodology gives sufficient attention to long-term risks, the presence of potentially dangerous unidentified compounds and the use of institutional controls become less problematic. Public trust in such an approach is likely to be greater because of the continued involvement of the responsible party through long-term monitoring and enforcement of institutional controls.

Because of the diversity of Navy facilities and sites in those facilities, the committee recommends developing a broad framework that can be customized for use at individual facilities. A possible starting point for constructing this framework could be the ASTM RBCA methodology, but this is not a requirement. The framework should be pilot tested at a single facility before being adopted on a widespread basis.

The 11 criteria identified as important for any risk-based approach to environmental remediation point to several avenues for further study. First, the process by which the remedial option is chosen requires significant analysis, explanation, and refinement. One possible study could expand on the second statement in the seventh criterion. The goal of this study would be to develop a quantitative analytical tool for evaluating the cost and effectiveness of remedial options. As currently envisioned by the committee, this tool would be based on the paradigm of optimizing risk reduction per dollar spent for a suite of available remedial options.

Another important aspect of a risk-based approach is its ability to assess risk over the long term. Improving long-term monitoring at sites where contamination is left in place will be critical to the use of a risk-based approach at Navy facilities. Techniques that would allow for successful and cost-effective monitoring of the site's responses to natural processes, treatment technologies, containment technologies, and institutional controls should be the focus of such efforts.

Finally, assessing and reducing uncertainties associated with both risk assessment and risk management should accompany the implementation of a risk-based approach to environmental remediation. It will be important for the Navy to develop guidelines aimed at remedial project managers for (1) using more sophisticated analytical techniques during risk assessment, (2) reducing the uncertainty associated with site characterization and treatment technologies, (3) conducting uncertainty analyses when appropriate, and (4) enforcement of institutional controls.

Success Metrics

The committee recommends that the military develop better terminology and metrics of success. Inconsistencies in the language used to describe stages in the Environmental Restoration Program have made it difficult for the Navy to measure the success of its remediation efforts. The military has recently suggested clarifications of terminology for the end stages of the cleanup process, including more precise definitions of the terms "response complete" and "site close-out." The committee recommends that the military reach consensus on processes that use or adapt this terminology. The committee further recommends that project managers—for regulatory agencies as well as the military—be quickly apprised of the terminology and associated goals.

In the committee's opinion, the Navy's Environmental Restoration Program focuses too heavily on "site close-out" as its metric of success. If a risk-based approach is to be developed, the committee recommends that the Navy put more emphasis on "response complete" as the most important metric of success. "Response complete" more adequately addresses progress at sites where contamination remains in place by rewarding the effective operation of the remedial option(s). Such a metric would reward progress toward long-term monitoring, containment, and enforcement of institutional controls, but it would also imply that continued monitoring or other responses may be necessary. Developing improved metrics of success for sites in which contamination remains in place may increase the public acceptability of risk-based approaches to environmental remediation.

In summary, the committee does not fully endorse the ASTM RBCA standard guides for implementation at Navy facilities. However, recognizing that a consideration of risk during environmental remediation can help to better allocate limited resources, the committee suggests 11 criteria that the Navy should incorporate into a risk-based methodology for use at its facilities. These criteria overcome many of the weaknesses of risk-based methodologies in general and afford a level of scientific credibility and protectiveness of human health and the environment appropriate for the Navy's Environmental Restoration Program.

1

Introduction

Over the past two decades, a massive effort has been under way in the United States to remediate sites at which hazardous materials threaten the environment and human health. Two recent National Research Council reports (NRC, 1994, 1997) have documented the magnitude of the problem by describing the sources of ground water and soil contamination, the number of contaminated sites, and types of contaminants commonly found at these sites. The U.S. Environmental Protection Agency (EPA) currently estimates that 217,000 sites exist where soil and/or ground water may require remediation to overcome the adverse impacts of past military, industrial, agricultural, and commercial operations (EPA, 1997). Cost estimates for hazardous waste site remediation over the coming decades range from $187 billion (EPA, 1997) to as high as $750 billion (Russell et al., 1991), depending on the assumptions made.

The main impetus for remediation of waste sites has been the enactment of federal hazardous waste statutes in the late 1970s and early 1980s. The two most noteworthy, the Resource Conservation and Recovery Act (RCRA) of 1976 (42 USC 6901) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 (42 USC 9601), set overarching national soil and ground water cleanup policy by prescribing priorities and decision frameworks. The federal laws establish minimum standards, and most states have adopted their own versions of these laws. Thus, the regulations that are used to enforce environmental laws vary from state to state and may be more prescriptive or more stringent than their federal counterparts (for example, the Washington State version of CERCLA, the Model Toxic Control Act of 1989).

The Navy's cleanup mission is enormous in scope (Figure 1-1). As of September 30, 1997, the Navy's Environmental Restoration Program encompassed

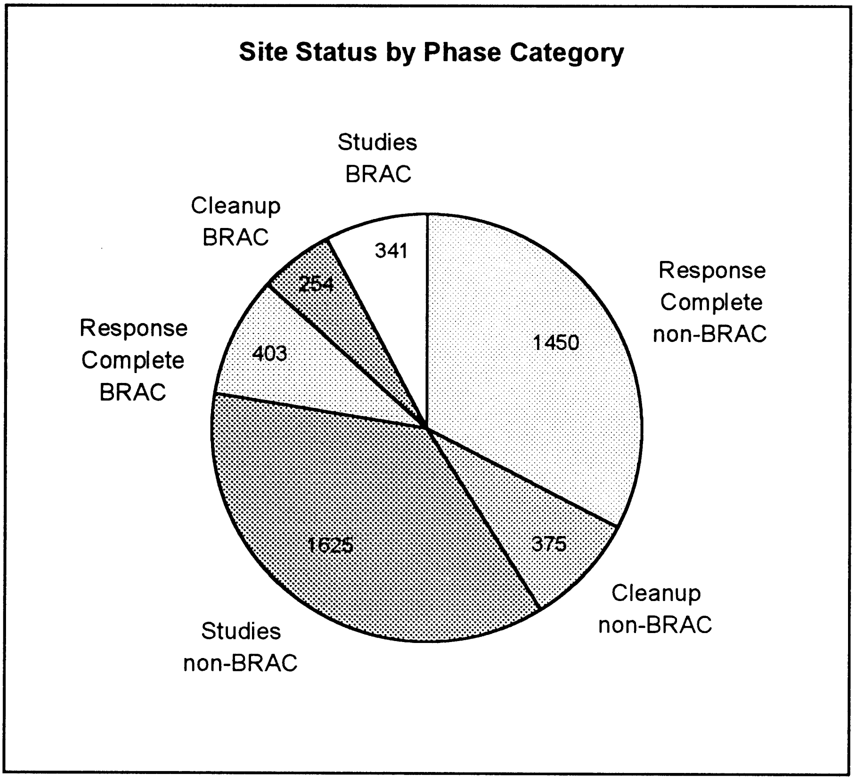

FIGURE 1-1 Department of the Navy sites classified by phase category. "BRAC" refers to the Base Realignment and Closure Act. SOURCE: Department of the Navy, 1998.

4,448 sites at 269 installations throughout 32 states and territories. Of the 4,448 sites, 1,966 sites were in a study phase, 629 sites were being remediated, and 1,853 sites were considered to require no further action. During FY97, the Navy spent a total of $549 million on environmental cleanup activities at its sites.

Of the 4,448 sites identified by the Navy, 998 sites are at facilities slated for closure under the Base Realignment and Closure (BRAC) program. CERCLA requires that the Navy clean up all environmental contamination on property to be transferred to non-federal entities or certify that appropriate remedial actions are in place. There is significant political pressure for property transfer, mainly from the communities in which the bases are located. Community members are eager to maintain the rates of employment that were present during operation of these facilities, while developers and local governments are hoping to capitalize on the large amounts of land that will become available. Cleaning up the closing bases is not only a legal obligation but also a necessity for economic redevelopment of the property. Furthermore, for the sites that have been cleaned up, whether under the BRAC program or at active bases, the Navy faces a major challenge in certifying to regulators, potential purchasers, and lenders that the property is in compliance.

Due to the considerable scientific uncertainties associated with conditions in the subsurface environment, cleanup of contaminated soil and ground water poses a great challenge to the Navy. Remediation of contaminated ground water (which is present at more than 80 percent of Navy sites[1]) under CERCLA and RCRA regulations usually means cleanup to maximum contaminant levels (MCLs) when available. Soil cleanup goals are sometimes based on the most restrictive use of the land, such as residential development. However, achieving these standards may not be practical at many locations due to the inherent complexities of the subsurface and the lack of effective treatment technologies. For example, the 1994 NRC report *Alternatives for Ground Water Cleanup*—the most comprehensive available assessment of ground water remediation—reviewed ground water cleanup systems at 77 sites and determined that regulatory standards had been achieved at only 8 of them. Further, the study found that at 42 of the 77 sites it would be unlikely for regulatory standards to be achieved in the future with conventional technologies. The study provided a matrix for determining the degree of difficulty of cleaning up contaminated ground water based on site hydrogeological conditions and contaminant characteristics. Sites in category 1 are easiest to clean up, while those in category 4 are most difficult.

Navy facilities span the entire range of complexity encountered in ground water and soil cleanup. For example, more than three-quarters of BRAC sites have locations where fuel (petroleum hydrocarbons) has leaked underground. As long as the hydrogeology is relatively simple, these sites belong to categories 1 and 2 in the matrix, which are the easiest to clean up according to *Alternatives for Ground Water Cleanup*. More than half of the BRAC facilities have some locations that are contaminated with chlorinated solvents, a recalcitrant class of compounds that would automatically place a site under category 3 or 4, indicating a difficult cleanup scenario. It is likely that most Navy facilities will include some contamination that can be cleaned up now with available technologies, but it is also likely that alternative management strategies and remedial technology innovation will be required to address the remaining contamination.

Since the costs of remedial measures required to achieve background or other conservative cleanup levels are high, and in many cases no existing technologies have been proven to achieve these low levels (NRC, 1994), alternative policies are being developed for site cleanup. Remediation policy is shifting toward increased use of risk-based decisions to establish cleanup goals and reduce the

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[1] Over 80 percent of all sites evaluated with the Navy's Relative Risk Site Evaluation model involve ground water contamination. These sites are a representative subset of all Navy sites in terms of the types of contamination and contaminated media.

amount of engineering effort required at sites. Short-term monetary cost savings and a swift return of properties to beneficial uses can be gained by using containment, long-term monitoring, and institutional controls to eliminate exposure pathways. This can be attractive when compared to expending huge sums of money on soil and ground water remedial technologies, which often remove only a small fraction of the contamination. However, risk-based approaches may not address harm to the underlying natural resources and may delay actual cleanup, thereby passing the contamination problem on to future landowners. This report evaluates the use of risk-based methodologies for closing waste sites at Navy facilities, recognizing that this approach could result in site management strategies that eventually cause unanticipated harm to human health and the environment.[2]

The introductory chapter of this report provides a brief overview of the current regulatory framework for environmental remediation, the characteristics of the contamination at Navy sites, and the pressing cleanup challenges facing the Navy. The report reviews and critiques risk-based approaches including EPA policies, American Society for Testing and Materials (ASTM) standard guidelines, and individual state regulations. Uncertainties in source, pathway, and receptor characterization are discussed, as are uncertainties in potential remedial options that are critical components of an effective risk analysis. Finally, the report recommends whether to use a risk-based methodology for cleaning up hazardous waste sites. Although this report centers on the environmental restoration challenges of the Navy, many of the challenges facing other potentially responsible parties are similar, and therefore the findings should also be relevant to a broader universe of sites and facilities.

This report was prepared by the Committee on Environmental Remediation at Naval Facilities, which was appointed by the National Research Council to provide guidance to the Navy on how it should cope with the technical challenges and costs surrounding its Environmental Restoration Program. The committee consisted of 15 members having expertise in environmental engineering, hydrogeology, soil science, geochemistry, ground water modeling, statistical sampling of ground water, toxicology, risk assessment, law, public health, and public participation/stakeholder involvement. Members came from academia, government, and the private sector. The committee met four times over a nine-month period to review technical information and deliberate policy issues. In conducting its study, the committee consulted a variety of stakeholders involved in site remediation, including federal and state regulators, managers of contaminated Navy sites, industry groups, and citizen groups.

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[2] Although epidemiological studies involving contaminated sites in the U.S. have not shown widespread acute or chronic health effects in potentially exposed populations (NRC, 1991), current epidemiological tools are not sensitive enough to demonstrate conclusively that there is no association (Bracken, 1997).

THE EMERGENCE OF RISK-BASED APPROACHES

Ground water contamination resulting from human activities has been a problem in the United States for the past 150 years. It was not until the early 1970s that this problem gained nationwide attention. A major catalyst for this increased awareness was the relocation of residents living adjacent to 21,800 tons of waste buried in the Love Canal hazardous waste landfill in Niagara Falls, New York. The waste had the potential to adversely affect the health of hundreds of people, including children at a neighborhood school built at the site. As a direct result of Love Canal, Congress passed CERCLA to clean up abandoned hazardous waste sites across the country. With CERCLA, Congress appropriated $1.6 billion to the cleanup, a sum that gave the law its famous nickname—Superfund. RCRA had been previously passed to prevent shoddy waste disposal practices, and in 1984 it was expanded to include corrective action as well.

Since the passage of these federal laws, environmental remediation of hazardous waste has undergone numerous changes in terms of the goals and expectations of these activities. The philosophy underlying both CERCLA and RCRA was in the tradition of resource conservation, which dictates that sites affected by anthropogenic wastes should be cleaned up to their original pristine condition. This concept, which places inherent value in the soil and ground water, strives for complete cleanup of the resource because it enables unrestricted use of the resource. The motivation for enacting RCRA and CERCLA was not strictly limited to the concept of resource conservation. It also emanated strongly from the risks to human health posed by environmental contamination. However, in the late 1970s and early 1980s, a formal distinction between resource conservation and risk was not made, as it was assumed that any degradation of the environment entailed risk.

RCRA and CERCLA outlined legal frameworks for identifying contaminated sites, assessing the liability associated with the sites, and cleaning them up. It soon became clear that cleanup would be a difficult undertaking. In 1980, there was virtually no proven technology available to clean up contaminated soils and ground water *in situ*. This problem was compounded by the thousands of sites requiring remediation. Although considerable progress has been made in the last 20 years, there are still many contaminated sites for which no technologies can achieve complete removal of contaminants. (For extensive reviews of the present capabilities of cleanup technologies for soil and ground water contamination, see NRC, 1994, 1997.)

In addition to technical limitations, significant fiscal limitations to the complete removal of contamination have become apparent. Depending on the amount of contamination and the type of affected media, cleanup activities at individual hazardous waste sites can range from several thousand dollars to tens of millions of dollars for the more recalcitrant contaminants in unfavorable hydrogeologic settings. During the 1980s, these fiscal limitations received considerable attention, and distinctions between resource conservation and other types of cleanup goals became a topic for public debate.

What has evolved in response to such concerns is a broad range of cleanup goals, from resource conservation to technology-based goals to goals based on the immediate risk to humans and the environment ("risk-based" goals). As shown in Figure 1-2, the choice of a cleanup goal determines whether reuse of the resource is more or less restricted. The goal of resource conservation is to return sites to unrestricted uses. Other cleanup goals, such as technology-based goals or risk-based goals, may result in more restricted uses of the land following such remedial activities as partial cleanup and containment.

Risk-based approaches to cleanup, as defined by the committee, view environmental contamination solely in terms of human health and ecological risk. Depending on the apparent risk, such an approach may lead to full-scale remedial activities (such as complete removal of the contaminant source), or it may lead to limited actions (such as containment measures). The distinguishing factor between this and other approaches is that risk-based approaches are more likely than technology-based approaches and resource conservation to result in remedies that leave contamination in place. Thus, risk-based approaches do not place inherent value in soil and ground water resources, unless human or ecological health is directly threatened by contamination of those resources.

For responsible parties such as the Navy, regulatory agencies, and the public, the decision of which environmental approach to embrace must take technical, fiscal, and social issues under consideration. For example, if resource conservation and unrestricted use is the goal, then environmental contamination will be cleaned up regardless of present or projected health risks to humans or wildlife. This can involve large capital costs associated with cleaning up environmental contamination, as well as non-monetary costs if, for example, cleanup activities

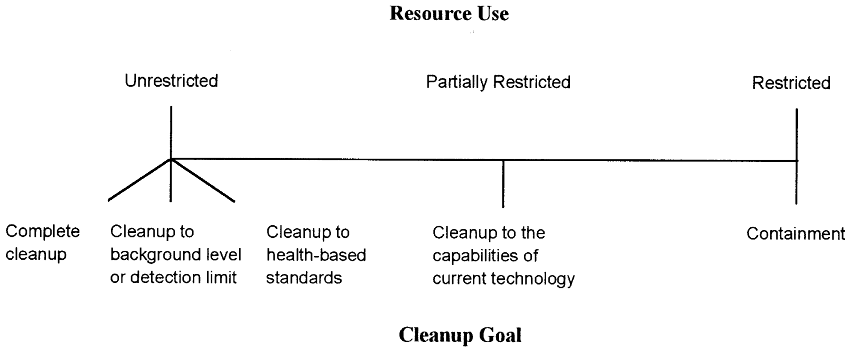

FIGURE 1-2 The range of possible ground water cleanup goals and the associated uses of the resource.

lead to the destruction of wildlife habitat. On the other hand, adopting a risk-based approach is more likely to result in some contamination being left in place, which may restrict future use of the resource. There may be fewer direct monetary costs associated with this approach, but there are other significant costs associated with the monetary value of the contaminated natural resources, with increased long-term monitoring efforts, and with potential future exposure to contamination and associated personal injury or property damage. Approaches that take multiple viewpoints into account are also foreseeable. One such approach might focus on maximizing the health benefits of dollars available for environmental remediation (risk-based approach) while minimizing the loss of natural resources (resource-conservation approach).

The technical and fiscal limitations of hazardous waste cleanup have led to a general shift away from resource conservation toward the use of risk-based approaches for prioritizing cleanup operations. Perhaps the best example to date of ranking hazardous waste problems based on risk has to do with the cleanup of underground storage tanks (USTs) of fuel. In the 1980s, many states took on significant environmental liability by committing themselves to remediating leaking USTs with funds from gasoline taxes. Since that time, the number of USTs has increased relative to the resources available for cleanup, compelling the states to informally prioritize their UST cases (EPA, 1995). Because USTs are regulated under RCRA-UST, which does not specify national cleanup levels or administrative procedures, the states have developed cleanup goals and procedures for leaking USTs that can vary tremendously. This inconsistency in cleanup goals among the state programs was recognized by the ASTM, which formed a committee to develop a standardized method for assessing the risk of petroleum hydrocarbons that could be customized and used by all states.

Much of the impetus for adoption of a uniform standard regarding cleanup of USTs came from potentially responsible parties that faced liabilities under both CERCLA and RCRA, including the states and the petroleum industry. These groups clearly saw that by transferring emphasis from resource conservation to human risk, it was possible to decrease their overall liability. The state UST programs and the petroleum industry, therefore, had similar interests in developing risk-based approaches for petroleum hydrocarbon contamination, and much of the technical input to the ASTM RBCA standard guide came from these organizations.

At the present time, many states have formally adopted a risk-based approach for managing soil and ground water contaminated with petroleum hydrocarbons. As discussed in Chapter 2, there is a trend toward adopting a risk-based approach for other environmental contaminants (such as chlorinated solvents, industrial chemicals, pesticides, and metals). The degree to which RBCA can be applied to non-petroleum hydrocarbons has not yet been established. In light of the recent creation of the ASTM RBCA standard guide and its rapid adoption by many states, the Navy requested that the NRC evaluate its use for cleaning up contamination at naval facilities.

CURRENT REGULATORY FRAMEWORK

In 1986, the Superfund Amendments and Reauthorization Act (SARA, PL 99-499) brought all military facilities under the authority of the Superfund Program. From that point on, the Navy's environmental cleanup occurred as part of the Environmental Restoration Program. Cleanup activities under the Environmental Restoration Program are dictated by a variety of regulatory programs, with most following CERCLA guidelines (Department of the Navy, 1998). At some individual sites, the military uses RCRA guidelines for cleanup rather than CERCLA. If the major contaminants at a site are exclusively petroleum hydrocarbons, RCRA-UST is the primary regulation followed. Both RCRA and RCRA-UST have milestones and terminology that are similar to CERCLA milestones and terminology.

Regulatory Authorities

The most contaminated military facilities in the country are on the National Priorities List (NPL). At these facilities, the Department of Defense (DOD) negotiates a Federal Facilities Agreement (FFA) with the EPA and its state counterpart to define roles and responsibilities, establish a mechanism for dispute resolution, and set cleanup milestones, thereby establishing clear EPA enforcement authority. A certain subset of military bases have been slated for closure under BRAC, with the goal of returning the land to the private sector. For BRAC facilities on the NPL, both cleanup and land transfer are supervised by the EPA.

When a military facility is not on the NPL, the EPA no longer has regulatory authority over the cleanup process (although the DOD almost always follows CERCLA guidelines when designing and implementing cleanup [Department of the Navy, 1998]). In these cases, most states sign statewide Defense State Memoranda of Agreement (DSMOA), which are similar to FFAs but contain no project milestones. Thus, enforcement under DSMOAs can be relaxed compared to enforcement under FFAs. (For example, in the San Francisco Bay area, regulators have less leverage at non-NPL bases, such as the Alameda Naval Air Station, than at NPL-listed Moffett Naval Air Station, because there is no FFA defining enforceable milestones at Alameda.) However, at BRAC facilities not on the NPL, the EPA is involved in the transfer process as dictated under CERCLA Section 120. Thus, unlike at other non-NPL facilities, the EPA has regulatory authority at non-NPL BRAC facilities, along with state environmental regulators.

It is evident from the above that the Navy operates its Environmental Restoration Program in a complex regulatory environment. Depending on the level of contamination, the type of contamination, and whether a facility is active or closing, a variety of federal, state, and regional authorities play a role in ensuring compliance from the Navy.

CERCLA Framework

The phases of environmental cleanup are essentially the same under the CERCLA, RCRA, and RCRA-UST scenarios. The first phase of the cleanup is called the preliminary assessment/site inspection (PA/SI). It involves identification of problem areas and review of existing site characterization data. Based on the information from the PA/SI, the property receives an initial ranking based on the degree of hazard presented using the Hazard Ranking System (HRS) (Federal Register, 1990). If the property receives a score of 28.5 or greater, usually the entire facility is placed on the NPL.

If the site inspection reveals contamination at the facility, a more detailed remedial investigation (RI) is conducted for one or more sites. The RI typically involves the installation of ground-water monitoring wells and/or soil sampling to identify the degree and scope of contamination. Current EPA guidance requires that a human health risk assessment and an ecological risk assessment be conducted, which, at the majority of sites, involves a quantitative assessment. Information from the remedial investigation is used to conduct a feasibility study (FS) to determine what the ultimate remedy should be to address the contamination. The factors that must be evaluated when choosing a remedy are discussed in the National Contingency Plan (NCP) (40 CFR 300). The chosen remedy is supported by a record of decision (ROD) for NPL sites or a decision document for non-NPL sites.

Once the ROD is approved, implementation of the remedy (or cleanup) begins. During remedial design (RD), technical specifications are prepared. This is followed by remedial action (RA), during which construction, operation, and implementation of the final remedy occur. Further guidance on remedial action has recently been provided by DOD management (Office of the Deputy Under Secretary of Defense, 1998) to clarify "terminology for work after remedial design," as illustrated in Figure 1-3. Remedial action-construction (RA-C) is the period during which the final remedy is put in place. The end date signifies that the construction is complete, all testing has been accomplished, and the remedy will function properly. The phase remedial action-operations (RA-O) is the period during which the remedy is in place (RIP) and is operating to achieve the cleanup objective identified in the ROD or equivalent agreement. Response complete (RC) signifies that the remedy is in place and the required RA-O phase has been completed. If there is no RA-O phase, then the RA-C end date will also be the RC date.

Response complete does not necessarily mean that the contamination has been eliminated. When contamination is left in place, long-term monitoring and

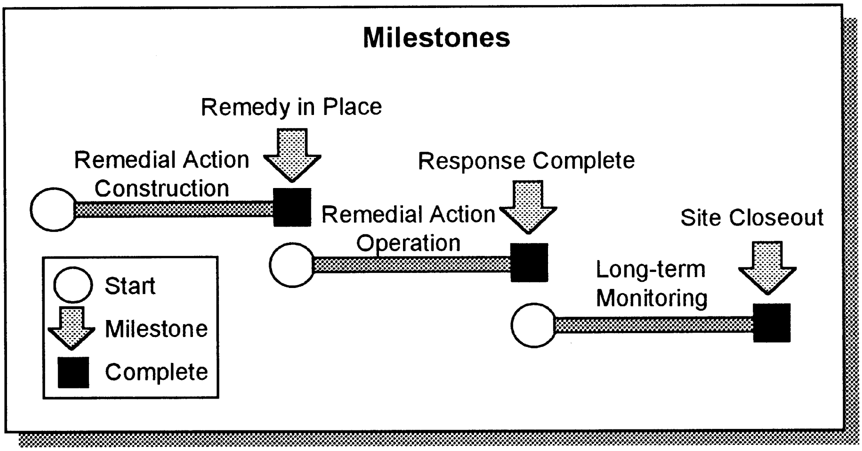

FIGURE 1-3 Milestones of the Defense Environmental Restoration Program. SOURCE: Office of the Deputy Under Secretary of Defense (Environmental Security), 1998.

institutional controls may be required. Under CERCLA, where significant contamination is left in place that has the potential to cause a risk to human health and the environment, five-year reviews are typically required along with continued monitoring. Similarly, under RCRA, post-closure care is required, which usually lasts for a minimum of 30 years where significant ground water contamination is involved. The subsequent monitoring that is required beyond "response complete" is termed long-term monitoring (LTM). LTM is reserved for monitoring once a site is "response complete," and should not be used to refer to monitoring after "remedy in place." After LTM demonstrates that the site no longer poses a significant risk to human health and the environment, the site can be closed.[3] Site closeout relieves the potentially responsible party of any further remedial activity at the site.[4]

Environmental cleanup at BRAC facilities follows the same time line outlined above, except that the ultimate goal is transfer of the facility to local governments, the private sector, or other federal agencies. The BRAC base closure process requires the DOD to close military facilities within a specified time frame

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[3] At some sites, long-term monitoring may be required indefinitely (Air Force/Army/Navy/EPA, 1998).

[4] Site closeout implies that the DOD has completed active management and monitoring at an environmental restoration site, and no additional environmental restoration funds are expected to be expended at the site, unless the need for additional remedial action is demonstrated. Site closeout occurs when cleanup goals have been achieved that allow unrestricted use of the property (i.e., no further long-term monitoring, including institutional controls monitoring, is required) (Air Force/Army/Navy/EPA, 1998).

but not necessarily to transfer the land within that time frame. BRAC facilities do not have to reach site closeout prior to the time the bases are closed or transferred. They are only required to reach RIP and RA-O at the time of transfer to non-federal ownership. The entire facility does not have to achieve RIP; the transfer of certain parcels that have achieved RIP is allowed.

Metrics of Success for the Navy Environmental Restoration Program

There are several success measures for BRAC and non-BRAC facilities used under the Environmental Restoration Program. The 1998 Defense Management Guidance lists both RC and RIP as measures of merit for both sites and entire facilities. The July 1997 Defense Planning Guidance Goals (FY 1999-2003) for BRAC facilities also target RIP and RC, stating that 75 percent of installations and 90 percent of all sites "will have remedial systems in place or responses complete" by the end of FY 2001. From the committee's experience, Navy managers also perceive site closeout to be an important metric of success.

Another important metric for active bases and former defense sites is risk reduction (Office of the Deputy Under Secretary of Defense, 1998). This refers specifically to the priority-setting process "Relative Risk Site Evaluation Framework" (Anderson and Bowes, 1997) that allocates funding in the Environmental Restoration Program. This framework qualitatively ranks sites according to risk by grouping sites into high, medium, and low risk categories. Information on contaminant sources, exposure pathways, and human and ecological receptors is used to assign sites to categories. Risk reduction is measured when sites are moved from the high or medium risk categories to lower categories. This framework is only used to request and allocate DOD cleanup funds and does not play a role in the CERCLA decision-making process.

The risk-reduction metric fits well with the stated goals of the Environmental Restoration Program. However, it is not clear whether this simple evaluation method, which was designed to hold down assessment costs and time and encouraging the understanding (and support) of external stakeholders, is precise enough to serve this purpose.

Navy project managers report another metric that they say comes from regulatory agencies—the signing of the ROD or other decision document formalizing the remedy for an operable unit. This apparently is not a formal metric but rather the culmination of the study process and a key milestone in most Federal Facility Agreements.

CHARACTERISTICS OF NAVAL HAZARDOUS WASTE SITES

Contaminant distributions at naval facilities are complex and varied. Of the 4,448 individual sites listed in the Environmental Restoration Program, 857 are

The fuel tank farm at the Newport Naval Education and Training Center, Newport, Rhode Island. These types of storage units often house multiple chemicals. Their enormous size underscores the amount of material that may be released if a tank were to leak. It also highlights the size and scope of the Navy's environmental cleanup program. Courtesy of the U.S. Navy.

classified as RCRA sites, 751 as UST sites, and 2,840 as CERCLA sites. It is important to note that under Navy terminology, an individual UST site can contain more than one underground storage tank. In addition, the total volume of an individual tank may exceed one million gallons.

Navy facilities span a broad spectrum of land use ranging from rural residential to urban residential, transportation support, and heavy industry. This varied land use has resulted in a complex and diverse set of contamination events and sources. In many cases, Navy facilities represent intact communities providing full residential, recreational, and urban services to their occupants. Virtually all types of contamination associated with urban centers can be found at Navy installations. These include such sources of soil and water contamination as municipal solid waste landfills, wastewater treatment plants, and underground storage tanks for automobile and truck fuels. Additional contamination can be associated with larger scale transportation activities, such as the transport and storage of marine and aviation fuels. Industrial activities (e.g., aircraft and ship maintenance) release waste solvents and heavy metals and often result in the creation of "industrial" solid waste landfills. Contamination at many Navy facilities can result from personnel training activities (e.g., "fire pits," where fire fighting techniques have been practiced, and target ranges). Finally, contamination can emanate from golf courses and other recreational facilities, as well as landscape maintenance at Navy complexes.

With such diverse activities giving rise to contamination at naval facilities, the array of contaminant types is extremely large, ranging from fuels and solvents to metals, pesticides, and household cleaners.[5] Although contaminant mass and concentration data for individual waste sites are collected at each Navy facility, there is no central compilation of comprehensive data. In an attempt to provide some overview of contaminant distributions, information compiled from the Navy is presented in Table 1-1. These data represent all hazardous waste sites in the United States and its territories, as reported by the Navy.

Organic contaminants are the most common contaminants found at Navy facilities. Petroleum, oil, and lubricants (POLs) and hydrophobic organic contaminants (HOCs) exist at over half of all installations, and pesticides are found at almost one quarter. Metals are also frequent contaminants. In most cases, multiple contaminants are present. It is not possible to determine from readily available data if the contaminants exist as mixed wastes or if they are present at separate sites in a given installation.

To gain some idea about the magnitude of contamination at Naval facilities, the committee studied maximum concentration data from seven sites across the

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[5] Because of its unusual properties, unexploded ordnance, a type of contamination unique to the military, was not considered during this study.

TABLE 1-1 Frequency of Contaminants at Navy Installations

Contaminant Category	Frequency(%)[a]
Petroleum, oil and lubricants (POLs)	59.5
Hydrophobic organic contaminants (HOCs)[b]	54.3
Metals	42.4
Pesticides	23.0
Paint	18.6
Acids	13.0
Electrolytes	4.5
Radionuclides	3.7
Bases	3.0
Cyanide	2.6
Acetone	<1
Ammonia	<1
Ethylene glycol	<1
Photo chemical	<1
Hydrogen cyanide	<1

NOTE: The table includes all contaminated media (ground water, soil, etc.).

[a] Frequency is defined as the number of installations reporting the contaminant category at one or more of its waste sites relative to the total number of Navy installations.

[b] Does not include POLs or pesticides.

SOURCE: Department of the Navy, 1998.

country. Characterization of these sites cannot go beyond the most general terms because of the wide range of contaminants and reported concentrations. Similar to the data found in Table 1-1, these sites contain predominantly POL-related contaminants, halogenated organic compounds, pesticides, and heavy metals, with the greatest total mass of contaminants probably being POLs.

The characteristics of a particular Navy facility, the North Island Naval Air Station in San Diego, California, are given in Box 1-1. The wide variety of contaminants, the unique hydrogeologic conditions, and the many regulatory authorities present at North Island demonstrate the highly variable environment in which cleanup takes place.

PRESSING CLEANUP CHALLENGES

Cleanup Cost

Like other responsible parties, the Navy is faced with environmental cleanup responsibilities that take time, resources, and attention away from its principal mission. Many top decision makers view cleanup as a discretionary expense that competes with readiness, modernization, and other military goals at a time when overall budgets are declining. The Navy is seeking ways to reduce the financial dimension of that obligation without increasing measurable risk to human or ecological receptors.

At closing bases, the Navy is also subject to political pressure to prepare property for transfer in a much more timely fashion, though state and local stakeholders often differ among themselves over whether to emphasize stringency of cleanup or timeliness of reuse. At closing bases, there is often tension over the level of cleanup, with the Navy urging limits on reuse as a way to cut cleanup costs, and the recipients, who do not pay for cleanup, wanting more stringent cleanup goals to enable greater flexibility in future use. Closures typically force the Navy to spend more money, or at least to expend funds faster, than at comparable active bases.

An interesting feature of the Navy's cleanup costs common to many multisite facilities is that the cleanup budget is disproportionately allocated to the most contaminated sites. According to data provided by Navy personnel, 59 percent of sites undergoing the Relative Risk Site Evaluation were ranked as high risk.[6] However, the cost of cleanup at these sites comprised 81 percent of the total cleanup cost. Low risk sites, on the other hand, comprised 25 percent of the sites but only 8 percent of the cost. This distribution of costs among Navy sites, which was expected and is appropriate, suggests that management and response at high risk sites is critical for controlling overall cleanup costs. The Navy has not completed an analysis of how cost estimates might vary if alternative remediation strategies for high risk sites were employed.

Regulatory Oversight

Like other responsible parties with broad national exposure, the Navy seeks standardized treatment from regulatory agencies. Each of the states (and recognized Indian tribes) have both sovereign and delegated authority to develop and enforce their own hazardous waste regulations. Some areas of the country are more sensitive to environmental issues than others. Some areas are more dependent on ground water, or have scarcer water supplies, than others. Some areas are willing to relax environmental standards to achieve other goals, such as job creation. It is, therefore, unrealistic to expect a unitary national regulatory framework, but it is possible to standardize terminology and process.

The Navy has made progress in this area. Compared to the other armed services, the Navy is concentrated in a relatively small number of states. This has made it possible to establish interstate regulatory cooperation, such as the efforts

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[6] It should be reiterated that the Relative Risk Site Evaluation model is a qualitative evaluation that provides only a rough estimate of the risk to human and ecological receptors from a waste site. The model is used only to request and allocate funding and is not used to determine cleanup action.

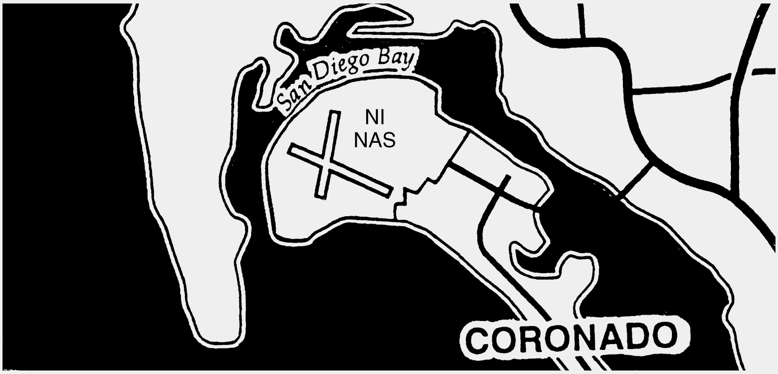
BOX 1-1
Environmental Contamination: North Island Naval Air Station

North Island Naval Air Station is at the northern tip of the peninsula that forms San Diego Bay, adjacent to the city of Coronado, California (see next page). Since the Navy assumed full control of the land in 1939, Navy activities at North Island have expanded. The base is currently home to two major carriers and their aircraft, the Third Fleet flagship, and deep submergence vehicles. With closure of other Navy installations, North Island has become the dominant active Navy base in California.

North Island is bordered on the north and west by San Diego Bay and on the south by the Pacific Ocean. The area is generally lacking in relief, providing little natural surface drainage. Because much of the land is paved, most surface runoff is captured by constructed storm drainage systems. However, two sloughs at the southern end of the base provide natural drainage into the Pacific Ocean. Historically, a fresh water aquifer was present at North Island, but extensive paving has limited fresh water recharge, resulting in intrusion of seawater into the aquifer. This has led the California Regional Water Quality Control Board to classify the ground water at North Island as unsuitable for beneficial use. Under this classification, contaminants in the ground water do not represent a drinking water threat to current or potential future property owners. However, a potential threat to marine biota exists. North Island is adjacent to a major spawning area and home of marine life (San Diego Bay). Additionally, its surrounding waters are used extensively for recreational purposes. For these reasons, migration of subsurface contaminants to the surrounding bodies of water is of concern. Two state statutes, the California Enclosed Bays and Estuaries Plan of 1993 and the California Ocean Plan of 1990, dictate acceptable levels of contamination in the waters surrounding North Island.

of the Naval Facilities Engineering Command Southwest Division to set priorities for projects among states. Furthermore, in many communities the Navy has been successful in establishing Restoration Advisory Boards (RABs), which facilitate the consideration of diverse local concerns at bases undergoing cleanup. In general, these efforts have made cleanup operations more consistent across regions.

BOX 1-1 continued



North Island contains one CERCLA site, 17 RCRA corrective action sites, and 3 RCRA underground storage tank sites (which include 190 individual USTs). These contain a range of heavy metals (As, Cr, Cu and Pb), PCBs, and volatile and semi-volatile organic compounds. Because the facility is mainly used for maintenance and repair of aircraft, a large proportion of the waste includes jet fuels and solvents. Most of the sites at North Island have been evaluated with the Navy's Relative Risk Site Evaluation model, indicating 10 high risk sites, 5 medium risk sites, and 4 low risk sites. Remedial activities mainly consist of studies, with only 9% of all sites response complete and 18% undergoing active cleanup.

SOURCE: Department of the Navy, 1998.

Proximity to Coastal Areas

The Navy's concentration in port cities creates more demands on its cleanup programs than on those of the other armed services. Naval bases have released contaminants into terrestrial, freshwater, estuarine, and marine environments that historically provide food for human consumption. Because contamination has occurred across this broad spectrum of environmental compartments, the need for and complexity of ecological risk assessments is great. Such ecological risk assessments must give consideration to a wide range of transport mechanisms and biological receptors.

Naval aircraft carrier U.S.S. Carl Vinson passing the battleship Missouri. Naval shipyards are often located in areas with multiple human and ecological receptors. Courtesy of the U.S. Navy.

Many closing Navy bases comprise valuable waterfront real estate. Potential future users, including developers of housing and other uses calling for high levels of cleanup, are eager to obtain the property. On the other hand, many Navy bases have released contaminants into aquifers that are non-potable because of saltwater intrusion, reducing demands for remedial action.

Types of Contamination Present at Navy Facilities

As previously noted, the primary contaminants found at Navy facilities, in terms of the overall numbers of affected sites, are petroleum products, oils, and lubricants (POLs). However, almost all naval facilities are also significantly contaminated with other organic contaminants, such as chlorinated solvents, heavy metals, and pesticides, that have different mobility and extremely long environmental half-lives in terrestrial, aquatic, and marine media (Department of the Navy, 1998). Treatment and removal of these compounds is far more problematic, and in some instances, no available technology is capable of reducing contaminant levels to meet health-based standards. In cases where the technology is available, it is sometimes costly to implement. Consequently, the types of contamination found at naval facilities present both technological and fiscal challenges that the Navy must address.

In addition to the recalcitrance of many chemicals found at Navy facilities, a single waste site may contain a mixture of contaminants that interact in unknown ways with each other and with potential human and ecological receptors. The Navy must have some mechanism for assessing the cumulative risk posed by multiple chemicals present at individual sites. Finally, large numbers of sites present at a single facility greatly increase the complexity of interactions that are possible between potential sources and human and ecological receptors. A facility-wide assessment of risk must be able to integrate the effects of multiple individual waste sites.

Long-Term Considerations

The DOD's plan to close additional bases early in the next century presents a final dilemma. Most remedial decisions at bases undergoing closure over the past decade have been made with knowledge that the base was closing and sometimes with reuse plans in place. The new closures, however, will take place at bases where remedies may have been chosen without knowledge that the base was closing. Transferees may insist that many cleanup agreements be reconsidered to accommodate potential changes in land use. Similar changes in land use may also occur at bases that remain active, as the Navy modifies its uses of major parcels of property to meet its evolving requirements.

In all cases where contamination remains in place after remedial actions are complete, there is tension over the permanence of the response. Any effort to base cleanup standards on risk, as measured today, must take into account this long-term uncertainty. The CERCLA cleanup process is sufficiently flexible to allow for the integration of information over time. In practice, however, remedial options tend to be permanent because site managers are influenced by pressures to clean up as quickly and inexpensively as possible. Greater discussion of long-term considerations during risk-based cleanup and the DOD's current obligations at closing facilities is found in Chapter 5.

In closing, multiple parties are urging the Navy to reduce the costs of its Environmental Restoration Program, while others insist that the program maintain adequate protection of human health and the environment. These factors, combined with the recent popularity of the ASTM Risk-Based Corrective Action standard guide for Petroleum Release Sites, have led the Navy to consider implementing a new risk-based methodology for cleanup of all their hazardous waste sites. As this report will demonstrate, risk-based methodologies have strengths and weaknesses that restrict their implementation at complex sites. This report reviews existing risk-based methodologies, describes their strengths and weaknesses, and makes recommendations to the Navy for their use in certain circumstances.

REFERENCES

ABB Environmental Services. 1997. Summary of 1997 Focused Groundwater Investigations, Site 11, Old Camden County Landfill, Kings Bay, GA, 32 pp. Prepared for Southern Division, Naval Facilities Engineering Command, North Charleston, S.C.

Air Force/Army/Navy/EPA Working Group. October 1998. The Road to Site Closeout (working draft). Washington, D.C.

Anderson, J. L., and M. D. Bowes. 1997. Appendix A: Relative Risk. In Department of the Navy Environmental Cleanup Program: Cost Control. Center for Naval Analysis. Washington, D.C.

Bracken, M. B. 1997. Musings on the Edge of Epidemiology. Epidemiology 8(4):337-339.

Chapelle, F. H. 1996. Identifying Redox Conditions that Favor the Natural Attenuation of Chlorinated Ethenes in Contaminated Ground-Water Systems. In Symposium on Natural Attenuation of Chlorinated Organics in Ground Water. EPA/540/R-96/509, 169 pp.

Department of the Navy. 1998. Department of the Navy Environmental Restoration Plan for Fiscal Years 1998-2002. Chief of Naval Operations, Arlington, Va.

Environmental Protection Agency (EPA). 1995. Risk-Based Decision-Making: A New Approach to UST Corrective Action. EPA 510-F-95-001. OSWER. Washington, D.C.

EPA. 1997. Cleaning Up the Nation's Waste Sites: Markets and Technology Trends (1996 Edition). EPA-542-R-96-005 (NTIS: PB96-178041), Technology Innovation Office, Washington, D.C.

Federal Register. 1990. Hazard Ranking System: Final Rule. Fed. Regist. 55(241):51532-51667.

National Research Council (NRC). 1991. Environmental Epidemiology, Volume 1: Public Health and Hazardous Wastes. National Academy Press, Washington, D.C.

NRC. 1994. Alternatives for Ground Water Cleanup. National Academy Press, Washington, D.C.

NRC. 1997. Innovations in Ground Water and Soil Cleanup: From Concept to Commercialization. National Academy Press, Washington, D.C.

Office of the Deputy Under Secretary of Defense (Environmental Security). March 1998. Management Guidance for the Defense Environmental Restoration Program, Washington, D.C.

Russell, M., E. W. Colglazier, and M. R. English. 1991. Hazardous Waste Remediation: The Task Ahead. Knoxville: University of Tennessee, Waste Management Research and Education Institute.

2

Review of Risk-Based Methodologies

INTRODUCTION

This chapter reviews EPA and American Society for Testing and Materials (ASTM) methodologies for risk-based cleanup at hazardous waste sites. These two methodologies, while not the only available, are the most widely used. Other frameworks considered by the committee include the Air Force's Enhanced Site-Specific Risk Assessment (ESSRA), the EPA Science Advisory Board's Integrated Risk Project, the Lawrence Livermore National Laboratory/University of California studies on leaking underground fuel tanks, and numerous state variations on the practices and methods of ASTM and the EPA.

A risk-based methodology is defined as a process that combines environmental data obtained for a hazardous waste site, risk assessment calculation(s), and a series of risk management decisions. The goal of such a methodology should be to determine how much and what kind of cleanup is necessary at the site, taking several factors into account including the extent of contamination, the risk posed by the contamination, the cost of cleanup, the values of the local community, and others. The risk-based methodologies reviewed by the committee were evaluated for their risk assessment and risk management components. Before turning to those reviews, the terms "risk," "risk assessment," and "risk management" are discussed.

Risk, Risk Assessment, and Risk Management

This report follows the definitions of risk, risk assessment, and risk management that have been developed by several previous NRC committees (NRC, 1983, 1993, 1994). A risk is the probability of an undesired event whose occurrence is uncertain. Risk assessment is the evaluation of a risk in terms of the nature and consequences of the undesired event, the potential causes of the event, and the probability that the event will occur. The assessment can be purely quantitative (as in actuarial analysis or engineering failure analysis), purely qualitative, or some combination of the two. Risk management is the implementation of measures to reduce either the probability that the event will occur or the consequences of the event if it does occur. Risk management decisions generally consider societal values, economic cost, and other factors that are outside the formal risk assessment process.

Risk Assessment

Risk assessment is generally applicable to a wide variety of scenarios, including environmental cleanup of hazardous waste sites. The goal of a risk assessment is to determine the inherent level of risk posed by contaminated sites. This is accomplished by quantitatively linking the contaminant source to potential biological targets. Risk assessments integrate information on the physical conditions at the site, the nature and extent of contamination, the toxicological and chemical/physical characteristics of the contaminants, the current and future land use conditions, and the dose-response relationship between projected exposure levels and potential toxic effects.

In 1983, the NRC defined the overall science of risk assessment by subdividing it into four major steps (NRC, 1983). Hazard assessment[1] is the process of determining whether exposure to an agent can cause an increase in the incidence of a health condition. This step involves evaluation of epidemiological data, animal bioassays, short-term *in vitro* studies, and other data relevant to determining the nature and severity of effects that might be caused by chemical exposure. Dose-response assessment is the process of characterizing the relation between the dose of an agent administered or received and the incidence of an adverse health effect. This step estimates the probability that an individual will be adversely affected by a given chemical dose, relying primarily on data obtained from animal studies. Exposure assessment is the process of measuring or estimating the intensity, frequency, and duration of human exposures to an agent currently present in the environment or of estimating hypothetical exposures that might arise from the release of new chemicals into the environment. Exposure assessment includes estimation of concentrations of chemicals in environmental

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[1] Hazard assessment is the analytical part of a larger process during risk assessment (sometimes known as Hazard Identification or Source Assessment) in which sources of contamination are evaluated, the site is described, and potential receptors are identified.

media to which humans are exposed, and the dose received by the exposed individuals. Risk characterization is the process of estimating the incidence of a health effect under the various conditions of human exposure described in the exposure assessment. It combines the exposure assessment with the dose-response curve. For carcinogenic compounds, the risk estimate is expressed as the probability of additional lifetime cancers (e.g., one in a million or 10^{-6}). For noncarcinogens, risk is described by the hazard quotient (HQ), which is the ratio of the dose of a contaminant over a specified time period to a reference dose for that contaminant derived for a similar exposure period (e.g., HQ = 0.8).

The framework described above has been widely accepted and today serves as the basis of the great majority of chemical-related risk assessments performed by federal agencies, state agencies, and private companies. In 1993, the NRC extended the framework to include ecological as well as human health risks. The fact that risk assessment has been embraced by the federal agencies does not mean, however, that risk assessments go without criticism, particularly in the arena of environmental cleanup. Because of uncertainties in the risk assessment calculation regarding the sources of contaminants, their transport to potential receptors, and their interaction with those receptors, there can be disputes over the value of the estimated risk among the regulatory agencies, the responsible parties, and the local community. The toxicological and exposure assumptions, as well as the quality of the data used in the risk assessment, are often the source of considerable disagreement.

Risk Management

The goals of risk management are to answer the questions: "What risk is acceptable?" and "How should we appropriately reduce, control, or eliminate risks to human health and the environment?" Risk management compares the risk assessment calculation to a defined level of acceptable risk and then describes the processes that will be used to reduce risk, if necessary.

Acceptable Risk. Defining an acceptable risk level gives meaning to the risk estimate generated from the risk assessment. There are few legislative, public policy, and judicial guidelines on how to define acceptable risk. Although "safe" has not been found to necessarily mean zero risk (State of Ohio v. EPA 997 F.2d 1520, 1533, D.C. Cir. 1993), the courts have not provided (1) a risk level above which risk management action must occur, (2) specific guidance as to what might be done to determine whether a risk is acceptable, or (3) workable definitions of acceptable, safe risk levels. The EPA currently "endorses" a risk range from 10^{-6} (one in a million) to 10^{-4} for one's lifetime risk from exposure to carcinogens and a hazard quotient of 1.0 for noncarcinogens. As our state survey shows, acceptable risk levels across the state regulatory agencies tend to mirror EPA guidance.

Risk Reduction. Although great strides in scientific methodologies have improved the science of risk assessment, improvements in the risk management decision-making process have not been as forthcoming. Risk management must balance the nation's interests in public health and environmental protection against the limits of public and private resources. Unfortunately, little guidance for balancing environmental protection and cost effectiveness in making cleanup decisions has been provided by the EPA. When such factors as feasibility and cost are not considered in an analytic paradigm similar to risk assessment, risk management frequently results in the misdirection of resources, incomplete protection of public health and the environment, and the loss of institutional credibility, public trust, and standing.

One of the most important risk management decisions to be made at hazardous waste sites is the selection of a remedy. The remedial option specifies how the risk from a contaminated site will be reduced through a combination of cleanup technologies, containment strategies, and institutional controls. Cleanup technologies include natural and engineered physical, chemical, and biological processes that remove or reduce sources of contamination. Containment strategies, also referred to as engineering controls, consist of technologies that are designed to prevent contaminant migration into otherwise uncontaminated areas. Finally, institutional controls refer to restrictions on use of or access to contaminated land in order to minimize exposure to contamination. Ideally, the process of choosing the remedial option should not only consider issues uncovered during the risk assessment phase but also integrate considerations such as engineering feasibility, financial resources, community needs, and real or potential benefit of the proposed risk reduction solutions. The limitations of certain remedies, including both engineering and institutional controls, are discussed in Chapter 4.

UNIVERSE OF RISK-BASED METHODOLOGIES

In reviewing a variety of risk-based methodologies, the committee noticed a central principle common to all—the source-pathway-receptor paradigm. This paradigm states that for a risk to exist there must be (1) a source of chemical release, (2) a human or ecological receptor that is potentially exposed to the released chemicals, and (3) an environmental pathway connecting the source and the receptor(s). If a risk is present, it may be reduced or eliminated by removing the source or the receptor, or by interrupting the pathway. The source-pathway-receptor paradigm provides a straightforward approach to performing risk assessments at contaminated (or potentially contaminated) sites and linking the results of the risk assessments to risk management actions. In the following sections, this paradigm will be used to explain and compare the risk-based approaches developed by various state and federal agencies and the ASTM. Table 2-1 lists sources, pathways, and receptors that may be associated with a hazardous waste site.

TABLE 2-1 Examples of Sources, Pathways, and Receptors[a]

Sources[b]

- leaking tanks (above-ground or underground)
- tank appurtenances (e.g., pipes, distribution)
- surface spills
- free product contained in the vadose zone or aquifer
- soils saturated with chemicals of concern (CoCs)
- soil or waste piles
- lagoons or ponds
- injection wells
- landfills
- sources associated with facilities operation (e.g., weapons training, manufacturing)

Transport Pathways

- migration of free product in vadose zone and saturated zone
- dissolution of free product into ground water
- partitioning of free product between water and subsurface solids (sorption/desorption)
- leaching to ground water (desorption from soil)
- leaching to surface water (desorption from sediment)
- ground water to surface water (and vice versa)
- volatilization from ground water to outdoor air
- volatilization from ground water to indoor air or other confined space
- volatilization from vadose zone (free product or soil) to outdoor air, indoor air, or other confined space
- volatilization from surface water to outdoor air
- erosion and surface water runoff
- fugitive dust (wind erosion)

Receptors[c]

- humans through:
  - dermal contact with soils, sediments, or contaminated water outdoors (e.g., swimming) or indoors (e.g., showering)
  - ingestion of soils, sediments, or contaminated water
  - ingestion of food sources (e.g., plants, aquatic species) that have bioaccumulated CoCs from contaminated water, air, or soil
  - indirect ingestion (e.g., baby exposed to breast milk)
  - inhalation of indoor air (or in other confined space)
  - inhalation of vapors from contaminated water (e.g., showering, running hot water)
  - inhalation of outdoor air
  - inhalation of fugitive particulates (e.g., dust)
- ecosystems (e.g., wetland, marsh)
- animals and other living species (e.g., endangered or protected species, fish, birds)
- ground water
- ground water wells

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[a] References include ASTM (1995, 1998); Farr et al. (1996); Rice et al. (1997).

[b] Some are classified as "primary" and some as "secondary."

[c] It should be noted that there is considerable controversy about considering non-living entities as receptors.

Environmental Protection Agency

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) established a national program for the management of potential public health and environmental threats posed by properties that are contaminated by hazardous wastes. CERCLA is implemented by regulations entitled the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 CFR Part 300) and enforced by the EPA. From CERCLA and the NCP, a regulatory process has evolved that has historically focused on the central metric of risk.

Initial Steps of CERCLA

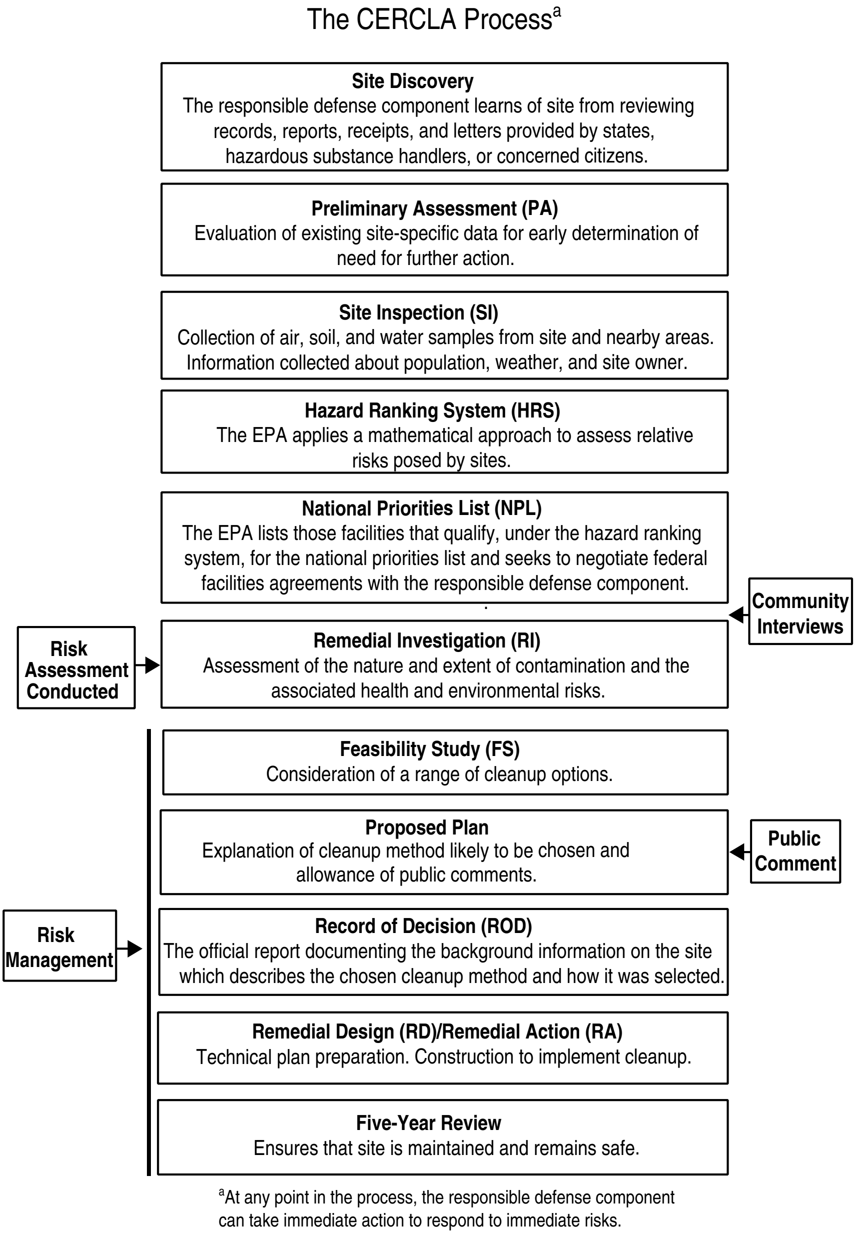
The steps that make up the CERCLA cleanup process are shown in Figure 2-1. After discovery of a contaminated site, a preliminary assessment (PA) is conducted during which site-specific data are evaluated to determine the need for further cleanup action at the site. This is followed by a site inspection (SI) that collects additional data on air, soil, and water from the site and surrounding areas. Based on the information obtained in these two information gathering phases, the entire facility receives an initial ranking based on the degree of hazard presented using the Hazard Ranking System (HRS). If the facility receives a score of 28.5 or greater, it is listed on the National Priorities List (NPL), necessitating a Federal Facilities Agreement between the responsible party and the EPA and state regulatory authorities.

Once contamination is demonstrated, a more detailed remedial investigation (RI) is conducted. The RI characterizes conditions at the site, identifying the sources of contamination, the extent of contamination, and the environmental characteristics and conditions contributing to unwanted exposure. During this phase, human health and ecological risk assessments are conducted, following the guidance provided by the EPA known as Risk Assessment Guidance for Superfund (EPA, 1989, 1991a, b, 1998a).

Risk Assessment Guidance for Superfund

EPA guidance documents covering risk assessment and management at hazardous waste sites are referred to as the Risk Assessment Guidance for Superfund (RAGS). RAGS estimates the risk to human health and the environment based on data generated during the RI, information that is essential for establishing the need for a remedial response and the extent of the action. These documents guide regulators, responsible parties, and stakeholders through the risk-based portion of the investigation, characterization, and remedy selection and implementation at a hazardous waste site.

The first document, Risk Assessment Guidance for Superfund, Part A, focuses on developing a baseline risk assessment. The risk assessment contains a



The CERCLA Process[a]

Site Discovery
The responsible defense component learns of site from reviewing records, reports, receipts, and letters provided by states, hazardous substance handlers, or concerned citizens.

Preliminary Assessment (PA)
Evaluation of existing site-specific data for early determination of need for further action.

Site Inspection (SI)
Collection of air, soil, and water samples from site and nearby areas. Information collected about population, weather, and site owner.

Hazard Ranking System (HRS)
The EPA applies a mathematical approach to assess relative risks posed by sites.

National Priorities List (NPL)
The EPA lists those facilities that qualify, under the hazard ranking system, for the national priorities list and seeks to negotiate federal facilities agreements with the responsible defense component.

Remedial Investigation (RI)
Assessment of the nature and extent of contamination and the associated health and environmental risks.

Feasibility Study (FS)
Consideration of a range of cleanup options.

Proposed Plan
Explanation of cleanup method likely to be chosen and allowance of public comments.

Record of Decision (ROD)
The official report documenting the background information on the site which describes the chosen cleanup method and how it was selected.

Remedial Design (RD)/Remedial Action (RA)
Technical plan preparation. Construction to implement cleanup.

Five-Year Review
Ensures that site is maintained and remains safe.

[a] At any point in the process, the responsible defense component can take immediate action to respond to immediate risks.

FIGURE 2-1 Steps in the CERCLA process. Each box describes the actions taken during the sequential phases of the CERCLA process. SOURCE: EPA, 1992a.

mathematical description of complete exposure pathways linking the contaminant source through the environmental compartments and media to the biological receptor. This requires information about

- the concentrations and location of the contaminants,
- actual or potential mechanisms of release, migration, and fate of the contaminants,
- the environmental compartment or media through which the contaminant is transported or acts as a reservoir,
- points of potential receptor exposure,
- exposure conditions at the point of contact,
- integration of multi-media and multi-pathway exposures into a comprehensive scenario, and
- toxicity of the contaminant of concern.

The end result is a numerical value of potential additional risk (e.g., 10^{-5} for carcinogens) from the contaminant source for the biological receptor at the exposure point. The risk assessment can be updated during the remedial investigation by integrating new site data into the risk calculation. Part A of RAGS is used for an initial estimation of risk at a hazardous waste site that can be compared to some acceptable target risk level. The risk estimate is generally calculated for both soil and ground water contamination.

If the Part A risk estimate is greater than the acceptable target risk level, the second document, Risk Assessment Guidance for Superfund, Part B, is used to develop initial goals for risk-based cleanup. The document gives standard, detailed procedures for using risk assessment calculations to establish site cleanup levels that reflect the site's objectives. This process is similar to the risk assessment calculation specified under RAGS Part A, except it is carried out in the reverse direction. First, an acceptable target risk level that takes into account the desired land use scenario is specified. Mathematical equations are then used to calculate the concentration of a contaminant that will give rise to that risk, assuming certain transport and exposure pathways. The resulting concentration is set as the preliminary remediation goal (PRG).

A PRG is a risk-based concentration limit for an individual contaminant in a specific environmental medium (e.g., soil) that is associated with a specific land use and exposure pattern. Values for PRGs can evolve with the characterization and understanding of a hazardous waste site. Generic PRGs can be developed initially based on general land use and exposure assumptions and minimal consideration of current or proposed site-specific conditions. The PRGs are refined as more site-specific data are gathered about the types of contaminants present, the nature and extent of contamination, and the potential site-specific exposure scenarios. RAGS advocates repeating the risk assessment calculation done during the remedial investigation. In practice, however, responsible parties rarely conduct more than one risk assessment for the major toxic or carcinogenic compounds identified at a site because of the time and cost involved in collecting the data.

It should be noted that site-specific risk assessment under RAGS Part B, which is meant to generate a PRG, is conducted for soil and sediment contamination more frequently than for ground water contamination. This is because statutes often force cleanup of ground water to "applicable or relevant and appropriate requirements" (such as MCLs) regardless of the site conditions. However, for soils and those contaminants for which no MCLs exist, site-specific risk assessment is necessary.

EPA Soil Screening Guidance

Because site-specific risk assessment for contaminated soils under RAGS Part B requires substantial data collection, the EPA created a methodology, the Soil Screening Guidance, that can be used to screen soil contamination quickly before doing a full-scale risk assessment (EPA, 1996a). The intention of the Soil Screening Guidance is to focus resources on sites that pose the greatest risk. Another reason for using the Soil Screening Guidance is to eliminate from further consideration low-risk sites containing soil-only contamination.

The Soil Screening Guidance provides a methodology to calculate risk-based, site-specific soil screening levels for a very specific subset of contamination problems. Only contamination problems that are similar to those used in the Soil Screening Guidance can be considered. The guidance assumes an acceptable risk of 10^{-6} for carcinogens and a hazard quotient of 1.0 for noncarcinogens, and it encompasses 110 chemicals. Only residential land use is considered, and six exposure pathways are specified, including direct ingestion of soil and ground water contaminated by soil, inhalation of volatiles and dust, dermal absorption, ingestion of produce that has been contaminated by soil, and migration of volatiles in basements. These criteria are used to formulate generic Soil Screening Levels (SSLs).

The soil screening process is a tiered approach with seven basic steps (Figure 2-2). First, a site conceptual model is developed to collect, organize, and analyze data from the site. The site must be confirmed to have conditions similar to those described above (residential land use, similar exposure pathways, etc.). Second, the concentration data from the site are compared with the generic SSLs. If those data are below SSLs, the screening process ends (see below). If the concentration data are above SSLs, additional data collection is done to narrow down the areas in excess. More sophisticated soil analyses and sampling are conducted, and the generic SSLs are updated to include this new information, thus generating site-specific SSLs. Concentration data from the site are now compared to these site-specific SSLs. If they fall below these levels, the screening process ends. If not, another round of data collection, modeling, and further enhancement of the SSLs

Soil Screening Process

Step One: Develop a Conceptual Site Model (CSM)

- Collect existing site data (historical records, aerial photographs, maps, PA/SI data, available background information, state soil surveys, etc.
- Organize and Analyze existing site data
  - — Identify known sources of contamination
  - — Identify affected media
  - — Identify potential migration routes, exposure pathways, and receptors
- Construct a preliminary diagram of the CSM
- Perform site reconnaissance
  - — Confirm or modify CSM
  - — Identify remaining data gaps

Step Two: Compare Soil Component of CSM to Soil Screening Scenario

- Confirm that future residential land use is a reasonable assumption for the site
- Identify pathways present at the site that are addressed by the guidance
- Identify additional pathways present at the site not addressed by the guidance
- Compare pathway-specific generic SSLs with available concentration data
- Estimate whether background levels exceed generic SSLs

Step Three: Define Data Collection Needs for Soils to Determine Which Site Areas Exceed SSLs

- Develop hypothesis about distribution of soil contamination (i.e., which areas of the site have soil contamination that exceed appropriate SSLs?)
- Develop sampling and analysis plan for determining soil contaminant concentrations
  - — Sampling strategy for surface soils (includes defining study boundaries, developing a decision rule, specifying limits on decision errors, and optimizing the design)
  - — Sampling strategy for subsurface soils (includes defining study boundaries, developing a decision rule, specifying limits on decision errors, and optimizing the design)
  - — Sampling to measure soil characteristics (bulk density, moisture content, organic, carbon content, porosity, pH)
- Determine appropriate field methods and establish quality assurance/quality control (QA/QC)

Step Four: Sample and Analyze Soils at Site

- Identify Contaminants
- Delineate area and depth of source
- Determine soil characteristics
- Revise CSM, as appropriate

Step Five: Derive Site-Specific SSL (if needed)

- Identify SSL equations for relevant pathways
- Identify chemicals of concern for dermal exposure and plant uptake
- Obtain site-specific input parameters from CSM summary
- Replace variables in SSL equations with site-specific data gathered in Step 4
- Calculate SSLs
- Account for exposure to multiple contaminants

Step Six: Compare Site Soil Contaminants Concentrations to Calculated SSLs

- For surface soils, screen out exposure areas where all composite samples do not exceed SSLs by a factor of 2
- For subsurface soils, screen out source areas where the highest average soil core concentration does not exceed the SSLs
- Evaluate whether background levels exceed SSLs

Step Seven: Decide how to address Areas Identified for Further Study

- Consider likelihood that additional areas can be screened out with more data
- Integrate soil data with other media in the baseline risk assessment to estimate cumulative risk at the site
- Determine need for action
- Use SSLs as PRGs

FIGURE 2-2 This figure describes actions taken during the seven steps of the soil screening process. Data collected from sites with contaminated soil are compared to generic Soil Screening Levels (SSLs). If the site data fall below generic SSLs, the screening process ends and site closeout is likely. If not, site-specific SSLs are generated considering relevant fate and transport and exposure pathways. Site data are then compared to site-specific SSLs. If site data do not fall below site-specific SSLs, these SSLs may be used as PRGs for the latter half of the CERCLA process. SOURCE: EPA, 1996a.

can occur. When concentration data fall below either generic or site-specific SSLs, it is likely that the site will require no further action under CERCLA (EPA, 1996a).

For those sites that cannot be eliminated from cleanup consideration using the Soil Screening Guidance, the SSLs can be used as preliminary remediation goals (PRGs), provided appropriate conditions are met (e.g., conditions found at a specific site are similar to conditions assumed in developing the SSLs). This obviates the need for calculating PRGs using RAGS Part B. It should be kept in mind that the Soil Screening Guidance may only be used for a subset of contamination problems found at hazardous waste sites. It is likely that complex hazardous waste sites will exhibit conditions that require the calculation of PRGs under RAGS Part B.

The generic Soil Screening Levels developed by the EPA have many counterparts in regulatory programs at the state level. (Many states have devised generic screening levels for contaminated ground water as well). These generic soil screening levels may be more or less stringent than the Soil Screening Levels of the EPA, and generally are based on similar assumptions, such as residential exposure and particular exposure pathways (such as direct ingestion of soil).

CERCLA Risk Management

Information from the remedial investigation, including the results of all risk assessments and PRGs, is used to conduct a feasibility study (FS) to determine the ultimate remedy for contamination. The FS begins the risk management phase of the cleanup effort. During this phase, alternative remedial measures are evaluated for their risk reducing ability and effectiveness. Guidance for performing such evaluations is provided in RAGS Part C (which is also intended to evaluate the selected remedial alternative during and after its implementation) and RAGS Part D (EPA, 1991b, 1998a).

A remedy is selected from the suite of remedial alternatives using the nine evaluation criteria described in the NCP:

(1) overall protection of human health and the environment;
(2) compliance with the chemical-specific standards that are considered the statutorily required “applicable or relevant and appropriate requirements” (ARARs);
(3) long-term effectiveness and permanence;
(4) reduction of toxicity, mobility, or volume through the use of treatment;
(5) short-term effectiveness;
(6) implementability;
(7) cost;
(8) state acceptance; and
(9) community acceptance.

The first and second criteria (threshold criteria) must be met in all circumstances. For example, assume that the PRG for an individual chemical is not feasible as a cleanup value under criteria 6 and 7. To meet the threshold criteria 1 and 2, isolation of the contaminant from the receptor may be the only remedy. Where total containment is not feasible under criteria 6 and 7, changes in land use may have to be considered. It is often the case that cost and technical feasibility issues can be anticipated early on in the CERCLA process. In such situations, multiple PRGs are developed, with the expectation that some will be met using treatment technologies, some will be met with containment strategies, and some will be met using institutional controls (Cooper, 1998). The preamble to the NCP makes it clear that the EPA has a strong preference for treatment technologies over engineering and institutional controls, especially for "principal threat" wastes[2] (Federal Register, 1990). The EPA does not encourage solutions in which institutional controls are the sole remedy and prefers that they be used in conjunction with containment strategies.

The remedial option chosen after consideration of the nine balancing criteria is described in the decision document, known as the record of decision (ROD) for facilities on the NPL. Following approval of the ROD, implementation of the remedy begins. Remedial design (RD) and remedial action (RA) encompass the design, construction, operation, and implementation of the final remedy.

The final stages of the CERCLA process include maintaining engineering and institutional controls and conducting long-term monitoring. These activities are evaluated by means of five-year reviews. If continued monitoring of all remedies demonstrates that the site no longer poses significant risk to human health and the environment, the site may be closed out.[3]

At any time during the investigation or cleanup phases, interim remedial actions (IRA) or removal actions may be taken to remove a source of contamination or block a contaminant pathway. These measures are not intended to be the final remedial action at the site. Rather, they are intended to stabilize the situation until a permanent remedy can be employed. IRAs can occur prior to, during, or after the RI/FS. IRAs and removal actions have been subject to controversy because they increase the possibility that actions may be taken without regulatory approval or public acceptance.

American Society for Testing and Materials

The American Society for Testing and Materials (ASTM) has developed two standard guides for risk-based corrective action (RBCA): (1) Standard Guide for

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[2] Principal threat wastes are broadly defined by the EPA as being liquid or solid wastes and soil containing hazardous substances that constitute a risk of 10^{-3} or greater. More detail is available in EPA, 1991c.

[3] See Chapter 1 footnotes 3 and 4 for details.

Risk-Based Corrective Action Applied at Petroleum Release Sites (E 1739-95; referred to here as petroleum RBCA) and (2) Standard Provisional Guide for Risk-Based Corrective Action (PS 104-98; referred to here as chemical RBCA). The ASTM documents are meant to be used as a framework for developing risk management strategies and not as "cookbooks" to be rigidly followed. It is presumed that states will develop their own versions of RBCA using the ASTM standard guides as models.

Both ASTM standard guides cover the same environmental remediation activities that the CERCLA process does, from site discovery to site closure. For the cleanup of petroleum underground storage tanks, which are not regulated under CERCLA, the petroleum RBCA methodology can be adopted by states and be made to reflect state regulations (this has occurred already in 14 states). Chemical RBCA is intended for use at sites other than petroleum release sites, which may be subject to regulation under RCRA, CERCLA, or state statutes. For CERCLA sites, implementation of chemical RBCA would have to occur within the CERCLA framework, perhaps as an alternative approach to RAGS. Because the chemical RBCA standard guide is relatively new, it has not yet been implemented in any state.

Petroleum RBCA and chemical RBCA are similar to EPA guidance on risk assessment (CERCLA, RAGS, and SSLs) in many ways. They all rely on the source-pathway-receptor paradigm to quantify risk, using many of the same mathematical calculations and transport and exposure models. Specific differences between the methodologies that translate into strengths and weaknesses are discussed in detail in Chapter 3. In general, the ASTM standard guides are meant to apply to petroleum and non-petroleum compounds under circumstances that can be customized to the user. In the following paragraphs, a description of petroleum RBCA is given, followed by a shorter description of chemical RBCA with an emphasis on pointing out the differences between the two.

Petroleum RBCA (E 1739-95)

Petroleum RBCA provides a tiered approach for developing a remedial action plan for leaking USTs (similar to the tiered approach of the Soil Screening Guidance). Each tier is successively more complex and requires more extensive data and assumptions. The RBCA approach differs from traditional risk assessment by deciding up front an acceptable level of risk and then calculating the corresponding cleanup levels for chemicals of concern (CoCs). For a tier 1 analysis, these cleanup levels are termed risk-based screening levels (RBSLs); for tier 2 and tier 3 analyses, they are called site-specific target levels (SSTLs). RBSLs and SSTLs for soil contamination are comparable to the EPA's generic and site-specific SSLs, respectively. The general goal of the RBCA process is to compare concentrations of CoCs with RBSLs and SSTLs and take appropriate action.

The petroleum RBCA framework is summarized in Figure 2-3. First, a site

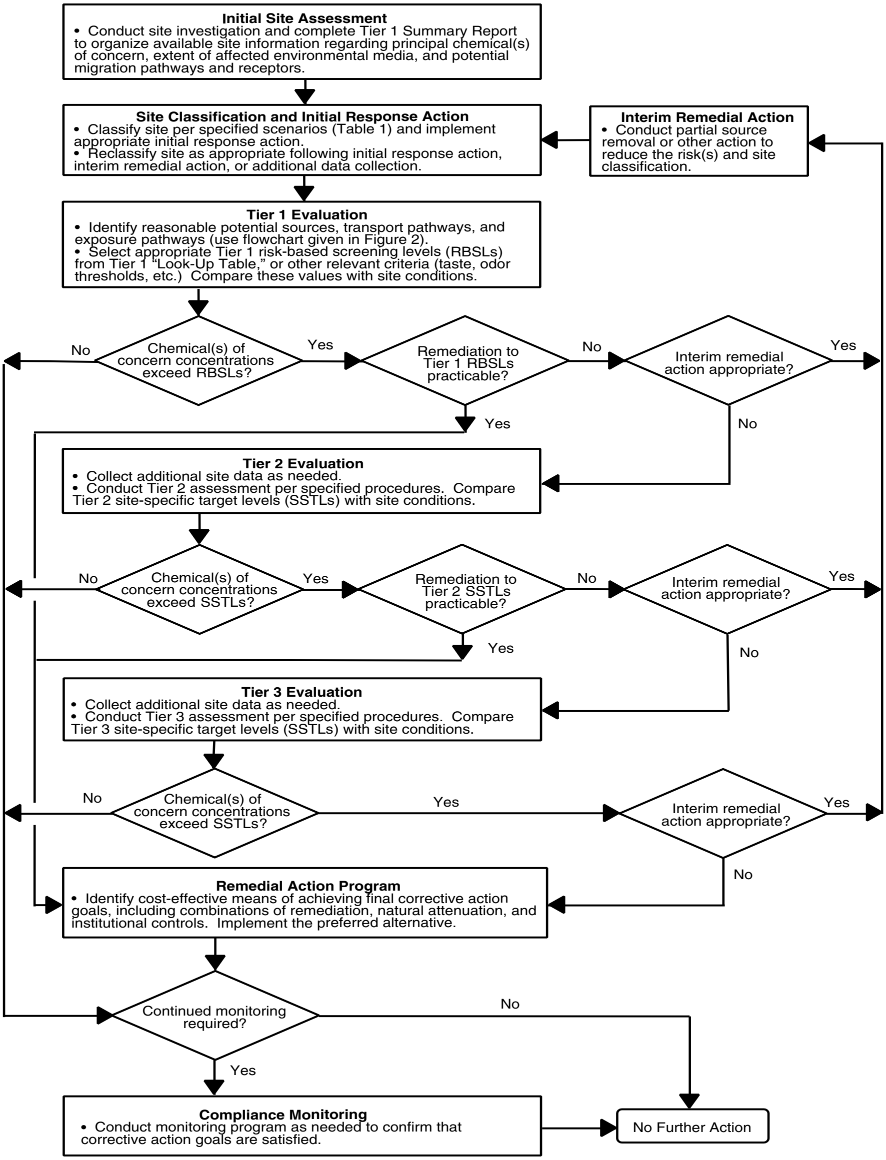

FIGURE 2-3 The three-tiered, 10-step petroleum RBCA flowchart. SOURCE: ASTM, 1995.

assessment is conducted that should result in an initial site classification with regard to interim remedial action. This is followed by a tier 1 analysis, which is followed by tier 2 and tier 3 analyses if necessary. Final and interim (if needed) remedial action plans are formulated from these analyses.

Initial Site Assessment and Classification. During this phase, sources, pathways, and potential receptors are identified and CoCs are quantified (concentration and extent of contamination). Sources include tanks, pipelines, and free product.[4] Possible exposure pathways include movement with the ground water, sorption onto solids, and volatilization and migration to the surface. Petroleum RBCA defines receptors as "persons, structures, utilities, surface waters, and water supply wells that are or may be adversely affected by the release."

Information gathered in this phase is used to classify the site, to determine what initial response is appropriate, to compare with RBSLs in a tier 1 analysis, and to develop SSTLs for tier 2 and tier 3 analyses, if necessary. Petroleum RBCA provides examples of site classification and initial response actions in Table 1 of the standard guide. What constitutes sufficient data collection during this phase is left to the discretion of the user. State RBCAs may specify what level of detail constitutes sufficient data.

The site is classified as an immediate threat, a short-term threat, a long-term threat, or no demonstrable threat. Initial response actions will vary with the severity of contamination. Thus, outcomes can range from monitoring the site in preparation for a tier 1 analysis to removal of sources (such as tanks and pipes) with or without additional control measures (e.g., free product recovery).

Tier 1 Evaluation. In a tier 1 analysis, concentrations of CoCs for different exposure pathways are compared with RBSLs in a look-up table. RBSLs are generic and do not consider site-specific information. For example, the default RBSL for ground water ingestion might be the MCL (if one exists). There are eight exposure pathways given in the sample look-up table in Appendix X2 of the standard guide:

- inhalation of vapors;
- ingestion of ground water;
- inhalation of outdoor vapors originating from contaminants in the ground water;
- inhalation of indoor vapors originating from contaminants in the ground water;

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[4] Free product refers to nonaqueous phase liquid (NAPL) contamination that has leaked from a primary source area into the subsurface and formed a pool of contamination.

- ingestion of surficial soil, inhalation of outdoor vapors and particulates emanating from surficial soils, and dermal absorption resulting from surficial soil contact with skin;
- inhalation of outdoor vapors originating from hydrocarbons in subsurface soils;
- inhalation of indoor vapors originating from subsurface hydrocarbons; and
- ingestion of ground water contaminated by leaching of dissolved hydrocarbons from subsurface soils.

The exposure pathways listed are not all-inclusive; other pathways are possible. There are many assumptions made in developing the equations and calculating these RBSLs. It is noted that the materials presented in the standard guide are "solely for the purpose of presenting an example tier 1 matrix of RBSLs, and these values should not be viewed, or misused as proposed remediation 'standards.'"

Development of RBSLs is a critical step in the RBCA process. First, the user must determine a level of acceptable risk. RBCA suggests using an acceptable risk of 10^{-4} to 10^{-6} for carcinogens and a hazard quotient of 1.0 for noncarcinogens. For mixtures of chemicals, a hazard index may be used where hazard quotients for different chemicals acting by the same mechanism (e.g., liver toxicity) are summed. In developing RBSLs, petroleum RBCA recommends use of toxicological information in the EPA's Integrated Risk Information System (IRIS) (EPA, 1993), Health Effects Assessment Summary Tables (HEAST) (EPA, 1992b), or other peer-reviewed data. Petroleum RBCA allows consideration of non-technical issues, such as future land use and cost of likely remediation in relation to potential risk reduction, in developing RBSLs, although these issues are more likely to be incorporated in the SSTLs developed in a tier 2 analysis.

Because of the potential for their misapplication, considerable attention has been given to the RBSL values given in the appendixes of the petroleum RBCA standard guide. Table 2-2 compares these RBSLs to the RBSLs found in the chemical RBCA standard guide, the EPA generic soil screening levels, RCRA cleanup criteria, and several state generic screening levels. The table includes soil screening values for a variety of contaminants assuming direct ingestion of soil, residential land use, a carcinogenic risk level of 10^{-6}, and a hazard quotient of 1.0. For most of the chemicals, the ASTM RBCA RBSLs are similar to the EPA values. The values for naphthalene and xylene are notable exceptions. The state generic screening values are highly variable and, in general, more conservative than either the EPA or the ASTM RBCA values.

Once RBSLs are developed for all appropriate exposure pathways, they are compared with site data. For a tier 1 analysis, exposure of receptors is assumed to occur at the source area, and generic exposure equations are used. This imparts a measure of conservatism on the tier 1 evaluation. If concentrations of CoCs at

TABLE 2-2 A Comparison of ASTM RBCA, EPA, and State Generic Soil Screening Levels

	Petroleum RBCA[a]	Chemical RBCA[b]	Soil Screening Levels[c]	RCRA Action Levels[d]	Florida[e]	Michigan[f]	New Jersey[e]	Rhode Island[e]	Washington[e]
Exposure Pathway	Direct ingestion	Direct ingestion	Direct ingestion	Direct ingestion	Direct ingestion	Direct ingestion	Direct ingestion	Direct ingestion	Direct ingestion and protection of ground water
Target Risk	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-5}	10^{-6}	10^{-6}	10^{-6}
HQ	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Benzene	5.8	4.7	22	NG	1.1	88	3	2.5	0.5
Benzo(a)pyrene	0.13	0.13	0.09	NG	0.1	1.4	0.66	NG	NG
Cadmium	NG	365	78	40	NG	210	NG	NG	NG
Ethylbenzene	7830	7190	7800	8000	240[g]	140[g]	1000[h]	71	20
Lindane	NG	0.143	0.5	0.5	NG	NG	NG	NG	NG
Mercury	NG	16.1	NG	20	NG	130	NG	NG	NG
MTBE	NG	NG	NG	NG	350	850	NG	390	NG
Naphthalene	977	75900	3100	NG	1000	15000	230	54	NG
Toluene	13300	NG	16000	20000	300	250[g]	1000[h]	190	40
Xylene	1450000	NG	160000	200000	290[g]	150	410	110	20

NOTE: All values for chemical screening levels are given in ppm, or mg/kg. All state values were confirmed with the appropriate regulatory agency.
HQ = hazard quotient
MTBE = methyl tertiary-butyl ether
NG = not given

[a] ASTM, 1995

[b] ASTM, 1998

[c] EPA, 1996b

[d] Federal Register, 1990

[e] Judge et al., 1997

[f] Michigan Department of Natural Resources, 1998

[g] Concentrations capped at the soil saturation limit. Different states used different limits for the same compound.

[h] New Jersey standards for toluene and ethylbenzene were capped at 1000 due to concerns over inhalation of these compounds.

the source area are below RBSLs and if there is confidence that RBSLs will not be exceeded in the future (there is no guidance as to how to arrive at this conclusion), then the site is deemed worthy of no further action. At this point the user and the regulatory agency may enter into some type of closure scenario, which varies from state to state. If, on the other hand, concentrations of CoCs at the source area are greater than RBSLs for one or more exposure pathways, the user has two options: (1) proceed to a tier 2 analysis or (2) institute remedial action. The major driver here is cost: will the cost of a tier 2 analysis and its projected outcome be less than remedial action to achieve RBSLs?

The tier 1 analysis does not consider uncertainty in the data used to make the decision. As currently formulated, the assumption is that RBSLs are conservative (for example, use of MCLs for ground water ingestion). Also, a quantitative determination of ecological risk is not part of petroleum RBCA. During the site assessment, environmental receptors are to be identified. However, there is no discussion about how the user is to decide whether remedial action is required for such receptors (i.e., no "ecological" RBSLs are determined).

Tier 2 Evaluation. In a tier 2 analysis, the point of compliance (where contaminant concentrations must be below target levels) is no longer the source area itself. Instead, contaminant concentrations are compared to target levels at areas away from the source area, where exposure might more realistically occur. Target levels in tier 2, termed SSTLs, are calculated by using the RBSLs from tier 1 in conjunction with site-specific fate-and-transport modeling. Additional site-specific data are required to develop parameters needed to adequately develop and apply fate-and-transport models. Obviously, a tier 2 evaluation will not reduce risk to human and ecological health, but it may result in significant savings in remediation cost.

Tier 2 evaluations require many decisions and assumptions about what types of data to collect, where to collect, and for how long. In order to make such decisions, the user must determine what transport processes and exposure scenarios may occur at the site. Possible fate-and-transport processes include advection, dispersion, sorption, and biodegradation. For example, if intrinsic (passive) bioremediation is thought to be occurring at a petroleum site, the user must collect sufficient data to establish the apparent rate at which biodegradation is occurring.

Once transport processes and exposure scenarios have been determined, the user must decide which fate-and-transport models to use. The examples given in petroleum RBCA (Appendix X3) are fairly simple, but they are not the only applicable models. These fate-and-transport models are more sophisticated than those used in calculating the EPA PRGs or SSLs, particularly for the migration of subsurface volatile organic compounds to indoor air. The increased level of modeling detail requires considerable site-specific environmental data for the calculations.

The development of SSTLs may also include the impact of non-technical issues. Among the most common are potential future land use, potential cost of remedial action, and aesthetic concerns, such as odor.

Once SSTLs are determined, they are compared with measured concentrations of CoCs for relevant exposure pathways. If CoCs are less than SSTLs, limited further action may be required. For example, monitoring may be required for some time to ensure that SSTLs are not exceeded in the future. It is possible that a closure plan can be developed in some cases. If concentrations of CoCs are greater than SSTLs for one or more exposure pathways, the user must decide whether to proceed to a tier 3 analysis or to institute remedial action. Again, the major driver is cost. The complexity and expense of a tier 3 evaluation must be weighed against the cost of remediation to tier 2 SSTLs, or to whatever target levels are mutually agreeable to the user and appropriate regulatory agency.

As with tier 1, petroleum RBCA's tier 2 evaluation does not include a consideration of uncertainty. Individual state RBCAs could include provisions and guidance for inclusion of uncertainty in the development of SSTLs.

Tier 3 Evaluation. Tier 3 involves much more complicated modeling (e.g., time-dependent numerical models) and may include probabilistic evaluation (e.g., Monte Carlo analysis) of sources and model predictions. This requires more site-specific information and more extensive data collection. Site-specific toxicological data may be developed. Petroleum RBCA does not include examples of a tier 3 evaluation.

Once tier 3 SSTLs have been developed for appropriate exposure pathways, they are compared with measured concentrations of CoCs. If CoCs are less than the SSTLs, then, as with a tier 2 evaluation, limited further action may be required. If CoCs are greater than one or more SSTLs, remedial action will be required.

Remedial Action. Remedial action may include a combination of active and passive processes. These include, but are not limited to, source removal, natural attenuation, a variety of engineering remedies (e.g., active bioremediation and soil-vapor extraction), containment technologies, and institutional controls. The remedial action plan may include delineation of monitoring requirements for assessing remediation success, but no specific guidance on monitoring is provided.

Site Closure. Once it has been demonstrated by monitoring or other measures that RBSLs or SSTLs have been achieved as described in the remedial action plan and further monitoring is not required, the site may be closed, "except to ensure that institutional controls (if any) remain in place."

Chemical RBCA (PS 104-98)

Chemical RBCA was written to provide an ASTM framework for sites contaminated with chemicals other than petroleum compounds (e.g., chlorinated organics, phenolics, nitroaromatics, and heavy metals). The general approach is very similar to petroleum RBCA with some important additions. The major additions are a consideration of ecological risk and cumulative risk and details contained in the appendixes where examples of the framework are given.

The chemical RBCA framework is summarized in Figure 2-4, which is almost identical to Figure 2-3, except for (1) the inclusion of ecological risk assessment and (2) an option to return to the tier evaluations if the remedy is not effective. First, a site assessment is conducted that should result in an initial classification of the site with regard to interim remedial action. This is followed by a tier 1 analysis, which is followed by, if necessary, tier 2 and tier 3 analyses. Final and interim remedial action plans are formulated from these tier analyses.

Initial Site Assessment and Classification. Sources, pathways, and potential receptors are identified and CoCs are quantified (concentration and extent of contamination) in this phase in a manner consistent with petroleum RBCA. Major additions include (1) the identification of ecological receptors, (2) a section on data quality objectives, (3) language strongly suggesting that local government and communities be involved in the site assessment, and (4) use of the terms "complete" and "potentially complete" pathways. Data collected must be sufficient to assess the completeness of potential pathways for human, ecological, and habitat exposure.

Tier 1 Evaluation. The framework for a chemical RBCA tier 1 evaluation is different from petroleum RBCA in two major ways, which are summarized in Figure 2-5. First, a conceptual model of the site is developed that delineates "reasonably" potential sources, transport pathways, and "reasonably" potential receptors. Using site assessment data, an analysis of pathway completeness is made. If this analysis indicates that relevant exposure pathways are not complete, no further action is recommended. If one or more relevant exposure pathways are complete or potentially complete, tier 1 evaluation continues. The second major difference is the inclusion of ecological risk in addition to human health risk.

As with petroleum RBCA, concentrations of CoCs for different exposure pathways are compared with RBSLs (calculated from predetermined acceptable risk assumptions) in a look-up table. RBSLs are generic and do not consider site-specific information. Two additional possible pathways are included in the chemical RBCA appendix examples: migration of free-phase liquid in saturated soil and migration of free-phase liquid in unsaturated soil.

In chemical RBCA, a tier 1 evaluation is also conducted for ecological receptors and habitats by developing relevant ecological screening criteria (RESC). These criteria would typically be taken from the literature in a tier 1 evaluation. The document is vague as to how these criteria are to be developed and evaluated.

If concentrations of CoCs are below RBSLs and RESC, no further action is

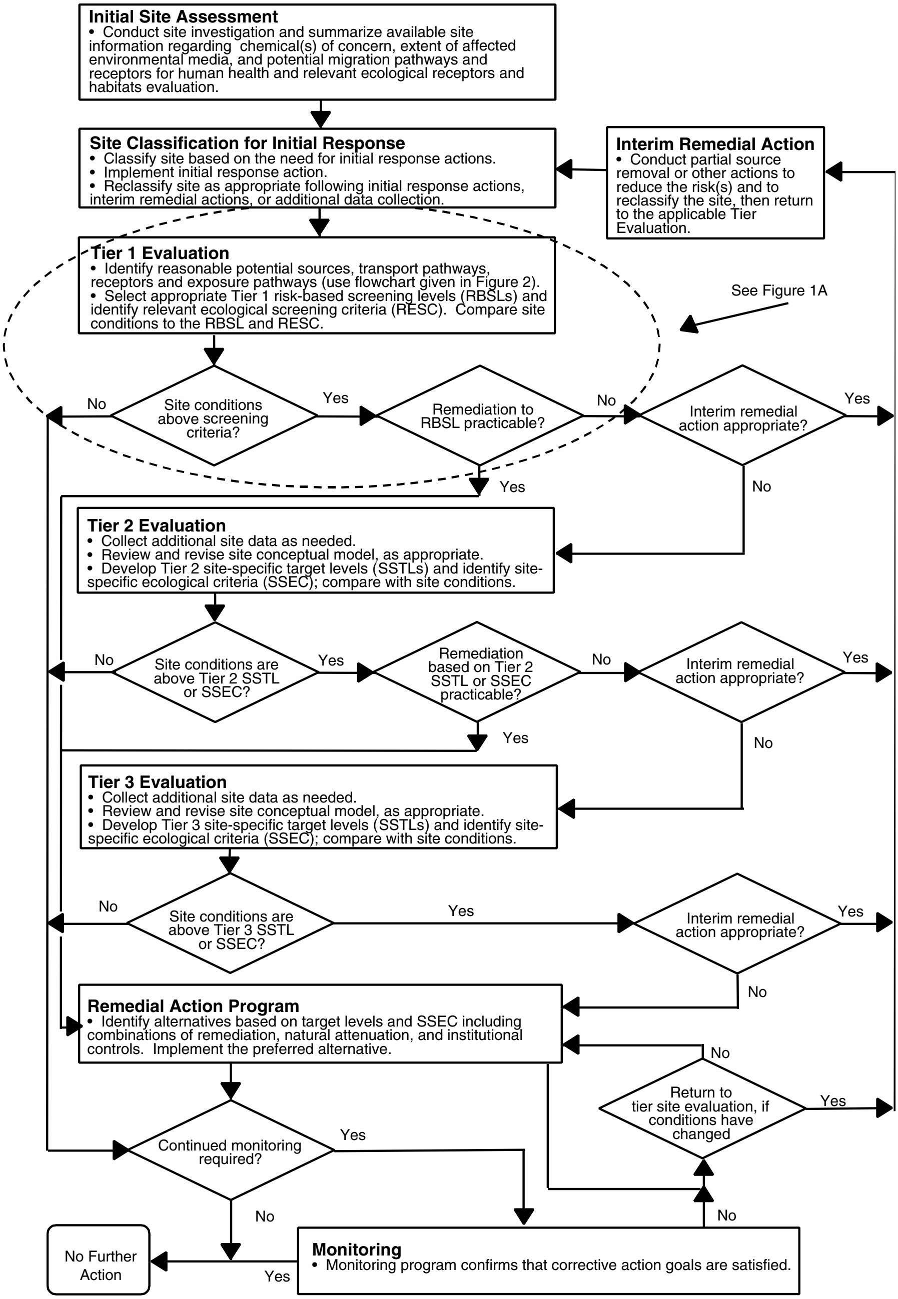


FIGURE 2-4 The three-tiered chemical RBCA flowchart. Note the inclusion of ecological risk at each stage, and the option of returning to a tier evaluation if site conditions change. SOURCE: ASTM, 1998.

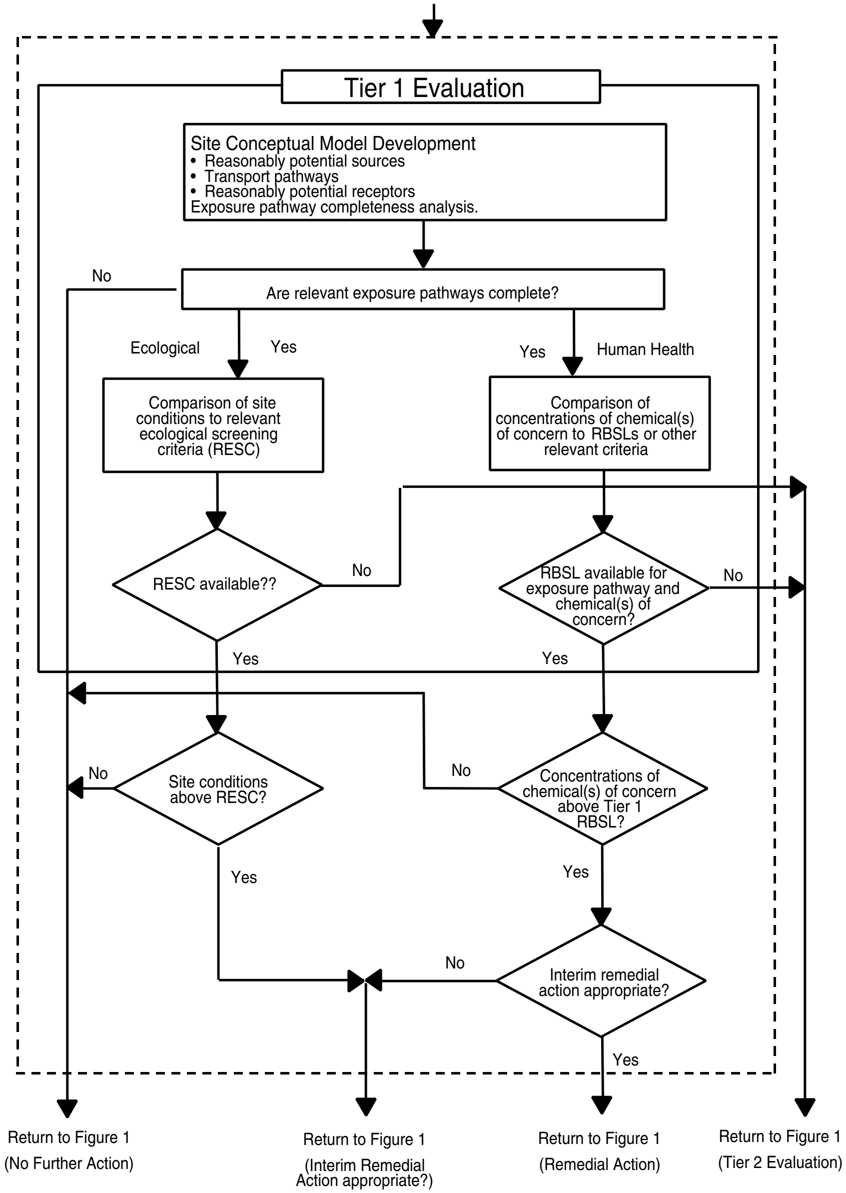


FIGURE 2-5 Framework for the tier 1 evaluation under chemical RBCA. The flowchart is used during the tier 1 evaluation in conjunction with Figure 1 from ASTM, 1998. This version of the tier 1 evaluation contains a consideration of relevant exposure pathways that can lead to early site closeout. SOURCE: ASTM, 1998.

recommended. If they are above RBSLs or RESC, either remedial action or a tier 2 evaluation can commence. A tier 2 evaluation is also recommended for those exposure pathways for which tier 1 RBSLs or RESC are not available.

Tier 2 Evaluation. In a tier 2 analysis, RBSLs and RESC are replaced with SSTLs and site-specific ecological criteria (SSEC), respectively. These are based on additional data collected at the site, revisions in the site conceptual model, and fate-and-transport modeling. RBSLs are applied at point(s) of exposure and then SSTLs for CoCs are calculated at source areas and points of compliance based on fate-and-transport modeling. SSEC can be developed by determining the toxicity of site media (e.g., ground water, soil, and sediment) to test organisms, by conducting biological surveys at the site, or by other lines of converging evidence. Cumulative risk, defined as the combined risk from multiple chemicals or multiple exposures on a single receptor, is mentioned for the first time as part of a chemical RBCA tier 2 evaluation. (Petroleum RBCA does not discuss cumulative risk.) In an attempt to capture the effects of uncertainty, a "statistical data handling method" may be applied to concentrations of CoCs during tier 2. Some guidance on these issues is given in the appendixes; however, much is left to the user's discretion.

Like petroleum RBCA, the chemical RBCA tier 2 evaluation requires many decisions and assumptions. Since many more chemical types are being evaluated, and for the most part our knowledge of the toxicity, fate, and transport of these chemicals is even more uncertain than for petroleum compounds, the decisions and assumptions associated with the calculated SSTLs and SSEC take on greater significance.

As before, once SSTLs and SSEC are determined, they are compared with concentrations of CoCs for relevant complete and potentially complete exposure pathways. If concentrations of CoCs are less than SSTLs and SSEC, limited further action may be required. If concentrations of CoCs are greater than SSTLs or SSEC for one or more complete or potentially complete exposure pathways, the user may proceed to a tier 3 analysis or institute remedial action.

Tier 3 Evaluation. The tier 3 evaluation of chemical RBCA involves much more complicated modeling (e.g., time-dependent numerical models) than tier 2, and it may include probabilistic evaluation (e.g., Monte Carlo analysis) of sources and model predictions, requiring more site-specific information. Values for SSTLs and SSEC may be revised based on this additional information. Once tier 3 SSTLs and SSEC have been developed for appropriate complete and potentially complete exposure pathways, they are compared with concentrations of CoCs. If concentrations of CoCs are less than the SSTLs and SSEC, then, as with a tier 2 evaluation, limited further action may be required. If concentrations of CoCs are greater than one or more SSTLs or SSEC, remedial action will be required.

Remedial Action. Remedial action under chemical RBCA may include a variety of active and passive processes similar to those described in petroleum RBCA. Chemical RBCA more explicitly discusses the criteria that must be considered when choosing the remedial option. These criteria are very similar to the nine NCP criteria and include (1) effectiveness of the remedial action to protect human heath and the environment; (2) long term reliability and probable success in meeting target levels now and in the future; (3) short term risks associated with the remedial activities; (4) amenability of the remedial action to integration with property redevelopment plans; (5) acceptability of the remedial option to affected parties; (6) implementability and technical practicability of the remedial option; and (7) cost effectiveness of the options to meet the target levels. Unlike petroleum RBCA, chemical RBCA discusses options for revisiting the remedy selection if land use or other site conditions change.

Monitoring requirements are more explicit in chemical RBCA. Chemical RBCA states that remedial action must continue until monitoring indicates that concentrations of CoCs are not above RBSLs or SSTLs for a “statistically significant number of monitoring periods.” The goals of monitoring are to : (1) demonstrate the effectiveness of the remedial action; (2) confirm that current conditions persist or improve with time; and (3) verify model assumptions and conditions. If monitoring cannot confirm these accomplishments, the user should reevaluate the remedy or return to the appropriate tier evaluation. Like petroleum RBCA, there is no specific guidance for designing the monitoring system and establishing performance criteria for that system.

Site Closure. Closure requirements are essentially the same as for petroleum RBCA except for the inclusion of ecological risk compliance requirements.

Appendix X1. A major addition to chemical RBCA is Appendix X1, “Considerations for Development of a RBCA Program.” Here general, although minimal, guidance is given regarding cumulative risk, the acceptable risk level, site characterization, ecological risk assessment, selection of remedial actions, monitoring network design, performance criteria, reopening of sites, site closure, and public involvement and risk communication. The appendix provides a matrix for use as an aid in making technical policy decisions and a checklist for implementing a RBCA program. It should be kept in mind that use of the appendixes is entirely up to the user.

State Applications

Like many responsible parties, state environmental cleanup programs are seeking methods that will allow available monetary resources to accomplish the greatest reduction in risk. This is particularly true for state UST programs, many of which are funded partially or wholly with gasoline taxes. Although considerable effort has occurred over the years to incorporate risk into the states' cleanup programs, these activities have been particularly noticeable since the issuance of ASTM's petroleum RBCA standard guide.

To understand the changes that states are making to adopt risk-based methodologies, such as the ASTM RBCA methodology, this committee created a survey to ask questions about state environmental cleanup programs. The survey form is illustrated in Appendix A. The survey was sent to 32 states known to have contaminated naval facilities (Department of the Navy, 1998). For the most part, the survey respondent was a member of the state's regulatory authority, but not always. Oklahoma is included in the survey although it does not have any contaminated naval facilities within its borders. The 19 states that completed the survey are Arizona, Connecticut, Florida, Georgia, Hawaii, Idaho, Indiana, Maine, Maryland, Massachusetts, Minnesota, New York, Pennsylvania, Oregon, Rhode Island, South Carolina, Tennessee, Virginia, and Washington.

Questions were asked about each state's environmental cleanup program including whether it uses some type of risk-based approach during the cleanup process. Answers and any unique or insightful policies are summarized below. The survey used the terminology "risk-based decision-making" rather than "risk-based methodologies" or "risk-based corrective action" to avoid any biases associated with the latter wordings. "Risk-based decision making" refers to the explicit consideration of the risks to human or ecological receptors when determining cleanup goals.

General Use of Risk-Based Decision Making

No state forbids the use of risk-based decision-making (RBDM) at sites contaminated with petroleum. Most states allow some form of this strategy, and seven states require its use. In almost all cases, risk-based decision-making facilitates prioritization of sites for cleanup by providing a metric that can be used to compare the relative risks of different contaminated sites. Almost all responding states allow the use of RBDM at sites contaminated with non-petroleum compounds, and three states (Florida, Oregon, and Rhode Island) require its use. Whether a state uses RBDM often depends on the non-petroleum contaminant present.

There is considerable variation in the differences between each state's risk-based decision-making process and the ASTM RBCA standard guidance. Many states have begun using the ASTM standard guide for petroleum releases at storage tank sites and have made only minor changes to the methodology. Some states have modified RBCA to be more flexible and comprehensive. Others have allowed site-specific values to be incorporated into fate-and-transport parameters prior to a tier 2 evaluation. Efforts have also been made to simplify the system, sometimes by creating a "tier 0" for certain classes of contamination.

For states that have not adopted the ASTM standard guide, there are greater

This collection of drums recovered during a time-critical removal action shows the diversity of tank condition. Courtesy of the U.S. Navy.

distinctions between that guide and the state's RBDM process. These states can be divided into those that use a tiered approach and those that do not. Of the states that use a tiered approach, many of these approaches are similar to the ASTM standard guide, but there can be fundamental differences. For example, some approaches focus more on source removal than ASTM RBCA, while other RBDM processes do not rely on a fixed risk level (e.g., 10^{-6}) or they do not use the same risk level for all compounds. Generic soil and ground water screening levels developed by states represent a type of tiered approach, because they allow low-risk sites to be eliminated from further consideration in the same way that a RBCA tier 1 evaluation does. Table 2-2, which compares RBCA tier 1 RBSLs with state generic screening levels, reveals the substantial variability in the value of these screening levels for direct ingestion of soil. Ten of the states that completed the survey have developed generic screening levels for some types of contamination, while eight states do not have generic screening levels at all.

Considerations of Source Characterization

The main reason risk-based methodologies were developed initially for petroleum compounds is that these compounds were assumed to biodegrade naturally in most soils. The development of risk-based approaches has not been as rapid for other types of contaminants (non-petroleum compounds) because of their recalcitrance and the uncertainties associated with their fate, transport, and toxicity to humans. The states were asked to respond about three particular contaminant classes that can complicate implementation of a risk-based approach to cleanup.

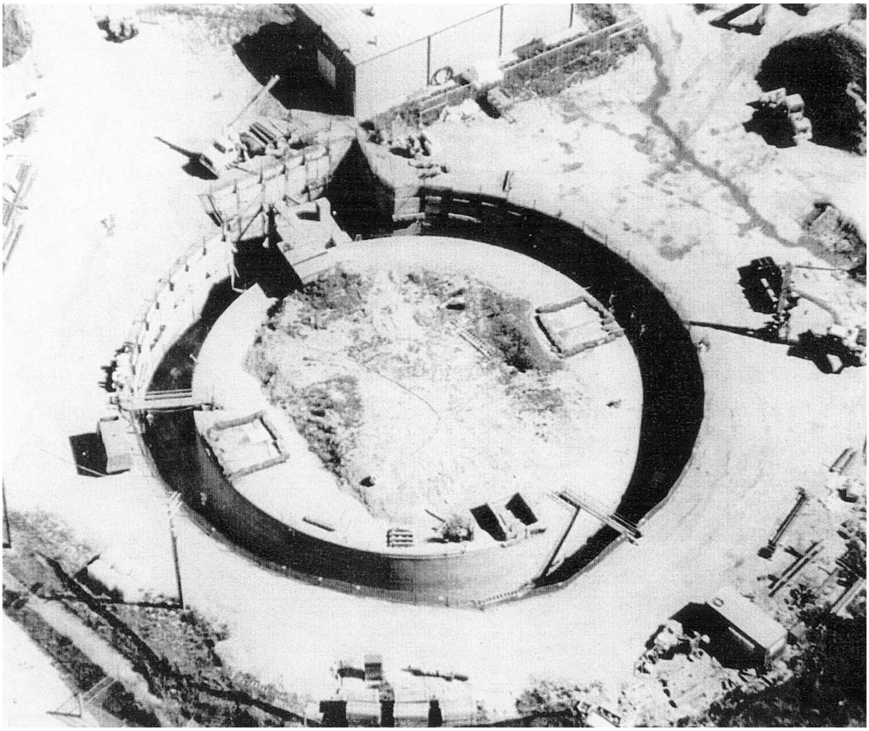
First, most states are moving away from requiring a determination of total petroleum hydrocarbons (TPH), which formed the basis for previous cleanup standards used for leaking USTs. Because the TPH result represents multiple chemicals that may have different chemical and toxicological properties, the risk assessment calculation for TPH is very complicated. States are devising alternative analytical and risk assessment strategies for the hydrocarbon range represented by TPH (e.g., use of surrogate hydrocarbon mixtures).

Approximately half of the responding states require an evaluation of methyl tertiary-butyl ether (MTBE), especially at sites where gasoline has been released. MTBE is a fuel oxygenate that allows fuels to burn more cleanly. It is also an inexpensive way of improving the octane level of gasoline. The EPA has encouraged the use of fuel oxygenates in parts of the country that have failed to attain minimum air quality standards. In December 1997, the EPA issued a health advisory for MTBE that will prompt additional states to regulate the release of this compound. Because it is more mobile and less biodegradable than benzene, the compound generally used to characterize petroleum UST sites, MTBE must be explicitly considered during a site-specific risk assessment. This process is anticipated to be difficult because there is no accepted dose-response relationship or hazard quotient for MTBE.

Most states require the removal of primary contamination sources during cleanup of a hazardous waste site, including any leaking tanks, pipes, and drums. Many states and the ASTM RBCA standard guide also consider free product to be a source. For many technical reasons, source removal of free product is particularly difficult (NRC, 1994). The presence of NAPLs or free product at a site will prevent the closure of a case in most of the states, and may often be the only impediment to UST site closure.

Characterizing Contaminant Pathways

Almost every state has ruled that all contaminant pathways must be evaluated (i.e., no pathway can be considered automatically insignificant). Pathways involving vapor migration appear to receive less attention than other pathways. Some states alter the allowable pathways depending on whether a generic or site-specific evaluation is being conducted.



Cleanup of contaminated soil around an underground storage tank. At this enormous UST, water level was drawn down below tank level and contaminated soil was excavated. Courtesy of the U.S. Navy.

Receptor Characterization

Part of any risk-based approach to cleanup is a decision about whether ground water near a contaminated site can be used as a potential source of drinking water. Almost all states protect the quality of ground water with statutes that declare all ground water to be a potential drinking water supply. This assumption introduces many more potential exposure pathways into the risk assessment process. Most of these states, however, will give the responsible party an opportunity to prove that ground water in the area of its site is not used as a drinking water supply. For example, at a Navy site located in a zone of salt-water intrusion, the state may relax the cleanup goals for ground water resources.

Risk Assessment

In order to implement a risk-based approach to cleanup at a hazardous waste site, states must decide about the many elements of the risk assessment process. A majority of the states have decided that an acceptable target risk for carcinogens is 10^{-5} or 10^{-6} (the states are evenly split between the two). Acceptable risk across all respondents ranges from 10^{-4} to 10^{-6} depending on the type of carcinogen, whether generic or site-specific cleanup goals are used, and the completeness of current and future exposure pathways.

The acceptable hazard quotient for toxicants in most states is 1.0, with values ranging from 0.2 to 3.0. Often, risk from individual chemicals is based on a hazard quotient of 0.2, while cumulative risk of multiple chemicals on a target receptor is based on a hazard index of 1.0.

An assessment of cumulative risk during a tier 2 evaluation is one of the major differences between chemical RBCA and petroleum RBCA. Most risk-based approaches embraced by the states consider cumulative risk, defined as the combined risks of many chemicals on a target receptor. Most of the responding states consider the cumulative risk from exposure to multiple carcinogens or toxicants to be additive. In some states, risks from individual compounds are added only when the toxicants target the same organs, while in other states risks are considered cumulative regardless of the target organ. In some states, the acceptable levels of individual and cumulative risk are different, with the cumulative risk level often being 10 times less conservative than the individual risk level.

Another major difference between petroleum RBCA and chemical RBCA is the inclusion in chemical RBCA of ecological risk assessment. The survey revealed that consideration of ecological risk is also permeating state cleanup programs, although the criteria for evaluating ecological risk vary widely across the country. In general, state guidance on ecological risk assessment is in its infancy. However, if it is known at a particular site that ecological receptors are affected, some states require further evaluation and possible remedial action.

Remedy Selection

The conditions under which each state will accept natural attenuation as a remedial strategy are somewhat variable and often not well documented. In a few states, the respondents were unaware of any policy regarding natural attenuation. In approximately half the responding states, natural attenuation is acceptable or may be considered if it can be shown that the contaminant plume is stable or shrinking, and that the source has been or is being removed. Generally, these determinations must be made by monitoring the plume for contaminant concentration and breakdown products indicative of biological activity. The other responding states were less specific about the criteria needed to validate natural attenuation, although they will accept the strategy if it can be shown to achieve cleanup levels or reduce risk.

States vary widely in how they deal with the technical feasibility of the proposed remedy. Few states have thought about the appropriate course of action to take when treatment technologies fail to meet cleanup goals. For those states that have developed, or are in the process of developing, guidance on this subject, there are three general categories of appropriate action: (1) search for better technology; (2) change the remediation goal to containment rather than removal and install long-term monitoring (and other engineering controls); and (3) impose institutional controls, such as restrictions on future land use. Depending on the affected media and other site-specific considerations, some states will allow certain contaminated sites to move to case closure or into long-term monitoring if technical impracticalities prevent those sites from meeting cleanup goals. Engineering and institutional controls were not mentioned in the responses of many states, although it is likely there are requirements for their use.

It is clear from the survey that the states are moving toward risk-based approaches for addressing environmental contamination. It also appears that many states are developing their own risk-based decision-making process that will satisfy existing environmental statutes. This is especially true for petroleum contamination; in such cases, the ASTM RBCA standard guide has been widely adopted as the cleanup framework.

It is not, however, apparent that the states have developed the appropriate tools to implement risk-based approaches. For example, the states are only now learning about ecological risk assessment. Few states were able to articulate the criteria for choosing natural attenuation as a remedial option and the appropriate monitoring that should accompany such a decision. Many states have yet to formally address the use of engineering and institutional controls, which inevitably must increase with the adoption of a risk-based cleanup approach. Each of these issues is characterized by significant uncertainty, which must be addressed to be confident that the risk-based approach is truly protective of human health and the environment.

The EPA, recognizing the increased use of risk-based approaches, is currently drafting guidance for the states on some of these emerging issues, such as ecological risk assessment, natural attenuation, and institutional controls (EPA, 1997a, b, c, 1998b). It is hoped that the states will incorporate this advice into their risk-based decision making process in a timely manner. The danger with widespread and rapid adoption of risk-based approaches is that some sites may be closed prematurely and inappropriately. Not adequately addressing the uncertainties associated with leaving contamination in place may result in significant risk to future receptors.

REFERENCES

American Society for Testing and Materials (ASTM). 1995. Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (E 1739-95). Annual Book of ASTM Standards. ASTM, West Conshohocken, Pa.

ASTM. 1998. Standard Provisional Guide for Risk-Based Corrective Action (PS 104-98). Annual Book of ASTM Standards. ASTM, West Conshohocken, Pa.

Cooper, D. 1998. Environmental Protection Agency. Personal communication.

Environmental Protection Agency (EPA). 1989. Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A) – Interim Final (EPA/540/1-89/002). Washington, D.C.

EPA. 1991a. Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals) – Interim, (USEPA ORD EPA/540/R-92/003 9285.7-0lB). Washington, D.C.

EPA. 1991b. Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part C, Risk Evaluation of Remedial Alternatives) – Interim (USEPA ORD EPA/540/R-92/004). Washington, D.C.

EPA. 1991c. A Guide to Principal Threat and Low Level Threat Wastes. (USEPA OSWER 9380.3-06FS). Washington, D.C.

EPA. 1992a. Understanding Superfund Risk Assessment. (USEPA 9285.7-06FS). Washington, D.C.

EPA. 1992b. Health Effects Assessment Summary Tables (HEAST). (EPA OSWER OS-230). Washington, D.C.

EPA. 1993. Integrated Risk Information System (IRIS). Washington, D.C.

EPA. 1996a. Soil Screening Guidance: Users Guide. (EPA/540/R-96/018). Washington, D.C.

EPA. 1996b. Soil Screening Guidance: Technical Background Document. (EPA540/R-95/128). Washington, D.C.

EPA. 1997a. Need to Develop Ecological Risk Management Guidelines. (EPA SAB-EPEC-ADV-97-002). Washington, D.C.

EPA. 1997b. Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments. (EPA 540-R-97-006). Washington, D.C.

EPA. 1997c. Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites. Interim Final. Washington, D.C.

EPA. 1998a. Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments) – Interim (USEPA ORD EPA 9285.7-01D). Washington, D.C.

EPA. 1998b. Institutional Controls: A Reference Manual (Working Group Draft).

Farr, J., G. Apostolakis, M. Collins, R. C. Crounch, G. Fogg, M. Reinhard, and K. Scow. 1996. Senate Bill 1764 Advisory Committee's Recommendations Report Regarding California's Underground Storage Tank Program. Submitted to the State Water Resources Control Board pursuant to the requirements of section 25299.38 of the California Health and Safety Code. Sacramento, Calif.

Federal Register. 1990. Corrective Action for Solid Waste Management Units at Hazardous Waste Management Facilities. Fed. Regist. 55(145):30865-30867.

Judge, C., P. Kostecki, and E. Calabrese. 1997. State Summaries of Soil Cleanup Standards. Soil & Groundwater Cleanup. November 1997:10-34.

Michigan Department of Natural Resources. 1998. Part 201 Generic Cleanup Criteria and Screening Levels Developed Under the Authority of the Natural Resources and Environmental Protection Act of 1994. Lansing, Mich.

National Research Council (NRC). 1983. Risk Assessment in the Federal Government: Managing the Process. National Academy Press, Washington, D.C.

NRC. 1993. Issues in Risk Assessment. National Academy Press, Washington, D.C.

NRC. 1994. Science and Judgment in Risk Assessment. National Academy Press, Washington, D.C.

Rice, D. W., B. P. Dooher, S. J. Cullen, L. G. Everett, W. E. Kastenberg, and R. C. Ragaini. 1997. Response to U.S. EPA Comments on the LLNL/UC LUFT Cleanup Recommendations and California Historical Case Analysis. Lawrence Livermore National Laboratory and the University of California.

3

Strengths and Weaknesses of Risk-Based Methodologies

Certain advantages of risk-based methodologies (over resource conservation or technology-based approaches) make them attractive for environmental cleanup. However, important disadvantages of risk-based methodologies cannot be ignored. This chapter includes a description of the strengths and weaknesses common to risk-based methodologies. The major characteristics of the ASTM RBCA methodology and the CERCLA process (including the EPA's Risk Assessment Guidance for Superfund and Soil Screening Guidance) are compared in an illustrative matrix that reveals their similarities and differences. The chapter then discusses how the strengths and weaknesses described for any risk-based methodology are manifested in the ASTM and EPA processes. Finally, other strengths and weaknesses of ASTM RBCA and CERCLA(RAGS/SSG),[1] beyond those characteristic of risk-based methodologies in general, are discussed. These strengths and weaknesses have important implications for the use of these methodologies at naval facilities.

STRENGTHS AND WEAKNESSES OF A GENERIC RISK-BASED APPROACH

Strengths

Risk-based methodologies rely on a systematic process for characterizing contaminated sites and the risks they pose. This feature allows for easier imple-

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[1] The committee recognizes that CERCLA is a federal law written by Congress, while RAGS and SSG are policy documents produced by the EPA for use during the CERCLA process and other cleanup efforts. To simplify terminology in this chapter, the term CERCLA(RAGS/SSG) will be used to refer to the entire CERCLA process, including those steps that use RAGS and the SSG.

mentation of the cleanup process at a large number of contaminated sites. The systematic nature of risk-based methodologies can be the result of a tiered approach, as in the ASTM RBCA standard guides and the EPA Soil Screening Guidance, or some other organizing framework.

Because a quantitative determination of risk is one of the main goals of any risk-based approach, significant amounts of high quality data about the contaminated sites must be collected. Thus, risk-based methodologies require extensive site characterization activities. These activities increase the user's understanding of the nature of the contamination and can identify the immediate need for response actions to reduce the risk. Many risk-based methodologies result in less stringent cleanup goals when significant site characterization efforts are made.

Risk-based methodologies are founded on scientific descriptions of contaminant fate and transport and exposure of human and ecological receptors, and they tend to be scientifically defensible. The best methodologies can incorporate new scientific information as it becomes available.

Associated with the systematic nature of risk-based methodologies is the ability to help prioritize sites. Generally, there are early opportunities during a risk-based process to make an initial determination of the risk posed by a contaminated site. Risks from multiple sites can be compared to rank sites in terms of the hazards posed. Such priority setting can be based on the relevant concerns of the responsible party (e.g., which sites should be targeted for cleanup first, which pose the greatest immediate risk, or which will be easiest to close).

An important benefit of the ranking of sites in a risk-based approach is the potential for the efficient allocation of resources. Depending on the goals of the user, a risk-based approach can help determine how to achieve the greatest risk reduction per dollar spent.

Weaknesses

Many of the weaknesses of risk-based methodologies are ramifications of the fact that they are more likely to leave contamination in place than resource conservation or technology-based approaches. In keeping with recent interagency guidance, the committee defines "contamination left in place" as "hazardous substances, pollutants, or contaminants remaining at the site above levels that allow for unlimited use and unrestricted exposure" (Air Force/Army/Navy/EPA, 1998). Risk-based methodologies are more likely to leave contamination in place because they rely on engineering controls and institutional controls as alternatives to treatment. Institutional controls are often very attractive in the abstract, but in reality they can be difficult to implement and enforce, especially over the long run. The committee has observed that (1) property law makes it difficult to enforce so-called deed restrictions against subsequent owners and (2) local jurisdictions responsible for land use planning rarely coordinate with environmental regulators. Institutional controls, therefore, do not necessarily control exposure, and in some cases, they simply postpone a necessary cleanup.

As stated in Chapter 1, one of the main reasons that potentially responsible parties have sought risk-based cleanup approaches is the lack of proven, affordable technologies for removing source contamination. For many reasons, the development of innovative technologies for removing source contamination has declined over the past ten years (NRC, 1997). It is possible that the adoption of risk-based methodologies will further slow this development, because there will be less demand for such technologies. This would be an unfortunate consequence of the adoption of risk-based methodologies, especially if source removal technologies could be developed that would rival containment technologies in cost and provide permanent risk-reduction.

Finally, leaving contamination in place makes it more likely that unidentified and potentially harmful toxicants will remain on site than if a significant amount of source removal is accomplished. The contents of contaminated sites may be largely unknown, especially at landfills and other sites where multiple waste types exist. These compounds could have fate and transport properties and toxicological properties that could pose significant unanticipated risk to receptors. An example of how the discovery of a previously overlooked compound, MTBE, derailed the implementation of a risk-based approach for cleaning up petroleum UST sites in California is presented in the case study in Box 3-1.

Risk-based methodologies suffer from one other major weakness: uncertainty. Unless all sources of contamination are removed, there will always be some amount of uncertainty regarding the effectiveness of a risk-based approach. (It should be noted that all approaches that leave some contamination in place, including technology-based approaches, are characterized by uncertainty.) Uncertainty affects the risk assessment calculations, as well as the efficacy of treatment technologies, engineering controls, and institutional controls. Risk-based approaches are generally scientifically defensible because they use mathematical descriptions of contaminant fate and transport, exposure pathways, and dose-response relationships; however, they are also inherently limited by the quality of the site data and the accuracy of those models.

The degree of uncertainty associated with the use of a risk-based methodology increases greatly for sites contaminated with non-petroleum compounds. The chemical and biological characteristics of these compounds in ground-water systems, as well as their mobility and toxicity, are much more poorly known than for petroleum hydrocarbons. The behavior of these contaminants can change dramatically in and between sites for the same compound. For example, perchloroethene is biodegradable in anaerobic environments, but it is persistent under aerobic conditions. The application of a risk-based approach to sites contaminated with metals is especially problematic, because the uncertainties in metal behavior are substantially greater than for petroleum hydrocarbons. Unlike many organic contaminants, metals cannot be eliminated from the site by a chemical or biological transformation. Depending on the pH and redox conditions at the site, metals can exist in different chemical forms, each of which may have a different toxicity and mobility. Thus, the uncertainties that accompany contamination by nonpetroleum compounds may be substantial. Risk-based methodologies that do not acknowledge the existence of uncertainty, or make assumptions to reduce uncertainty that may or may not be valid, imply a level of certainty that in fact does not exist.

COMPARING ASTM RBCA AND CERCLA(RAGS/SSG)

The ASTM RBCA standard guides and the CERCLA framework (including RAGS and the Soil Screening Guidance) are both types of risk-based methodologies. Before describing how the previously mentioned strengths and weaknesses manifest themselves in these two methodologies, the basic characteristics of the two methodologies are compared.

As shown in Table 3-1, there are many more similarities than differences between ASTM RBCA and CERCLA(RAGS/SSG). The Soil Screening Guidance and the ASTM RBCA standard guides are both tiered approaches in which generic cleanup levels are replaced with site-specific cleanup levels as more data become available. Both methodologies allow for removal actions throughout the duration of the process. Both mention the use of certain fate-and-transport and dose-response models, although the models given as examples in RBCA tend to be more advanced than those required by the EPA. CERCLA and chemical RBCA contain almost identical criteria for choosing the remedial option, and point to long-term monitoring as an important way of ensuring that the remedial option (including treatment technologies, engineering controls, and institutional controls) works over the long term.

A number of procedural differences between the two methodologies affect their implementation. First, the tiered approach for evaluating increasingly complex sites is available under RBCA for all types of contamination, while under CERCLA the tiered approach is not universal. An explicit tiered approach is given only for soil contamination (the Soil Screening Guidance), although some states have developed generic screening levels for both soil and ground water (see Chapter 2). A comparison of the ASTM and EPA tiered approaches reveals that RBCA has slightly more management options available to the user than the Soil Screening Guidance. That is, under a RBCA tier 1 or tier 2 evaluation, if the site conditions exceed target levels (RBSLs or SSTLs), the user may clean up the site to target levels or proceed to a higher tier evaluation. Under the Soil Screening Guidance, if site conditions exceed generic or site-specific SSLs, the user must proceed to the next tier of evaluation. Thus, RBCA allows management options to be taken earlier in the cleanup process than the Soil Screening Guidance.

Other important differences between ASTM RBCA and CERCLA(RAGS/SSG) relate to how the methodologies are perceived. The ASTM documents are brief, simple, and generally accessible, while EPA documentation tends to be lengthy and scattered. This has resulted in the general perception that the ASTM

BOX 3-1
Case Study: LLNL/UC Recommendations for Leaking Underground Storage Tanks

This case study illustrates an attempt to implement a risk-based approach to cleanup that ultimately failed because of the presence of a previously unidentified compound at the contaminated sites. It also highlights the importance of scientific peer review during the design of risk-based methodologies.

The Lawrence Livermore National Laboratory (LLNL) and the University of California (UC) have been involved in a variety of activities that assess leaking underground fuel tanks (LUFT) for the state of California. Recently, several projects have been undertaken to (1) determine to what extent California's ground-water resources are affected by LUFT, (2) determine what factors affect the length and mass of fuel hydrocarbon (FHC) plumes, and (3) assess whether FHC plumes behave in a predictable fashion (McNab et al., 1997a, b; Rice et al., 1995a, b; Rice et al., 1997; Rice and Kavanaugh, 1997).

In 1995, LLNL/UC analyzed 271 sites that did not have fractured rock hydrogeology, had fairly uniform water chemistry and hydrogeologic characteristics, and often had shallow depth to ground water (< 15 feet). Since gasoline is the major fuel released from LUFTs, and because benzene is considered to be the most toxic of the gasoline components, it was selected as the chemical for study and generalization. The focus was ground water contamination; soil-only cases were not included and exposure via drinking water wells was the only pathway considered. In general, the sites appeared to be characterized by conditions necessary for intrinsic bioremediation.

The conclusions of the initial study (given its stated limitations) were that (1) 90% of the benzene plumes with >10 ppb were less than about 260 feet in length; (2) benzene plumes were relatively stable or shrinking; (3) benzene concentrations decreased with time without active remediation; and (4) LUFTs do not have a significant impact on California's ground-water resources or on public or ecological health. The panel recommended that California immediately modify the ASTM RBCA framework based on the LUFT case data and apply this modified ASTM RBCA framework as soon as possible to LUFT cases.

During a second phase of activity, the LLNL/UC panel developed such a modified RBCA framework and applied it to ten DOD demonstration sites. For these case studies, sites were assessed and a site conceptual model describing sources, concentrations of most chemicals of interest, and potential pathways and receptors was developed. Further, an as-

BOX 3-1 continued

sessment was made concerning future land and resource (e.g., ground water) use. Unlike the more formal ASTM RBCA methodology, the major emphasis of this approach was to collect enough site characterization data to allow estimation of plume stability and length (using benzene as the chemical of concern), and to determine if intrinsic bioremediation was occurring. If it could be demonstrated that the plume was stable, that intrinsic bioremediation was occurring, and that potential receptors were located far enough from the plume, then no further cleanup action would be warranted. These were the conclusions for the two reports made available to this committee. Removal of tanks, pipes, and free product was the only remedial action recommended (if it had not already been done) and monitoring requirements were minimal (either for 2 years or 5 years, with at least 2 monitoring wells).

Although this approach may seem relatively simple compared to the ASTM RBCA methodology, it is not a trivial matter to estimate plume length and stability and determine whether intrinsic bioremediation is occurring. Extensive monitoring and fairly complex modeling are required. In fact, one might argue that this type of modeling is more complex than the fate-and-transport models recommended for a tier 2 ASTM RBCA evaluation.

There was an indication that California policies may be changed as a result of the LLNL/UC reports (Pettit, 1995). A simple variation of the risk-based methodology for LUFT cleanup used at the ten DOD sites was even proposed (California Water Resources Control Board, 1997). In the end, however, the new methodology and the recommendations of the LLNL/UC panel were not endorsed for two main reasons (Farr et al., 1996). First, the recent discovery of widespread MTBE contamination at LUFT sites shifted attention from benzene to MTBE as the chemical of concern. MTBE is more mobile than benzene, far more resistant to biodegradation by indigenous organisms, and its toxicity is not well documented. Several of the sites studied by the LLNL/UC panel were found to contain MTBE plumes that were larger and more mobile than the benzene plumes present at the site. Had a cleanup policy based on average conditions for benzene plumes been developed for LUFT sites, it would have incorrectly accounted for the risks of MTBE. The second factor that hindered the adoption of a risk-based approach in California was the lack of scientific peer review of the LLNL/UC reports and the methodology developed from the report recommendations (Giannopoulos, 1998). This situation highlights the need for broad, independent, and ongoing scientific peer review of risk-based methodologies.

TABLE 3-1 Comparison of EPA and ASTM Risk-Based Approaches

Characteristics/Issues	CERCLA(RAGS/SSG)	ASTM pRBCA & cRBCA[a]
Tiered approach	Soil Screening Guidance only	Yes
Applies to both petroleum and non-petroleum compounds	RCRA-UST - petroleum USTs CERCLA or RCRA - all compounds	Petroleum RBCA - petroleum Chemical RBCA - all compounds
Data requirements	Generally large	Generally large; depends on tier used
Acceptable cancer risk level	10^{-4} - 10^{-6}	10^{-4} - 10^{-6}
Allows for either generic or site-specific cleanup standards	Only under the Soil Screening Guidance	Tier 1 is generic Tiers 2 and 3 are site-specific
Uses a prescribed set of models	Provides default models and assumptions with deviation on approval	Models suggested in the appendix and the literature; appendix models are often used
Removal actions allowed	Yes	Yes
Quantification of uncertainty	Not well described	Not well described
Remedial options	Preference for source removal rather than containment and institutional controls	All remedial options available, including institutional controls
Takes into account the 9 NCP criteria	By definition	Not mentioned - pRBCA Yes - cRBCA
Provides options to revisit sites over the long term	Yes, but seldom practiced	Yes - cRBCA
Underwent scientific peer review	Yes	ASTM peer review only
Public involvement during design	Public comment period	Limited
General perception of the methodology	Costly and time-consuming	Inexpensive and easy
Size of the document(s)	Large	Small

[a] pRBCA = petroleum RBCA, cRBCA = chemical RBCA

RBCA standard guides are easy to use and will result in faster site closeout than CERCLA.

Finally, the ASTM RBCA standard guides did not undergo external scientific peer review prior to their release and were designed by a limited group of stakeholders. EPA methodologies, on the other hand, are designed in an open forum in which the public is allowed months to comment, and they are subject to extensive external peer review.

STRENGTHS AND WEAKNESSES OF ASTM RBCA

How the Strengths of a Risk-Based Approach Are Manifested in ASTM RBCA

The ASTM RBCA methodology is a streamlined and systematic approach to evaluating contamination, mainly as a result of its tiered structure. The tiered structure enables conservative cleanup goals to be replaced by site-specific cleanup goals, when appropriate. The nature of the problem and the quality of data characterizing the site help determine which tier is chosen. Generally, moving from tier 1 to tiers 2 and 3 requires more site-specific data. The tiered approach also makes a large number of diverse sites more manageable by providing a consistent framework for application at all sites and for all contaminants.

Like other risk-based methodologies, ASTM RBCA requires site characterization to evaluate immediate risks, prioritize sites, and define the need for remedial action. Chemical RBCA, in particular, emphasizes the importance of setting data quality objectives. There is little discussion in the standard guides about the quality of data needed for a tier 1 assessment. Some feel that the needs for high quality data are minimized by ASTM's tier 1 evaluation, while others feel that tier 1 data needs are more extensive than is currently required at sites not using ASTM RBCA. Nonetheless, a consistent requirement for some site-specific data is a strength of ASTM RBCA.

The ASTM RBCA methodology is scientifically defensible in its handling of individual risk assessment calculations. The human exposure and health risk assessment models recommended by ASTM are accepted by the regulatory community. Many of the chemical fate and transport concepts recommended for use in the pathway analysis involve current scientific and engineering understanding.

The ASTM RBCA methodology facilitates the prioritization of sites for cleanup. Table 1 in petroleum RBCA explains the initial classification of sites based on immediate, short-term, long-term, or no demonstrable risk to human health and the environment and prescribes response actions for each site category. This information can be used to rank sites for a variety of purposes, including the allocation of financial resources. Experience in Oklahoma, which is using a modified ASTM RBCA methodology for underground storage tank cleanup, has clearly demonstrated the effectiveness of ASTM RBCA in prioritizing sites.

The ASTM RBCA methodology has other unique strengths that account for much of the attention given to the standard guides. For three reasons, the RBCA process may accelerate the cleanup process and expedite site closure: (1) as mentioned above, management options, including remedial actions are available at each tier of the RBCA process (including tier 1); (2) the RBCA methodology makes greater use of engineering and institutional controls, which may take the place of cleanup efforts that are perceived to be time-consuming; and (3) the assessment procedures are standardized for all types of contamination due to the systematic tiered nature of the methodology.

The standardized RBCA process is also beneficial to voluntary cleanup programs. Because it is a well-defined set of rules, the RBCA methodology can be easily used by certified independent risk assessors, and responsible parties will be more likely to implement voluntary cleanup activities. This should allow for a greater number of contaminated sites to be considered under voluntary programs.

Petroleum RBCA's streamlined documentation has facilitated its comprehension and adoption both by states and industry professionals. Though only a qualitative measure, its extensive statewide use (see Chapter 2) supports the notion that petroleum RBCA is an improvement over other available methodologies. Many states have used the ASTM guidelines to develop programs for cleaning up leaking underground storage tanks, and many are considering similar strategies for other chemicals (Begley, 1996). However, even with all the interest in and application of the ASTM RBCA approach, it is still too soon to evaluate comprehensively the success of the methodologies, especially chemical RBCA.

How the Weaknesses of a Risk-Based Approach Are Manifested in ASTM RBCA

Like other risk-based methodologies that leave contamination in place, the ASTM RBCA standard guides suggest remedial options that include combinations of treatment technologies, engineering controls, and institutional controls. All of the negative consequences of remedies that rely on institutional controls will pertain to cleanups done under RBCA. Although the ASTM documents contain information on types of institutional controls, they do not discuss the drawbacks of their use as part of a remedial option or discuss mechanisms for enforcing them.

The potential threat of unidentified compounds left in place is not addressed in the ASTM RBCA methodology. The petroleum RBCA standard guide contains weak language on revisiting sites over the long term. There is no guidance on how long monitoring (or other measures) should be conducted to ensure protection of public health, or how one might reassess the risk of a hazardous waste site at a later date. If the concentrations of CoCs are less than target levels, and the user is confident that sufficient data exist to support the conclusion that concentrations will not exceed target levels in the future, the site can be closed. Chemical RBCA is greatly improved in this respect. It describes more specifically what the purpose of long-term monitoring should be after remedial options are complete. However, chemical RBCA also contains a preliminary step during a tier 1 evaluation that assesses the completeness of the pathways connecting sources of contamination to potential receptors (see Figure 2-5). If it can be shown that relevant exposure pathways are incomplete, sites may be closed prior to comparison of site data with any target cleanup levels. The ASTM has left the interpretation of this figure to the discretion of the state regulatory agencies (Waldorf, 1998). This figure constitutes a significant weakness of the RBCA methodology if it is interpreted to mean that sites can be closed with no further action, rather than being monitored for some period of time to document that relevant exposure pathways remain incomplete.

The potential for risk-based methodologies to discourage development of innovative technologies for source removal has been widely discussed since publication of the ASTM petroleum RBCA standard guide (Hazardous Waste News, 1998; Thompson, 1997). Because the methodology advocates engineering and institutional controls to eliminate receptors and pathways, rather than relying solely on remediation of contaminant sources, there is less incentive to develop new technologies that could remediate a site to unrestricted uses. Critics of the ASTM standard guides suggest that the term "standard" to describe RBCA may be slowing the development of innovative technologies because this term implies that RBCA is a universal standard.

Uncertainty is not dealt with effectively in the ASTM RBCA standard guides. The guides lack explicit considerations of uncertainty factors throughout. Both ASTM RBCAs confront the issue of uncertainty in risk assessment by assuming that RBSLs and, to a certain degree, SSTLs are conservative numbers that take uncertainty into account. Problems with the use of such conservative cleanup goals are discussed in detail in Chapter 4. Little consideration is given to the variability and uncertainty in the concentrations of the chemicals of concern. Appreciation of sampling errors is lacking; it is assumed that all data collected are accurate and precise. Although use of Monte Carlo techniques is suggested as a part of a tier 3 analysis, it is not mentioned for earlier tiers that use site-specific data. ASTM RBCA makes absolutely no mention of the uncertainties in (1) the toxicity of exposure to multiple chemicals, (2) ecological risk assessment, (3) engineering controls, or (4) institutional controls.

The committee identified other weaknesses in the ASTM RBCA methodology beyond those common to all risk-based approaches. As other parties have noted (Cal/EPA, 1994, 1995; Cooper, 1998), the RBCA standard guides give insufficient consideration to cumulative risk. Cumulative risk assessment is completely absent from petroleum RBCA and appears minimally in chemical RBCA during tiers 2 and 3. To be a valid alternative to source removal or technology-based approaches, risk-based approaches must assess the combined risks emanating from multiple contaminants or from multiple pathways on a target receptor.

The RBCA framework is subject to misuse and misinterpretation. For example, the look-up tables and equations presented in the appendixes may be used at sites for which they are inappropriate. Misinterpretation of the document can result if users assume that ASTM RBCA includes all exposure pathways. Unlike other ASTM publications, the RBCA standard guides are not comprehensive tools that require minimal customization on the part of the user. Instead, the methodology was designed so that users could modify the framework to include almost any facet deemed important. Potential misuse has been recognized as a problem by those involved in creation of the RBCA standard guides (Rocco, 1998). ASTM has made efforts to prevent such misinterpretations of the methodology by listing (in section 4.5 of petroleum RBCA and section 4.4 of chemical RBCA) what should be done to apply the frameworks successfully (ASTM, 1998).

The lack of public involvement called for during RBCA implementation is a weakness of the ASTM standard guides, particularly petroleum RBCA. Because the environmental movement is generally wary of risk assessment and risk-based approaches, this lack of public participation can be damaging (Tal, 1997). Chemical RBCA improves upon petroleum RBCA by including a recommendation that the public be involved early in the cleanup process. Two EPA manuals are cited

The excavation of two inactive underground storage tanks is one of thousands taking place at Navy facilities across the country. Courtesy of the U.S. Navy.

as resources for identifying and communicating with interested stakeholders (EPA, 1992a, 1996). Public involvement in the application of risk-based approaches is critical if the goal is to move away from complete remediation toward a level of environmental contamination that does not exceed acceptable health risks.

Finally, a drawback of both RBCA standard guides that cannot be altered now is their design by a limited group of stakeholders. The participants were not necessarily representative of a diverse range of viewpoints, especially those of environmental advocacy organizations. In addition, the RBCA methodology did not undergo documented external, independent scientific peer review prior to being released. An external peer review would not only have added credibility to the ASTM RBCA approach but it would have helped to remove any perceived bias toward the petroleum and chemical industries. (It should be noted that because ASTM standard guides are voluntary, they are not typically drafted by a broad group of stakeholders, nor do they generally undergo external scientific peer review.)

STRENGTHS AND WEAKNESSES OF CERCLA

One of the interesting features of the ASTM RBCA standard guides is their embrace of concepts that are not significantly different from EPA guidance on the same topic. Given all the similarities between the two (as described in Table 3-1), it is not surprising that many strengths and weaknesses of RBCA are shared by CERCLA, RAGS, and the Soil Screening Guidance. There are, however, some important differences between the two. In general, the strengths and weaknesses of a risk-based methodology are not manifested in CERCLA to the same extent as they are in ASTM RBCA.

How the Strengths of a Risk-Based Approach Are Manifested in CERCLA

Site characterization is heavily stressed under the CERCLA framework, taking place during both the preliminary assessment/site inspection and the remedial investigation. The equations used during the RAGS risk assessment calculations are also scientifically defensible. Like other risk-based methodologies, CERCLA is systematic. The RI/FS process, which is used nationwide at thousands of hazardous waste sites (including almost 3,000 Navy sites) is well organized and logical. However, unlike RBCA, which uses the tiered approach for all types of contaminated sites, only the Soil Screening Guidance is tiered. The EPA has not developed a similar tiered approach for ground water because remedial options under CERCLA must comply with ARARs, which often specify maximum contaminant levels for ground water. It is true that many states have devised generic screening levels for soil and ground water contamination that are similar to RBCA tier 1 RBSLs. However, because of the enormous variability in these screening levels from state to state, their existence does not impart greater consistency to the cleanup process. Thus, the different methods for considering ground water and soil contamination, and the variability between state programs that may or may not use generic screening levels, complicate the CERCLA process relative to ASTM RBCA, and make CERCLA less streamlined and systematic.

Another general strength of risk-based methodologies not clearly apparent in the CERCLA process is the prioritization of sites. The Hazard Ranking System, which is used early in the CERCLA process to determine whether facilities should be placed on the National Priorities List, does not allow for a ranking of sites according to relative risk. RAGS was not designed to be a priority-setting tool, as it requires too much data and occurs too late in the process to generate an initial ranking of sites. The military has created its own strategy for requesting and allocating resources among sites (see Chapter 1). However, this evaluation, which involves a cursory estimation of potential sources, pathways, and receptors, does not rank sites for remedial action.

There are important, unique strengths of CERCLA. It is a well-documented methodology that has a history of use at federal facilities. Many Navy remedial project managers expressed confidence in CERCLA over newer methodologies and disliked the notion of retraining personnel to learn a new methodology. They also were skeptical that local regulators would accept newer methodologies, especially at facilities that were being transferred to the private sector. The public is comfortable with the CERCLA framework, largely because it requires clear community relations strategies and offers legal avenues for appeal. Opportunities for the public to become involved in the cleanup occur primarily during the presentation of the proposed remedy. Finally, because CERCLA was generated through a legislative process, it is less likely to be tied to any special interest other than environmental protection. Thus, the public may perceive CERCLA as providing the best assurance of follow-up commitments (e.g., maintenance of long-term monitoring and institutional controls). Whether these commitments are in fact being met at CERCLA sites, however, is under debate.

How the Weaknesses of a Risk-Based Approach Are Manifested in CERCLA

As with the general strengths, the general weaknesses of risk-based methodologies are also less apparent in the CERCLA process. The EPA prefers remedial options that treat sources of contamination, so all weaknesses related to leaving contamination in place are somewhat lessened. Regarding uncertainty, the EPA has acknowledged its importance in the cleanup process (Browner, 1995; EPA, 1992b), but it has yet to provide concrete guidance on how to quantify and reduce uncertainty. Thus, it is not clear that the CERCLA process includes a more thorough consideration of uncertainty than the ASTM RBCA methodology. Like ASTM RBCA, there is no indication that the EPA has considered uncertainties inherent in potential remedial options.

Because CERCLA is somewhat less systematic than ASTM RBCA, the process is likely to be slower. An explicit tiered approach, which can make a large number of diverse sites more manageable, is only available for soil contamination, and even then it can be applied only to sites that fit the criteria outlined in the Soil Screening Guidance. Generic screening levels for soil and ground water are available only in some states and tend to be highly variable.

Finally, the National Contingency Plan clearly states that institutional controls are a last choice for remedial options under CERCLA and should be considered only in combination with containment strategies. In the committee's opinion, the use of institutional controls speeds up the remediation process compared to remedies requiring treatment technologies, because the latter take longer to design and implement. Thus, minimal reliance on institutional controls also contributes to the perception that the CERCLA process is slow.

CONCLUSIONS

This chapter has illustrated that the ASTM RBCA and CERCLA processes share many similarities. However, the ASTM RBCA methodology exhibits more of the characteristics of a typical risk-based methodology, while the CERCLA process focuses more on source removal and unrestricted use of the resource. The potential speed of the cleanup process and the general perception of the methodologies seem to constitute the greatest differences between the two approaches. Neither CERCLA nor ASTM RBCA deals quantitatively with uncertainty. Because uncertainty is the major weakness of risk-based approaches over source removal, it deserves more recognition than it is currently afforded. The next chapter reviews the sources of uncertainty in both the risk assessment and risk management processes and suggests ways for either reducing or quantifying these uncertainties. The committee considers such activities vital to the successful implementation of a risk-based approach for hazardous waste site cleanup.

REFERENCES

Air Force/Army/Navy/EPA Working Group. 1998. The Road to Site Closeout (working draft). Washington, D.C.

Begley, R., 1996. Risk-based Remediation Guidelines Take Hold. Environ. Sci. & Technol. 30:438A-441A.

Browner, C. M. 1995. Policy for Risk Characterization at the U.S. Environmental Protection Agency. Washington, D.C.

California Environmental Protection Agency (Cal/EPA). 1994. Memorandum dated 4/4/94 from G. Michael Schum, Office of Scientific Affairs, to Dennis Rounds, chairman of ASTM E50.01 Subcommittee.

Cal/EPA. 1995. Analysis of RBCA. Memorandum dated 12/1/95 from Ned Butler, staff toxicologist, to Ted Rauh, deputy director, Hazardous Waste Management Program.

California State Water Resources Control Board. 1997. Resolution #01-21-97. Sacramento, Calif.

Cooper, D. 1998. Environmental Protection Agency. Personal communication to Helen Waldorf, chairman of the ASTM chemical RBCA task force.

Environmental Protection Agency (EPA). 1992a. Community Relations in Superfund: A Handbook. EPA540/R-92/009. Washington, D.C.

EPA. 1992b. Understanding Superfund Risk Assessment. USEPA 9285.7-06FS. Washington, D.C.

EPA. 1996. RCRA Public Participation Manual. EPA/530/R-96/007. Washington, D.C.

Farr, J., G. Apostolakis, M. Collins, R. C. Crounch, G. Fogg, M. Reinhard, and K. Scow. 1996. Senate Bill 1764 Advisory Committee's Recommendations Report Regarding California's Underground Storage Tank Program. Submitted to the State Water Resources Control Board pursuant to the requirements of section 25299.38 of the California Health and Safety Code. Sacramento, Calif.

Giannopoulos, J. 1998. California State Water Resources Control Board. Personal communication.

Hazardous Waste News. 1998. ASTM Debate Continues. Hazard. Waste News 20(9):65.

McNab, W. W., B. P. Dooher, D. W. Rice, M. C. Kavanaugh, P. C. Johnson, S. J. Cullen, L. G. Everett, W. E. Kastenberg, and M. C. Small. 1997a. Assessment of Appropriate Fuel Hydrocarbon Risk-Management Strategies for George Air Force Base, Victorville, California, Using a Risk-Based Approach. Lawrence Livermore National Laboratory and the University of California.

McNab, W. W., B. P. Dooher, D. W. Rice, M. C. Kavanaugh, P. C. Johnson, S. J. Cullen, L. G. Everett, W. E. Kastenberg, and M. C. Small. 1997b. Assessment of Appropriate Fuel Hydrocarbon Cleanup Strategies for Travis Air Force Base, Fairfield, California, Using a Risk-Based Approach. Lawrence Livermore National Laboratory and the University of California.

National Research Council (NRC). 1997. Innovations in Ground Water and Soil Cleanup: From Concept to Commercialization. National Academy Press, Washington, D.C.

Pettit, W. 1995. Lawrence Livermore National Laboratory (LLNL) Report on Leaking Underground Storage Tank (UST) Cleanup. Memorandum dated 12/8/95 to all regional water board chairpersons, all regional water board executive officers, and all LOP agency directors.

Rice, D. W., B. P. Dooher, S. J. Cullen, L. G. Everett, W. E. Kastenberg, R. D. Grose, and M. A. Marino. 1995a. Recommendations to Improve the Cleanup Process for California's Leaking Underground Fuel Tanks (LUFTs). Lawrence Livermore National Laboratory and the University of California.

Rice, D. W., J. C. Michaelson, B. P. Dooher, D. H. MacQueen, S. J. Cullen, L. G. Everett, W. E. Kastenberg, R. D. Grose, and M. A. Marino. 1995b. California's Leaking Underground Fuel Tank (LUFT) Historical Case Analyses. Lawrence Livermore National Laboratory and the University of California.

Rice, D. W., B. P. Dooher, S. J. Cullen, L. G. Everett, W. E. Kastenberg, and R. C. Ragaini. 1997. Response to U.S. EPA Comments on the LLNL/UC LUFT Cleanup Recommendations and California Historical Case Analysis. Lawrence Livermore National Laboratory and the University of California.

Rice, D. W., and M. Kavanaugh. 1997. Site Assessment Review to Apply Risk-Based Corrective Action at Site 390 Marine Corps Air Station El Toro, California. Lawrence Livermore National Laboratory.

Rocco, J. 1998. British Petroleum Oil. Personal communication.

Tal, A. 1997. Assessing the Environmental Movement's Attitudes Toward Risk Assessment. Environ. Sci. Technol. 31:470A-476A.

Thompson, D. 1997. ASTM – A Good Thing Gone Astray. Civil Engineering. September, 1997.

Waldorf, H. 1998. Massachusetts Department of Environmental Protection. Personal communication.

4

Uncertainty in Risk-Based Methodologies

From the preceding chapter it should be apparent that a major concern with using risk-based methodologies for hazardous waste cleanup is the uncertainty associated with the risk assessment and risk management processes. Adherence to resource conservation, on the other hand, involves less uncertainty, because, ultimately, contamination is not left in place (although there may be episodic uncertainties regarding the effectiveness of source removal actions). This chapter explores the types of uncertainty encountered during risk assessment, including those associated with sources, pathways, and receptors. A case study illustrates the trade-offs of doing an uncertainty analysis versus using conservative cleanup goals. The chapter closes with an examination of the uncertainties associated with remedial options, including both technical and non-technical solutions.

UNCERTAINTY IN RISK ASSESSMENT

Uncertainty in risk assessment can be dealt with in one of three ways: (1) using conservative cleanup goals, (2) conducting extensive long-term monitoring to reduce uncertainty, or (3) conducting a quantitative analysis of the uncertainty in the risk assessment. An analysis of existing risk-based approaches indicates that most do not adequately address uncertainty (ASTM, 1995, 1998; CA SWRCB, 1997). Decision-makers may recognize uncertainty in risk analysis, but there has been little agreement on how that uncertainty should be incorporated into the risk management process. Almost all risk-based approaches have traditionally relied on the use of conservative assumptions and cleanup goals to account for uncertainty. For example, an "upper-bound" point estimate of risk is often specified. This approach, unfortunately, does not convey the degree of confidence or uncertainty in the risk estimate, and it provides no information about how likely that risk may be.

Long-term monitoring has also been historically conducted on a regular basis, although perhaps not with the stated intention of reducing uncertainty. Long-term monitoring is effective at reducing uncertainty because it helps to further refine the assumptions on which the risk assessment was based. It can also reveal the effectiveness of remedial actions and warn of potential increases in risk over time. However, long-term monitoring cannot reveal the relative importance of different sources of uncertainty, nor can it evaluate how different management strategies might alter those uncertainties.

Although not frequently conducted, a systematic, quantitative assessment of the full range of risk uncertainties and their implications for risk management has significant advantages over the previous two options. Formal uncertainty analyses of risk estimates can actually help to inform decision-makers and the public about the level of conservatism contained in the risk assessment. They can also give risk managers an opportunity to describe the knowledge and rationale used to develop the risk estimate. Such analyses are useful for identifying the uncertainties that create the greatest differences in risk estimates (as the case study presented in this chapter demonstrates). Research or data collection can then be directed toward reducing these major uncertainties. Recent trends indicate that uncertainty analyses may become more commonplace during risk assessment and management (Finkel, 1990; Morgan and Henrion, 1990; NRC, 1994a, 1996; Browner, 1995). The first half of this chapter discusses the major uncertainties to consider when conducting an uncertainty analysis during risk assessment.

Source Characterization

Three conditions are necessary for a risk to exist: a source of contaminants, one or more pathways for contaminant migration, and receptors that are susceptible and exposed to the contaminants. There are significant uncertainties associated with each of these conditions that are briefly described in the following sections and listed in Table 4-1.

Pollutants originate in source areas, either primary or secondary. Primary source contaminants enter the natural environment as a result of specific activities. Examples include chemical storage and transmission (tanks, drums, and pipelines), facility operations (manufacturing, weapons training, civilian services), waste management operations (landfills, impoundments, or sludges), or other direct sources. Secondary sources refer to contaminants that have been transferred from primary sources to the adjacent natural environment and can serve as contaminant “reservoirs.” Examples include residual nonaqueous phase liquids (NAPLs) in either the saturated or unsaturated zones and soils containing adsorbed or precipitated contaminants.

A principal uncertainty in carrying out a risk assessment stems from various

TABLE 4-1 Important Sources of Uncertainty in Subsurface Contaminant Risk Assessment

Sources	Contaminant Pathways	Receptors
• Lack of information on source location(s) • Poorly known history of contaminant releases • Unknown variability in mass or concentration distributions of contaminants • Complexity in the chemical composition of contaminants	• Unknown pattern of subsurface heterogeneity • Complexities due to natural and anthropogenic stresses • Inability to define and characterize physical, chemical, and biological fate and transport processes • Limitations of models of contaminant fate and transport processes • Difficulties in estimating parameters for contaminant fate and transport models	• Limitations of the dose-response models – extrapolation of hazard and toxicity data – insufficient data to identify hazards or dose-response relationship – model selection – parameter estimation for dose-response model • Problems characterizing exposure and outcome – identification of toxicants – identification of target population over time – variability in receptors

unknowns associated with the contaminant source. Often, there is a lack of information about (1) the location of the contamination source; (2) the chemical composition of the contamination; (3) the amount of contaminant released; (4) the time release history of the contaminant; and (5) the present mass and concentration distribution of the contamination.

Some of these uncertainties are amenable to significant reduction. Extensive, focused studies can usually reveal the composition of the contamination, the location of the source, and the approximate mass distribution of the contaminants. This ability to reduce uncertainty underscores the importance of site characterization in any risk-based methodology. Reducing the other uncertainties, though, can be much less straightforward. Typically, only bounds can be put on the quantity of contaminants present and the history of release, because records of facility waste disposal or materials usage are often poor, and leaks may have been undiscovered for long time periods.

There are also uncertainties in source characterization brought about by measurement errors during data collection. For example, delineating a primary or secondary source in three dimensions requires extensive sampling efforts, and a potential source of uncertainty lies in possible errors associated with the location, density, and handling of samples. Fortunately, these sources of uncertainty may be assessed (or even reduced through improved techniques). Thus, sampling and measurement errors may be considered independent of other types of uncertainties in source characterization.

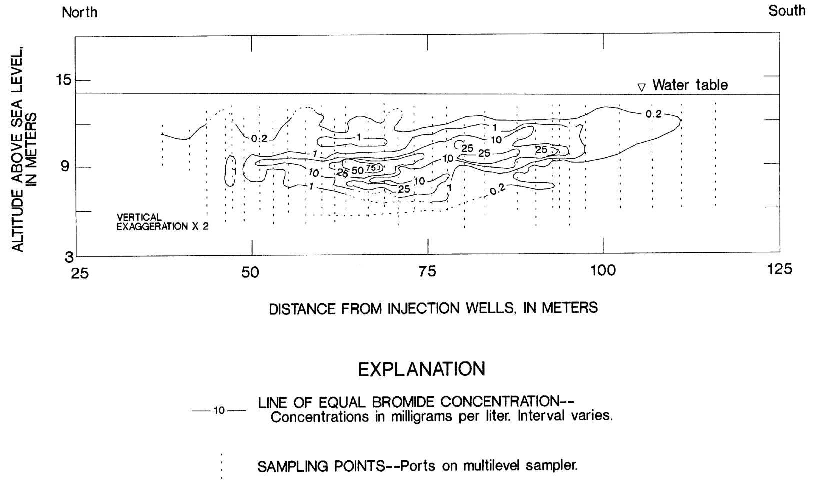


FIGURE 4-1 The spatial distribution of a bromide plume in the subsurface 174 days after injection of the bromide. SOURCE: LeBlanc et al. (1991).

Finally, variability plays a role in the uncertainties encountered during source characterization. As discussed in more detail later, aquifer soil and rock properties are spatially heterogeneous. Variability in aquifer structure gives rise to variability in the subsurface distribution of any contaminant spill. For example, Figure 4-1 illustrates the spatial distribution of a bromide contaminant plume at the U.S. Geological Survey's Cape Cod research site 174 days after injection. Extensive site characterization revealed a contaminant distribution that was highly irregular as a result of variability in aquifer properties. Because acquiring complete knowledge of the soil or rock properties is not possible, a complete description of the concentration distribution of contaminants in the subsurface can never be achieved. However, increasing the sampling of the subsurface (as demonstrated in Figure 4-1) can result in more effective delineation of contaminant plumes.

Pathway Characterization

Pathway characterization with contaminant fate-and-transport models is an essential ingredient of risk assessment and management. The purpose of fate-and-transport modeling is to determine contaminant concentrations at human or ecological receptors as a function of time, given some measured or assumed source concentration. The receptor concentrations are used in exposure modeling to determine the health risk.

Development of quantitative fate-and-transport models requires understanding the physical, chemical, and biological processes that control the transport and fate of contaminants along pathways. These processes have been described extensively in the ground-water literature (e.g., NRC, 1990; Mercer and Faust, 1981). The physical processes of advection, diffusion, and dispersion are responsible for transporting the contaminants. Chemical processes (radioactive decay, sorption, dissolution/precipitation, complexation, and volatilization) and the microbial degradation of organic compounds redistribute mass among the solid, liquid, and gas phases.

Once the prevailing fate-and-transport processes are understood, a conceptual model of the system and its behavior is developed. This conceptual model leads to a mathematical model that can predict contaminant concentrations in space and time. Examples of fate-and-transport models used in risk assessment can be found in the ASTM RBCA standard guides (Appendixes 2 and 3) (ASTM, 1995, 1998) and other guidance documents (Moskowitz et al., 1996).

Table 4-2 summarizes the types of information required for modeling a contaminated site, all of which have some degree of uncertainty in their obtained values. Uncertainties in subsurface fate-and-transport modeling arise from the complexities of the process and the system being modeled, and because limited information is generally available about the site. Many of the uncertainties of fate-and-transport modeling can be reduced by collection of more data. How-

TABLE 4-2 Information Needed for Fate and Transport Modeling

- Aquifer heterogeneity and the spatial variability of inferred parameters
- Geology and geologic boundaries
  - Fractured vs. porous media
  - Consolidated vs. unconsolidated
  - Confined vs. unconfined
  - Single vs. multiple aquifers
  - Location of bedrock
- Hydrologic boundaries
  - Rivers, lakes, water table
- Recharge—spatial and temporal variability
- Source/plume delineation
- Field measurements—hydraulic heads, solute concentrations
- Inferred parameters calculated from field observations
  - Hydraulic conductivity
  - Specific storativity
  - Effective porosity
  - Dispersivity
  - Matrix diffusion
  - Distribution coefficient
  - Chemical and biological degradation rates
  - Reaction rates, stoichiometry

ever, the natural variabilities of aquifer parameters cannot be reduced, although their effects on model outputs can be assessed.

Aquifer heterogeneity and the spatial variability of parameters. The main feature of aquifers that gives rise to uncertainty in fate-and-transport modeling is the intrinsic heterogeneity of aquifer materials. Natural soils and fractured rock formations are highly variable because of fluctuations in the geologic and climatic processes that give rise to their formation. Hydraulic conductivity (or permeability), the most important aquifer property controlling water movement, has been found to vary over several orders of magnitude over small distances (LeBlanc et al., 1991; Rehfeldt et al., 1992).

Although the heterogeneity of subsurface materials affects source characterization by hampering a determination of the spatial extent of contamination, its effects on contaminant migration are more far-reaching. Not only do subsurface heterogeneities affect the physical movement of contaminants in the subsurface but they also affect the chemical form of those contaminants, the local sorptive capacity of the aquifer for the contaminants, and chemical and biological rates of contaminant degradation.

Variability in the hydraulic conductivity of subsurface materials directly affects the dispersive properties of an aquifer (i.e., how the aquifer material causes a contaminant to mix with the native ground water). When hydraulic conductivity varies over several orders of magnitude in a short distance, complex contaminant distributions can result, with portions of the contaminant plume traveling at differing velocities. Measuring hydraulic conductivity distributions in spatial detail and their effect on contaminant dispersion is, for all practical purposes, an impossible task. However, modeling methods can be used to consider the effect of hydraulic conductivity on contaminant transport (Gelhar, 1993).

In addition to physical heterogeneity observed in the subsurface, investigators have documented accompanying mineral or chemical heterogeneity. The distribution coefficient (K_d), which is used to quantify the extent of sorption to subsurface materials, has also been postulated to be correlated with hydraulic conductivity (Robin et al., 1991; Foster-Reid, 1994). The spatial variability of field-scale biotic and abiotic decay processes is also likely due to the variability in substrate and nutrient distribution in the subsurface. For example, variability of substrates, such as natural organic matter, benzene, and toluene, has been shown to impede determination of an apparent biodegradation rate constant for a given subsurface condition (Chapelle et al., 1996).

Geologic boundaries. Basic uncertainties exist regarding how to represent mathematically the geologic boundaries of a contaminated site. Necessary information includes whether the subsurface is porous or fractured, whether it is confined or unconfined, whether it can be represented as single or multiple aquifers, and the location of bedrock or other confining layers. Although this kind of information is unknown at the beginning of a modeling project, it can be approximated with such routine methods as field reconnaissance and examination of any existing geologic maps. Therefore, this source of uncertainty can be reduced with a known level of confidence.

Hydrologic boundaries and recharge. Constant-head boundaries, such as streams, lakes, and the water table, exhibit temporal variability, a source of uncertainty that may be difficult to quantify and will require examination of historical hydrologic records. The temporal and spatial variability of recharge to an aquifer due to rainfall is also an important phenomenon that must be quantified because of its significant effect on the downward migration of contaminants. Although it is fairly easy to assess temporal variability of precipitation from rainfall records, spatial variability cannot generally be assessed.

Measurement errors. Field measurements used as direct inputs to fate-and-transport mathematical models, such as aquifer properties, hydraulic head, and solute concentration, are all subject to uncertainty because of errors associated with making such measurements. These sources of uncertainty can usually be quantified.

Parameter estimates. The parameters of ground water flow and solute transport models are hydraulic conductivity, specific storativity, effective porosity, dispersivity, matrix diffusion, distribution coefficients, decay coefficients, and reaction rates. These parameters are inferred by fitting mathematical models to measured head and solute concentration data. If there are errors in the measured values of head and concentration, these errors will affect the calculated parameter values, which will give rise to uncertainty in the risk assessment.

Like the uncertainties in source characterization, many uncertainties in pathway characterization can be reduced with intensive data collection. However, for dissolved plume and vapor transport pathways, the most important uncertainty is the variability of aquifer properties. Although uncertainties due to variability cannot be reduced, they can be quantified by examining the statistical properties of model inputs and the way these statistics propagate to the model output.

Models that can represent variability in their output are termed stochastic, while deterministic models generate a single output. The use of stochastic modeling implies that the input parameters, and therefore the outputs, are not known with certainty. One of the most common methods of stochastic modeling is the Monte Carlo simulation, in which various realizations of equally plausible, spatially variable input parameters are numerically generated and then the appropriate transport model is applied. The mean output, as well as the variability about the mean, is calculated. In this way, confidence limits can be specified for both the inputs and outputs, and the inherent uncertainty in the model output due to aquifer heterogeneity can be quantified. Monte Carlo analysis has been used successfully to represent uncertainty in fate-and-transport modeling derived from the variability in hydraulic conductivity (Maxwell et al., 1998) and biodegradation rates (McNab and Dooher, 1998).

Receptor Characterization

Uncertainties in human and ecological receptors arise because basic biologic processes of most organisms and systems are not well understood, exposures are not easily established and are often complex, and sufficient data are not available to estimate health effects. In general, the uncertainties in receptor characterization are as significant as those in source and pathway characterization, and they are less amenable to assessment and reduction.

Human health was the initial focus of environmental regulations and has received considerably more study than ecological health. Assessing the impact of contamination on ecological health presents additional complexities because of the variety of potentially affected organisms and their inter-relations, and the impact of contamination on habitat and natural resources.

Human Receptors

Receptor characterization during risk assessment requires the quantifying of two parameters, both of which are characterized by uncertainty: (1) probable exposure to chemical contamination and (2) the resulting outcome (how the receptor responds to a given exposure).

Exposure. Two principal types of uncertainty are characteristic of human exposure to toxicants: uncertainty concerning the bioavailability of toxicants in environmental media and uncertainty regarding actual doses. Bioavailability refers to the actual concentration of a toxicant that is accessible by humans, which depends greatly on the chemical form of the toxicant. Whether contaminants are bioavailable to humans depends on (1) the particular medium in which the contaminant occurs and (2) a variety of co-factors that will vary among individuals and in the same individual at different times. For example, absorption of ingested contaminants is strongly affected by the presence or absence of food and micronutrients in the gastrointestinal tract.

Determining the actual dose received by humans is challenging. Human exposure to chemicals occurs through intake of food, air, water, soils, and dust. If contaminants have traveled through the subsurface, variable aquifer parameters, such as hydraulic conductivity, will create variable exposure patterns for receptors. This variability can be eliminated only if toxicants are measured directly at the point and time of exposure.

Humans are often exposed to complex mixtures of chemicals. Uncertainty may derive from a lack of data about the effects of certain compounds, incomplete knowledge about chemical reactions occurring in the mixture, and not knowing how best to approximate exposure to mixtures (either by adding or multiplying the exposures from the individual contaminants).

Human behaviors vary greatly, resulting in substantial differences in exposure even in the same environment. For example, children eat, drink, and breathe more per unit of body weight than adults, and their normal behavior results in greater ingestion of soil and dust. Variations in cultural practices may also result in varying ingestion rates. Future research on identifying exposure biomarkers may improve our ability to assess human exposure to toxicants.

Outcome. The outcome of exposure to chemicals can be as difficult to assess as the actual exposure, since, for most chemicals, the health outcome is unknown. This uncertainty is troubling because of the enormous range of known toxic effects of chemicals. Outcome uncertainties can also be caused by variability in the sensitivity to chemical exposures. Among the most important factors contributing to variability are genetic make-up, age, state of health, and previous exposures. The unique genetic make-up of individuals results in inherent differences in the ability to absorb and metabolize toxicants and to repair cellular damage. Gender, body size, and relative fat content affect the response to chemical challenges. Age is possibly the factor that results in the greatest range of sensitivity to chemicals in otherwise healthy people. Children's immature physiologic systems may prevent them from efficiently detoxifying toxicants, while the elderly have a decreased ability to repair genetic and cell damage. The state of health at the time of exposure contributes to the variability in response. Cardiac or respiratory disease, liver disease, and pregnancy can influence susceptibility to toxicants. Finally, previous chemical exposure contributes to individual variability of response and can be difficult to assess.

Dose-Response Relationship. Uncertainties arise when relating exposure and outcome with a dose-response curve. These result from a lack of information about underlying principles of chemical toxicity and the need to make estimates based on available data. Use of a dose-response relationship requires extrapolation from high-dose animal experiments to the low-dose scenarios characteristic of human exposure. When adequate human data are available, extrapolation from short-term to long-term exposure scenarios is necessary.

Of the uncertainties described above, the uncertainty of the toxic potential of unstudied or incompletely studied compounds is probably of greatest significance. Differences in chemical toxicity can vary by a billion-fold or more (Kamrin, 1990, p. 7). Among the remaining uncertainties, human variability as a function of age can greatly influence the effect of a toxicant. For reasons stated above, risk assessment models that consider only adult receptors may underestimate the impact of any particular waste site on children. This problem can be overcome by replacing single exposure models based on adult males with a series of models that take into account children, pregnant women, and the elderly, with adjusted parameter values for food, water, and air intake and other significant physiological and behavioral parameters.

Assessing the uncertainty in human receptor characteristics can be accomplished with the same stochastic mechanisms used to model contaminant fate and transport. For example, Monte Carlo analysis can also be used to express the degree of variability of human exposure (Price et al., 1997; Maxwell et al., 1998). However, unless more animal studies, mechanistic toxicology studies, and well-defined epidemiological studies are conducted, reducing the uncertainties associated with the toxicity and dose-response curves of most chemicals is unlikely.

Ecological Receptors

Most of the uncertainties that affect human health risk assessment have close analogues in ecological risk assessment. However, ecological risk assessment must address a vast array of organisms about which little is known, rather than a single species about which much is known.

Exposure. Like human receptors, uncertainty in the exposure of ecological receptors is related to the bioavailability of toxicants and to the actual doses received. Many factors influence the dose received by an organism. The mobility of organisms and the temporal and spatial variability of toxicants produce considerable uncertainty regarding the amount of a specific toxicant absorbed and its resulting internal concentration in target organs. For vertebrate animals exposed primarily through ingestion of contaminated food, rather than from direct dermal contact with environmental media, additional uncertainties relate to the chemical concentrations found in food, the ingestion rates of different foods, and the absorption of chemicals in the gut. Behavioral factors can cause variability in exposure as well, as animals may be either repelled by or attracted to contaminated media.

Outcome. As with humans, there is significant uncertainty about the way an ecological receptor will respond to toxicant exposures. These uncertainties derive from inherent limitations in the available toxicity testing methods, differences in individuals, and differences between species. Different ecotoxicological testing methods, which expose groups of organisms to known chemical concentrations, have inherent uncertainties related to extrapolating the results to the responses of intact organisms. Variability in individuals can also introduce uncertainties. The organisms tested in laboratories are typically genetically homogeneous and are raised under specific conditions. In addition to genetic differences, the age, developmental stage, nutritional status, parasite loads, reproductive condition, and previous exposure history can affect the response of an organism to chemical exposure.

The above uncertainties are essentially the same as the uncertainties in human health risk assessments. Two additional types of uncertainty are unique to ecological risk assessment, and are potentially more important. First, there is variability in the response of different taxonomic groups of organisms to a given contaminant release. The diversity of physiological processes and chemical sensitivities among green plants, fungi, arthropods, mollusks, annelids, vertebrates, and many other types of organisms is much greater than the differences between different human receptor groups. The second and more important uncertainty in ecological risk assessment concerns the ultimate effects of contaminant exposures on the integrity of ecosystems. Under normal conditions, the reproductive potential of most organisms is far greater than is needed for each generation to replace itself. This excess reproductive capacity permits populations to maintain themselves indefinitely in a variable environment. Variability outside the normal range, however, can cause irreversible collapse of ecosystems; the scale of disturbance that can be tolerated is generally unknown.

It might appear from the above discussion that successful management of ecological risks is an impossible task. However, over the past several decades, ecological risk assessors have developed a variety of strategies for identifying and dealing with these uncertainties, such as site-specific studies of impacted

Western gulls nesting on a landfill at the Alameda Naval Air Station. Courtesy of the U.S. Navy.

ecological receptors. Although imperfect, these strategies have led to improvements both in the scientific foundation of ecological risk assessment and in the quality of ecosystems exposed to toxicants.

Conclusions and Recommendations Regarding Uncertainty in Risk Assessment

This chapter opened by identifying three options that could be taken to deal with uncertainty, assuming a risk-based approach is used: (1) use conservative cleanup goals, (2) perform more extensive long-term monitoring to reduce uncertainty, and (3) conduct an analysis of the uncertainty in the risk assessment. Depending on which option or combination of options is chosen, uncertainty in the risk assessment process will have a greater or lesser effect on risk management decisions.

The committee strongly supports the use of a properly designed and implemented long-term monitoring program to reduce uncertainty at contaminated sites. Long-term monitoring provides data that can be used to evaluate assumptions made during fate-and-transport modeling, and these data can be used to improve the estimates of various model parameters, thereby leading to a reduction in modeling uncertainty. Long-term monitoring is also the best way to demonstrate the effectiveness of risk management strategies that have been implemented, and to guarantee that risks do not increase over time. Because most cleanup scenarios already involve some long-term monitoring, enhancing the monitoring program to reduce uncertainty should not require substantial additional expenditures of time and money. It should be noted that although long-term monitoring is an effective strategy for reducing uncertainty, there will always be some "residual" uncertainty about a site (unless the density of monitoring points is impractically large).

To complement long-term monitoring, the committee favors a formal analysis of uncertainty over the use of conservative cleanup goals. Uncertainty analyses allow the user to know the level of uncertainty in a risk estimate, and they reveal the relative significance of different sources of uncertainty (allowing uncertainties to be ranked). This has important implications for future site characterization efforts, for choosing the remedial option, and for design of long-term monitoring networks. As a hypothetical example of the way an uncertainty analysis might focus cleanup efforts, consider a site contaminated by a leaking underground storage tank (UST). If the UST contained highly degradable petroleum products for which the toxicological data, exposure pathways, and biodegradation pathways are well established, the most significant uncertainty may involve the quantity of contaminant released from the tank. At an identical site where MTBE is also present, the greatest uncertainty may shift to the toxicological effects of MTBE on human and ecological receptors. If the UST contains primarily TCE, a highly mobile, relatively nondegradable substance, the variability in aquifer parameters may pose the greatest uncertainty.

Though the preceding example is highly simplistic, uncertainty analyses are complex and must be crafted on a site-by-site basis. It is possible that Navy facilities will need to call on the expertise of ground-water modelers and risk assessment professionals. Forming interdisciplinary partnerships to carry out risk assessment calculations may be a future direction that should be promoted if risk assessment calculations are to become more accurate. The decision to conduct an uncertainty analysis must be made early in the cleanup process prior to the collection and assessment of data. Ideally, the interested public should be involved in this decision-making so that the uncertainty analysis is not perceived as a way to avoid conservative cleanup goals.

Little information is available concerning the cost of conducting an uncertainty analysis. Because it relies on extensive site characterization and the expertise of professional risk assessors, it is likely to be an expensive undertaking. However, the monetary benefits to be gained from an uncertainty analysis can be substantial if such an analysis results in less overestimation of the risk than is typical when using conservative exposure parameters. This is clearly shown in the unique case study by Maxwell et al. (1998) found in Box 4-1. First, the case study demonstrates how an uncertainty analysis resulted in a substantially less stringent cleanup goal than would have been specified by a conservative cleanup goal. The study suggests that quantifying uncertainties may save money in the long run, even though the cost of modeling and data collection to quantify the uncertainties may be high up front. Second, the case study provides a clear example of how variability in the hydraulic conductivity of natural materials and variability in human receptors can be quantitatively incorporated into risk assessment calculations. The same method could be expanded to include uncertainties in other parameters. Finally, the example demonstrates that risk should not be thought of as a single value but rather as a range of values.

UNCERTAINTY IN RISK MANAGEMENT

The uncertainties inherent in conducting risk assessment comprise a major source of the overall uncertainties in the cleanup of hazardous waste sites. Beyond uncertainties in the risk assessment calculation, though, there are more qualitative uncertainties associated with the risk management process. Decisions on appropriate treatment technologies and whether to use engineering and institutional controls in situations where cleanup is not possible are marked with significant uncertainty. Much of the uncertainty arises from factors that have already been discussed; for example, the effectiveness of some treatment technologies is uncertain because of subsurface heterogeneities. These factors, as well as the qualitative uncertainties unique to risk management, are discussed below.

BOX 4-1
Uncertainties Caused by Geologic Heterogeneity and Variability in Human Exposure During Risk Assessment

Part 1: A recent study by Maxwell et al. (1998) quantitatively illustrates the impact of uncertainty in aquifer hydraulic conductivity and human exposure patterns on risk assessment. A hypothetical ground water flow system was considered in which a plume of perchloroethene (PCE) is located upstream of 36 pumping wells (Figure 4-2). As with most field sites, hydraulic conductivity could not be measured everywhere, so a model was used to generate different scenarios of hydraulic conductivity. For each scenario, the mean and variance of hydraulic conductivity values are approximately the same, but the detailed spatial pattern of hydraulic conductivity differs, revealing the variability typical of the subsurface.

A ground water transport model was run for each case, resulting in a time history of PCE concentrations at all pumping wells for each hydraulic conductivity scenario. Ten of these time histories, for equally likely hydraulic conductivity scenarios, are shown in Figure 4-3. The differences between the 10 curves represent the uncertainty in PCE transport due to variable hydraulic conductivity. In the fate-and-transport model, the contaminant was assumed to be conservative and all other parameters were assumed known and certain.

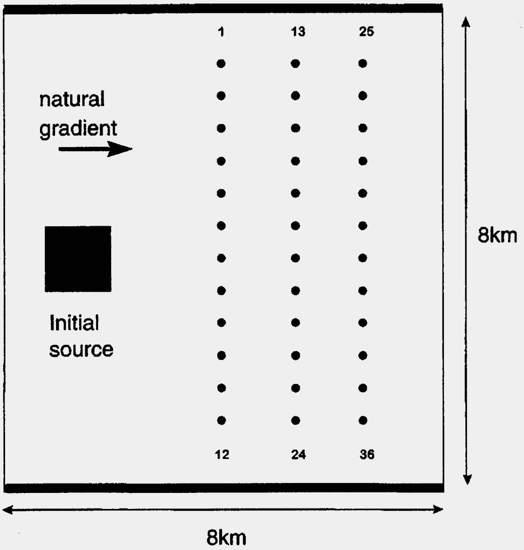


FIGURE 4-2 This site diagram shows the contaminant source relative to the 36 ground water wells, numbered from top to bottom and forward to back.

BOX 4-1 continued

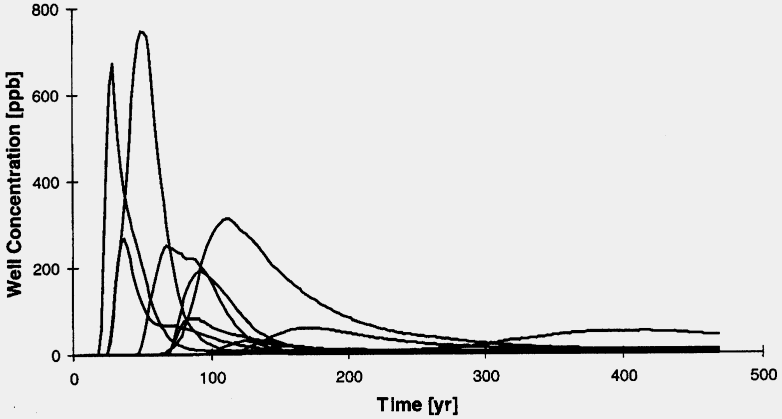


FIGURE 4-3 Concentration breakthrough curves at a well directly downgradient from the PCE source for 10 equally likely scenarios of hydraulic conductivity. Variation between curves represents the uncertainty associated with the aquifer hydraulic conductivity.

Part 2 : To determine how these uncertainties in hydraulic conductivity affect the risk assessment calculation, Maxwell et al. (1998) linked the variable PCE concentrations present at the wells to the potential exposure of humans. Exposure assumptions were: (1) individual well water was mixed before distribution into the drinking water system; (2) exposure duration was 30 years; and (3) exposure pathways included ingestion of tap water, indoor inhalation of vapors transferred from tap water, and sorption through the skin in baths and showers.

Maxwell et al. (1998) also evaluated the uncertainty in the receptor population by considering variability in ingestion rate, inhalation rate, skin permeability, and other parameters. To do this, Monte Carlo sampling of the exposure parameters was used to generate 7,500 “types” of individuals. The variable exposure of individuals is characterized by the difference between two curves: (1) the 50th fractile curve, which represents the “average” exposed individual and (2) the 95th fractile curve, which encompasses 95 percent of the population.

The variable exposure scenarios and PCE concentrations at the wells were combined to determine the increased cancer risk to humans. Figure 4-4 shows how the cancer risk calculations are affected by both hydraulic conductivity variability and receptor variability. Each of the two curves corresponds to a particular fractile of the exposed population, so the difference between the curves demonstrates the uncertainty due to receptor population variability. Any particular curve represents the cumulative probability distribution of cancer risk over all the hydraulic conductivity

BOX 4-1 continued

scenarios for the given fractile of the receptor population. Therefore, the spread of each curve reflects the uncertainty in cancer risk due to the uncertainty in the hydraulic conductivity scenario. Figure 4-4 shows that the "average" exposed individual (the 50th fractile curve) has about a half an order of magnitude less cancer risk than the 95th fractile individual. The spread of each curve reveals that the hydraulic conductivity uncertainty also causes about a half an order of magnitude variability in cancer risk estimates. An important conclusion of this study is that uncertainty in aquifer parameters and exposure parameters exert equal influence on the estimated risk, which is a significant new finding.

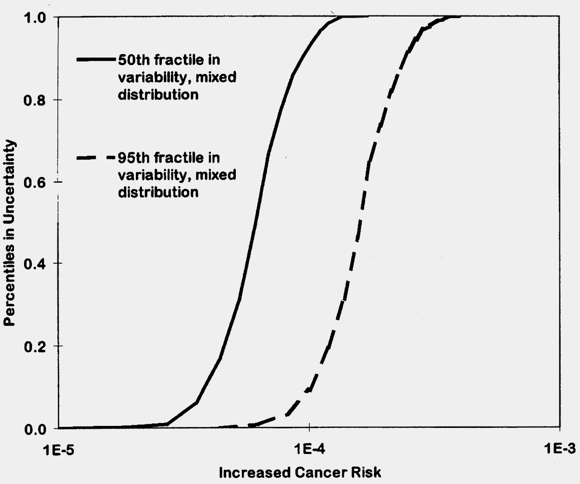


FIGURE 4-4 Cumulative probability distribution over all 400 hydraulic conductivity scenarios for the 50th and 95th fractile individuals in the receptor population. The difference between the two curves represents the effect of variability in the receptor population on the risk estimate, while the spread of each individual curve represents the effect of variability in hydraulic conductivity on the risk estimate. As can be seen, the effects of these two variabilities on the risk estimate are similar in magnitude.

Part 3: Maxwell et al. (1998) compared their uncertainty assessment to more traditional approaches for setting cleanup goals that do not consider uncertainty explicitly. Results are summarized in Figure 4-5. Taking hydraulic conductivity and exposure parameter uncertainty into account generates curves D and E, which are approximately equivalent to curves in Figure 4-4. All the vertical lines in Figure 4-5 are cases in which uncertainty in hydraulic conductivity is neglected. Lines A and C demonstrate a risk methodology that considers uncertainty in the receptor popu-

BOX 4-1 continued

lation but neglects uncertainty in the aquifer parameters. Comparing lines A and C with curves D and E shows that neglect of aquifer parameter uncertainty leads to an underestimation of the increased cancer risk.

Lines B and F represent a methodology that ignores uncertainty in both receptor exposure and hydraulic conductivity parameters by using a fixed value for each of the uncertain exposure parameters and the hydraulic conductivity. Line B considers "average" exposure parameters, while line F assumes 95th percentile values of the exposure parameters, which would be highly conservative. Line F demonstrates that choosing conservative exposure parameters can lead to a dramatic overestimation of the cancer risk. This hypothetical case study suggests that the approach of neglecting uncertainty and using conservative values for the exposure parameters can lead to an overly stringent estimation of contaminant cleanup goals.

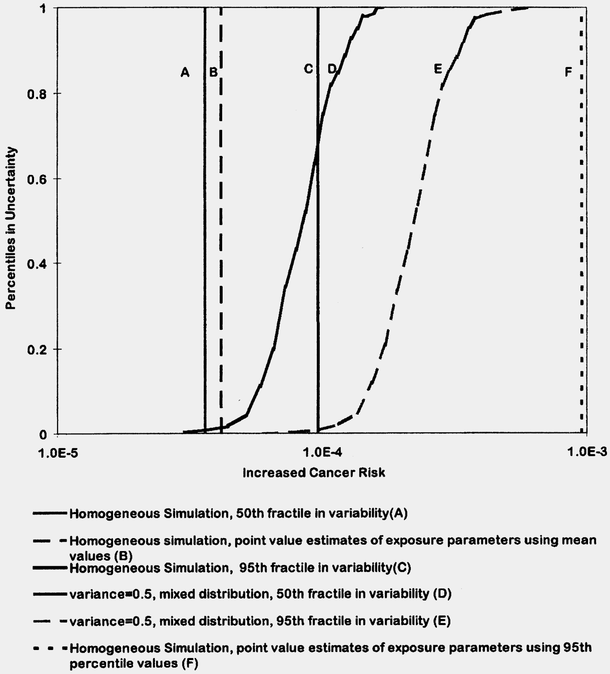


FIGURE 4-5 Comparison of predicted cancer risk for three methods: (1) uncertainty in both receptor exposure and hydraulic conductivity parameters (curves D and E); (2) a homogeneous aquifer model with uncertainty in only the receptor exposure parameters (curves A and C); (3) neglecting all uncertainty and using fixed values for hydraulic conductivity and exposure parameters (curves B and F). Curve F represents conservative exposure parameters.

Technological Solutions

One of the difficulties in managing risks from ground water and soil contamination is the uncertainty of treatment technologies and engineering controls. In making risk management decisions for contaminated ground water and soil, policy makers and risk managers have generally not had enough information to judge the capabilities of technological solutions for the diversity of conditions at waste sites. The historic premise of CERCLA is that ground water should be restored to its beneficial uses (generally to drinking water standards), and many state ground water cleanup programs require the restoration of ground water to pristine conditions (NRC, 1994b). Until recently, insufficient attention was paid to the feasibility of restoration using current technologies. Even now, evaluating the performance of treatment and containment technologies is generally limited to short-term considerations since many of these systems have not been operating for long periods of time (more than 10 years).

Feasibility of Technological Solutions

Determining the feasibility of technological solutions is subject to significant uncertainty for many of the reasons already discussed in this chapter. Difficulties in characterizing the subsurface affect not only source and pathway characterization but also complicate the design of effective cleanup and containment systems. Many technologies require the flushing of fluids, such as water, air, and steam, through the subsurface. Uncertainty about the physical heterogeneity of the subsurface complicates predictions of the flow paths of these treatment fluids (NRC, 1994b, 1997). In addition, cleanup and containment systems often require direct contact between treatment fluids and contaminants. The difficulty in locating contaminant mass, along with inaccessibility of contaminants entrapped in low-permeability zones or in micropores of geologic materials, will limit contact between the treatment fluids and the contaminants, contributing to the uncertainty in system performance (NRC, 1994b, 1997).

Considerable attention has recently been given to the limitations of both treatment technologies and engineering controls. In a 1994 study, the NRC reviewed the performance of conventional ground water cleanup systems, known as pump-and-treat systems, in achieving cleanup standards (NRC, 1994b; MacDonald and Kavanaugh, 1994). Whether these systems would achieve cleanup standards was found to be highly uncertain. After examining 77 active pump-and-treat systems in detail, it was determined that only 8 of the systems had achieved ground water cleanup goals. Whether the remaining systems would achieve cleanup goals was unlikely at 34 of the 77 sites. The NRC found that it was common for contaminant concentrations to rebound above cleanup goals after these goals had apparently been achieved and the pump-and-treat systems shut down. Although the limitations of pump-and-treat systems for complete remediation are now widely

This Soil Vapor Extraction Treatment System is being used for removing petroleum vapors from the underlying vadose zone above the ground water aquifer. Courtesy of the U.S. Navy.

recognized, these systems are still the most common treatment technology at large contaminated sites (used at 93 percent of CERCLA sites where ground water restoration is under way, according to the most recent available EPA data [NRC, 1997]).

As yet, no innovative ground water cleanup technology that can overcome all of the major difficulties in subsurface cleanup has been identified. In a recent review of cleanup technologies, the NRC concluded, "The current state of remediation technology development is relatively rudimentary" (NRC, 1997). Technologies are available for treating mobile and reactive contaminants (such as petroleum hydrocarbons and, to a lesser extent, chlorinated solvents) in permeable, relatively homogeneous geologic settings. However, the treatment of recalcitrant contaminants (such as metals and polychlorinated biphenyls) in complex geologic settings is subject to significant technological limitations.

Reviews of the performance of containment systems have also produced mixed results. Although shown to have limited effectiveness as a treatment technology, pump-and-treat systems that establish hydraulic barriers to isolate contaminant sources can be highly effective in preventing the spread of contaminant plumes. Of the 77 sites reviewed by the NRC (1994b), containment of the contaminant plume was achieved at 40 sites, although cleanup goals were achieved at only 8 sites. Of the 40 sites, 31 were categorized as hard-to-clean sites because of unfavorable hydrogeologic conditions and the type of contamination. Thus, there is less uncertainty associated with the use of pump-and-treat systems when the objective is containment rather than achievement of cleanup goals.

Physical containment systems, such as engineered barriers, have also been investigated for their effectiveness. A review of 34 sites containing vertical barrier walls or caps found that only 4 systems had detectable leaks (Rajaram, et al., 1997). Of 27 horizontal containment systems using liners made of various materials, 10 were found to be ineffective (Bass et al., 1985). A clear understanding of the performance and long-term reliability of containment systems will be critical to the use of risk-based approaches to remediation, which rely less on source removal and more on engineering and institutional controls. In fact, the development of innovative containment systems has been partially attributed to the increased use of risk-based approaches (International Containment Technology Conference, 1997).

The technologies available for treating major classes of contaminants (WASTECH, 1994; NRC, 1997; WASTECH, 1998) and for containing sources of contamination (Rumer and Mitchell, 1995) are extensively discussed in the literature. Whether the technologies can remove contaminants to achieve cleanup goals or contain contaminant sources may be uncertain at the outset of remediation and may need to be determined by trial and error after remediation commences. Risk managers may need to adjust risk management goals based on the capabilities of currently available remediation technologies. This feature is discussed in Chapter 5 as an important criterion for a risk-based approach.

Reducing Uncertainties in Technological Solutions

Several approaches can be taken to manage the uncertainties in the use of treatment technologies and engineering controls.

Use an iterative approach to remediation in which the cleanup or containment system is adjusted in response to data from a monitoring system. With an iterative approach, the accuracy of initial performance estimates can be determined and the system can be adjusted accordingly. Although this approach is presently available, in the committee's experience there is little evidence that it is used on a routine basis or written into decision documents.

At complex sites make greater use of expert panels to review cleanup plans and the feasibility of achieving cleanup goals. A panel of independent reviewers could provide guidance on the site conceptual model, design of the cleanup system, probability of achieving cleanup standards, and the need for a containment system when achievement of cleanup goals is not feasible. This level of oversight will ensure that the remedial options are more durable and scientifically defensible. It will also result in reduced operations and maintenance costs and sustained risk management results.

Develop a data base containing information on the performance of cleanup and containment systems at Navy sites that can be used to reduce uncertainties in future applications of cleanup technologies. This data base would contain information on the specifications of each contaminated site, design parameters for the cleanup or containment system(s) employed, and performance and cost data. The EPA has data bases of RODs and other technologies, but they contain limited information on system performance and cost.

Institutional Controls

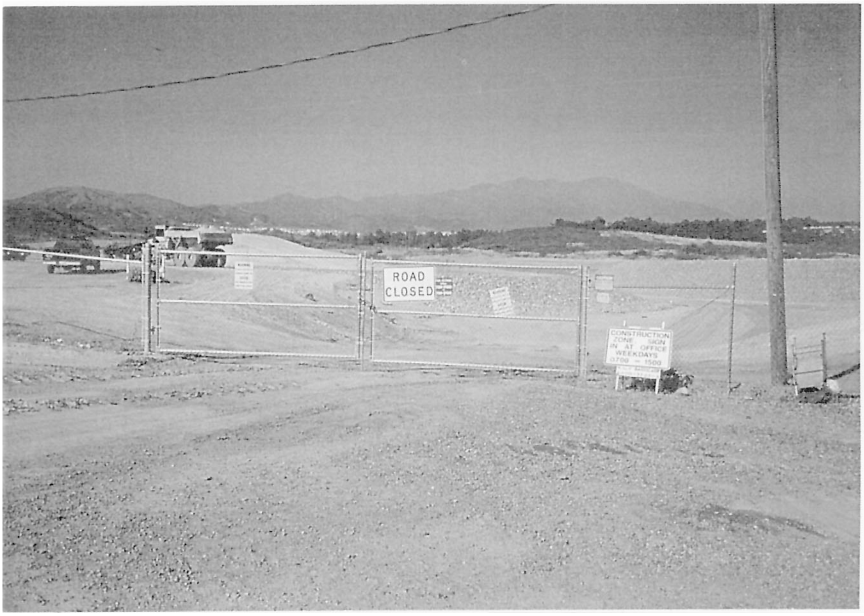
Institutional controls are an essential element of the risk-based approach to remediation. When the elimination of pathways or removal of receptors is used to reduce risk, rather than removal of the source itself, there must be some mechanism to ensure an adequate margin of safety for the life of the hazard. These mechanisms often are controversial, because the contamination problem passes from the responsible party to neighbors or future users of the property. For many reasons, institutional controls generally require long-term monitoring and strict enforcement to be effective.

Institutional controls are defined as non-engineering measures that restrict the use or access to a site or facility to prevent or reduce exposure to hazardous substances (EPA, 1998). The most common scenario involves restrictions on use that significantly reduce public access to contaminated land (e.g., fences, deed restrictions, and restrictive zoning). Another common institutional control is to limit access to ground water by shutting down drinking water wells and restricting new well drilling.

Although risk-based cleanups are often described with zoning terminology (e.g., residential, commercial, industrial), a zoning ordinance is not an effective institutional control, as it is rarely considered sufficiently permanent to limit exposures to hazardous material. Risk assessors, therefore, do not consider zoning; rather, they focus directly on exposure pathways and potential receptors. Institutional controls should block exposure pathways, including inhalation, ingestion, and dermal contact with contaminated media.

Uncertainties in Institutional Controls

At both active bases and closed or former military bases, the lack of enforcement of institutional controls is a major source of uncertainty. Initial decisions about appropriate institutional controls can be difficult because of the conflicting goals of the military, nearby residents, and potential land owners. The military, in an effort to lower cleanup costs, tends to support less stringent cleanup goals that will restrict land use. In contrast, nearby residents and future land owners do not want to be restricted from construction on or access to land, and generally advocate the highest possible cleanup level.



Security fencing is one type of access control used at Navy facilities. Courtesy of the U.S. Navy.

At closed and former military bases, regulators have used various legal instruments to impose long-term controls, including deed restrictions, deed notices, and negative easements. These mechanisms are generally unreliable because they are not supported by long-term oversight. Often institutional controls are adopted with no review by local planning bodies. Even when local communities are consulted (through Restoration Advisory Boards, Local Reuse Authorities, or local governments) there is no guarantee that restrictions will last.

Enforcement of legal institutional controls at active military bases is even more difficult, since there is no property deed, and local governments have no zoning authority. The military has a poor record for keeping track of toxic hazards because it is not subject to local building codes. In addition, the repeated turnover of management, including base commanders, undermines the enforcement of controls. In California and Florida, regulators and the military have developed a plan to rely on a variety of documents, including Federal Facilities Agreements and base master plans, to reinforce institutional controls, but it is too soon to measure their success.

The effectiveness of access controls—responses designed to keep receptors away from hazards—varies with ownership. At active bases, the Navy can effectively enforce such controls, since access to most facilities is restricted for national security purposes. (Whether enforcement actually occurs, however, is dependent on facility size, the land use in surrounding areas, and other factors.) On former military property now in the hands of other federal agencies (the Department of the Interior, for example), access controls are more difficult to maintain. The mission of land management agencies is to encourage, not limit, public use of public lands. Finally, at property transferred to private and other non-federal entities, access controls are also difficult to sustain. Most new uses (economic development, recreation, transportation, and education) require greater public access to the property. Local reuse authorities, developers, and owners have virtually no interest in fencing or patrolling potentially hazardous property.

Even when an institutional control has been agreed to by all relevant parties, there may be unforeseen future changes in land use that negate the effectiveness of the control. At active military bases, if the military must change its use for a section of the base or, more likely, if the installation is later designated for closure, remedies based on institutional controls could backfire.

Reducing Uncertainties in Institutional Controls

Institutional controls are most successful in areas that have physical attributes that are consistent with the controls, or in combination with containment systems. Examples of such controls include:

- building restrictions on a capped landfill in an area already designated, because of its unique habitat, permanent open space;
- building restrictions on runways constructed to withstand a nuclear attack in an area that wants a large airport; or
- restrictions on well drilling into aquifers already classified as nonpotable because of high levels of saltwater intrusion.

Such physical foundations for institutional controls, however, do not eliminate the need for continued monitoring of their performance.

In the absence of favorable physical conditions, enforcement of institutional controls is more difficult. The most important requirement is that institutional controls be reliable in the long run, when the present-day stakeholders are gone. The following recommendations for improving enforceability are made.

Strengthen the legal basis of deed restrictions and easements by modifying real estate law and by writing them explicitly into cleanup Records of Decision or other enforceable agreements. Today, such restrictions are subject to challenge, particularly after multiple transfers of ownership.

Encourage local jurisdictions to sustain land use restrictions through zoning, subdivision maps, building permits, and other activities. Currently, institutional controls may be imposed as part of a cleanup without notifying the local planning body. Furthermore, since local planners have no jurisdiction over federal property until transfer takes place, local reuse authorities need to negotiate institutional controls so their rules and designations match those assumed by the military.

For current and former federal properties, establish a national entity that regularly audits the effectiveness of institutional controls. This could be done by the EPA's Federal Facilities Enforcement Office. The EPA should develop criteria for determining whether institutional controls are functioning properly and under what conditions controls can be relaxed. (The five-year review under CERCLA is designed to make this determination, but there appears to be no standard process for translating such reviews into the arena of institutional controls.)

Encourage public pressure as an oversight tool by systematically providing more information to the public (such as the Toxic Release Inventory and the 800-number hotlines used for utility trenching). A comprehensive national registry, or a network of standardized state registries, of contamination-based institutional controls would be particularly effective. Increasing public awareness about the use of institutional controls should help ensure their protectiveness.

Uncertainties that arise in the long-term effectiveness of institutional controls should make responsible parties and regulators cautious when proposing them. Interim controls remain necessary under any system, and at sites where cleanup is technically impracticable, they may be unavoidable. In other cases, decisions to substitute institutional controls for cleanup to unrestricted use must be carefully weighed. The following two case studies (Boxes 4-2 and 4-3) illustrate the success and failure of institutional controls.

REFERENCES

Abernathy, A. 1998. EPA Office of Solid Waste and Emergency Response. Personal communication.

American Society for Testing and Materials (ASTM). 1995. Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (E 1739-95). Annual Book of ASTM Standards. West Conshohocken, Pa.

ASTM. 1998. Standard Provisional Guide for Risk-Based Corrective Action (PS 104-98). Annual Book of ASTM Standards. West Conshohocken, Pa.

Applegate, J. S., and S. Dycus. 1998. Institutional Controls or Emperor's Clothes? Long-Term Stewardship of the Nuclear Weapons Conflict. Environmental Law Reporter 28(11) 10631-10652.

Bass, J. M., W. J. Lyman, and J. P. Tratnyek. 1985. Assessment of Synthetic Membrane Successes and Failures at Waste Storage and Disposal Sites. Project Summary, EPA/600-S2-85/100. U.S. Environmental Protection Agency, Cincinnati, Ohio.

Browner, C. M. 1995. Policy for Risk Characterization at the U.S. Environmental Protection Agency. Washington, D.C.

California State Water Resources Control Board. 1997. Resolution #01-21-97. Sacramento, Calif.

Chapelle, F. H., P. M. Bradley, D. R. Lovley, and D. A. Vroblesky. 1996. Measuring Rates of Biodegradation in a Contaminated Aquifer Using Field and Laboratory Methods. Groundwater 34(4):691-698.

BOX 4-2
An Institutional Control Success Story

In 1986 the Smuggler Mountain Superfund Site in Aspen, Colorado, was placed on the National Priority List because of elevated levels of metals, particularly lead, in soil in the vicinity of residences. The EPA's proposed remedial options, which included the removal of substantial amounts of soil and the deposit of funds in escrow accounts for future environmental cleanup, were opposed by the community. A catalyst for the opposition was a blood-lead survey that found lead concentrations in the children living near the site below that for the general population.

In an effort to resolve differences between the Aspen community and the EPA, a Technical Advisory Committee (TAC) reviewed documents pertaining to the site; received testimony from experts representing Aspen and the EPA; and answered questions relating to the level of present human risk, future human risk, and any public health measures that should be taken. The TAC concluded that there was no current health threat to any of the residents on or near the site. In addition, the likelihood of a future threat was thought to be small if the demographics, land use, and environmental conditions remained essentially unchanged. Consequently, the TAC recommended the following institutional controls:

- A program of blood-lead surveillance should be established for young children.
- The contaminated berm adjacent to the mobile home park and the Smuggler tennis courts should be capped, covered with clean soil, and planted with appropriate vegetation (a type of engineering control). Monitoring should be instituted to ensure the integrity of the cap, and actions should be taken to correct any breach.
- Vegetable gardens should be planted in raised beds with at least 12 inches of clean soil.
- Soil testing should be made available upon request by residents.
- Proposed changes in site use should be reviewed by the city and county health departments.

These institutional controls have been in place since 1992 and have so far been successful in protecting public health.

BOX 4-3
Institutional Control Failures

Examples of the failure of institutional controls are difficult to obtain because of the varying definition of institutional controls and the controversy surrounding controls that fail. The potential for institutional controls to fail in protecting humans from hazardous waste sites first became apparent with the Love Canal hazardous waste site. The site in upstate New York was filled with chlorinated hydrocarbons, residues, process sludges, flyash, and other materials from both Hooker Chemical Company and the City of Niagara Falls. After dumping ceased in the 1940s, the site was covered over.

In the early 1950s, the City of Niagara Falls School Board became interested in the site for development and construction of a school. Under threat of condemnation, Hooker Chemical, which owned the property, conveyed the site to the School Board in 1953. At that time, institutional controls were poorly defined and standardized mechanisms for implementing institutional controls did not exist. To convey the dangers associated with the site, Hooker warned of the presence of chemicals and the need to keep the Canal covered and advised the School Board not to dig through the waste. However, the deed for the property did not restrict land use, and in 1954, the School Board built an elementary school near the central section of the Canal.

Residential housing expanded adjacent to and around the Canal, and by 1972 housing development was virtually complete. Over the years there were periodic complaints of chemical odors in homes. The heavy snows of 1977-1978 resulted in increased runoff, which coincided with

Environmental Law Institute. 1995. Institutional Controls in Use. Washington, D.C.

Environmental Protection Agency. 1998. Institutional Controls: A Reference Manual (Working Group Draft).

Finkel, A. M. 1990. Confronting Uncertainty in Risk Management - A Guide for Decision-Makers. Center for Risk Management, Resources for the Future. Washington, D.C.

Foster-Reid, G. H. 1994. Variability of hydraulic conductivity and sorption in a heterogeneous aquifer. S. M. Thesis, MIT, Cambridge, Mass.

Gelhar, L. W. 1993. Stochastic Subsurface Hydrology, Prentice Hall, Englewood Cliffs, N.J.

International Containment Technology Conference. 1997. U.S. Environmental Protection Agency, St. Petersburg, Fla., February 9-12.

Kamrin, M. A. 1990. Toxicology Primer. Lewis Publishers, Inc., Chelsea, Mich.

LeBlanc, D. R., S. P. Garabedian, K. M. Hess, L. W. Gelhar, R. D. Quadri, K. G. Stollenwerk, and W. W. Wood. 1991. Large-Scale Natural Gradient Tracer Test in Sand and Gravel, Cape Cod, Massachusetts. 1. Experimental Design and Observed Tracer Movement. Water Resour. Res. 27(5):895-910.

Box 4-3 continued

reports of chemicals at the surface of the Canal and in runoff in the streets, and of odors in basements. These events set off a chain of investigations and environmental and health assessments that led to the closure of the elementary school and the relocation of families adjacent to the Canal. These events also spurred the regulation and control of hazardous waste by state and federal agencies and were the major impetus to the creation of CERCLA.

Other than Love Canal, which has been defined as a failure of institutional controls (Applegate and Dycus, 1998), only anecdotal evidence exists for most failures (Abernathy, 1998). One documented case comes from the state of Oregon, which has a comprehensive planning law designed to prevent contaminated sites from being used inappropriately. This state statute requires all municipalities to submit land use plans to the Oregon Department of Environmental Quality for review. Land use plans are evaluated for their compatibility with existing environmental conditions, especially at sites that contain residual contamination. Recently, state employees discovered that a housing unit had been built on top of a closed landfill (Environmental Law Institute, 1995). The state had previously informed the county that the site could not be built upon without state approval, but this institutional control had failed. Sampling of drinking water wells on the residences at the site revealed contamination, and the residents were instructed to use bottled water. These types of failures are expected to become more frequent in Oregon as development encroaches on rural areas that had been previously used for hazardous waste disposal.

Mackay, D. M., W. P. Ball, and M. G. Durant. 1986. Variability of Aquifer Sorption Properties in a Field Experiment on Groundwater Transport of Organic Solutes: Methods and Preliminary Results. J. Contam. Hydrol. 1:119-132.

MacDonald, J. A., and M. C. Kavanaugh. 1994. Restoring Contaminated Groundwater: An Achievable Goal? Environ. Sci. Technol. 28(8):362A-368A.

Maxwell, R. M., S. D. Pelmulder, A. F. B. Tompson, and W. E. Kastenberg. 1998. On the Development of a New Methodology for Groundwater-driven Health Risk Assessment. Water Resour. Res. 34(4):833-847.

McNab, W. W., and B. P. Dooher. 1998. Uncertainty Analyses of Fuel Hydrocarbon Biodegradation Signatures in Ground Water by Probabilistic Modeling. Ground Water 36(4):691-698.

Mercer, J. W., and C. R. Faust. 1981. Ground-Water Modeling. National Water Well Association. Worthington, Ohio.

Morgan, M. G., and M. Henrion. 1990. Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis. Cambridge University Press. Cambridge, U.K.

Moskowitz, P. D., R. Pardi, V. M. Fthenakis, S. Holtzman, L. C. Sun, and B. Irla. 1996. An Evaluation of Three Representative Multimedia Models Used to Support Cleanup Decision-Making at Hazardous, Mixed, and Radioactive Waste Sites. Risk Anal. 16(2):279-287.

National Research Council (NRC). 1983. Risk Assessment in the Federal Government: Managing the Process. National Academy Press. Washington, D.C.

NRC. 1990. Ground Water Models, Scientific and Regulatory Applications. National Academy Press. Washington, D.C.

NRC. 1993. Issues in Risk Assessment. National Academy Press. Washington, D.C.

NRC. 1994a. Science and Judgment in Risk Assessment. National Academy Press. Washington, D.C.

NRC. 1994b. Alternatives for Ground Water Cleanup. Washington, D.C.: National Academy Press.

NRC. 1996. Understanding Risk. Informing Decisions in a Democratic Society. National Academy Press. Washington, D.C.

NRC. 1997. Innovations in Ground Water and Soil Cleanup: From Concept to Commercialization. Washington, D.C.: National Academy Press.

Price, P. S., R. E. Keenan, J. C. Swartout, C. A. Gillis, H. Carlson-Lynch, and M. L. Dourson. 1997. An Approach for Modeling Noncancer Dose Responses with an Emphasis on Uncertainty. Risk Anal. 17(4):427-437.

Rajaram, V., P. V. Dean, S. A. McLellan, A. Mills, P. L. Chandler, G. W. Snyder, and D. L. Namy. 1997. Performance of Engineered Barriers. In Proceedings of International Containment Technology Conference. St. Petersburg, Fla., February 9-12.

Rehfeldt, K. R., J. M. Boggs, and L. W. Gelhar. 1992. Field Study of Dispersion in a Heterogeneous Aquifer, 3. Geostatistical Analysis of Hydraulic Conductivity. Water Resour. Res. 28(12):3309-3324.

Robin, M. J. L., E. A. Sudicky, R. W. Gillham, and R. G. Kanachanoski. 1991. Spatial Variability of Strontium Distribution Coefficients and Their Hydraulic Conductivity in the Canadian Forces Base Borden Aquifer. Water Resour. Res. 27(1):2619-2632.

Rumer, R. R., and J. K. Mitchell. 1995. Assessment of Barrier Containment Technologies: A Comprehensive Treatment for Environmental Remediation Applications. Prepared under the auspices of the USDOE, USEPA, and DuPont Co. NTIS #PB96-180583.

WASTECH. 1994. Innovative Site Remediation Technology: Phase I (Process Descriptions and Limitation). American Academy of Environmental Engineers, Annapolis, Md.

WASTECH. 1998. Innovative Site Remediation Technology: Phase II (Design and Application). American Academy of Environmental Engineers, Annapolis, Md.

5

Conclusions and Recommendations

THE NAVY'S ENVIRONMENTAL CHALLENGES

This report is the culmination of efforts to help the Navy solve problems in its Environmental Restoration Program. The goals of the first phase of the study were to review the ASTM RBCA standard guides and other relevant methodologies and consider their implementation at Navy facilities. As stated in Chapter 2, the ASTM standard guides and the EPA guidance to which they were compared are risk-based methodologies that contain elements of both risk assessment and risk management. Risk management is considerably more difficult to conduct than risk assessment because it involves issues that go beyond purely scientific considerations. This fact was reflected in discussions with Navy personnel, who characterized their risk assessment process as relatively straightforward, but their risk management decision-making process as complex, variable, and unstructured. The major hurdles the Navy Environmental Restoration Program is struggling to overcome are summarized below.

Cost Control

Environmental remediation competes with the Navy's obligations to maintain a seaworthy and battle-ready fleet. Because of the balanced budget agreement, there is a direct trade-off between money spent on hazardous waste site cleanup and money spent on other Navy activities. As a result, the Navy's budget for performing cleanup of hazardous waste sites is limited. The combined Defense Environmental Restoration Account and BRAC funding for FY97 was $549 million, and the Navy is under pressure from Congress to reduce that figure in future years.

Over the last five years, there has been a trend at Navy facilities toward spending more money on cleanup and less on the study phase that precedes cleanup. The Navy feels this is a move in the right direction in terms of justifying the large amounts of money spent (Department of the Navy, 1998). However, for the most part, the true fiscal requirements of cleanup exceed the budget allocated to the Navy for that purpose. This is because most of the technological solutions are expensive, especially for sites containing highly recalcitrant compounds.

The monetary pressures brought on by the waste cleanup process are not unique to the Navy. General experience in environmental remediation indicates that considerable resources have been spent remediating sites over long periods of time with little to show in terms of percent contaminant removal or risk reduction (NRC, 1994).

The CERCLA process, which the Navy uses for 66 percent of its hazardous waste sites, is complicated and lengthy, and is perceived by some in the Navy as being too expensive. The Navy is seeking alternative strategies that will save money in cleaning up both petroleum and non-petroleum sites. Other risk-based methodologies, such as ASTM RBCA, in which the focus is shifted from treatment technologies to engineering and institutional controls, were perceived as a less expensive way to close sites. The variability between state RBCA programs makes it difficult to assess the validity of these perceptions. However, a recent report summarizing data from 18 states suggests that RBCA could lower cleanup costs for petroleum underground storage tanks by as much as 36 percent (Environmenta1 Information, Ltd., 1997).

Timely Site Close Out

A second problem confronting the Navy is the need to close sites more quickly. As discussed in Chapter 1, pressure to close out sites is coming mainly from communities and developers in areas adjacent to BRAC facilities. Developers are eager to convert the land to other uses, and community members want to maintain the employment levels that existed when the base was active. There is also DOD-wide pressure for the military to complete all necessary environmental remediation. Meeting its cleanup obligations as soon as possible is viewed by the military as an opportunity to focus its resources on objectives relating to national security (Eikenberry, 1998).

The average time needed to complete the CERCLA process has been 10.6 years from initial site investigation to construction of a remedy (GAO, 1998). The Navy has increasingly used removal actions (interim remedial actions) to eliminate sources of contamination before a complete RI/FS is accomplished, thereby accelerating the CERCLA time line. Unfortunately, these actions are effective only if removal of contaminated soils, tanks, and pipes eliminates risk to potential receptors. Very often, enough residual contamination in the soil or tank spillage has leached to the ground water to form a secondary source of contamination. In such cases, removal actions have accomplished important long-term benefits by preventing the contaminant pool from growing, but an RI/FS is still needed to facilitate cleanup or containment of the secondary source. In the same way that other risk-based approaches were perceived as possibly saving the Navy money, they were also thought to accelerate the site closure process. (Experience with the ASTM RBCA methodology in Oklahoma to date has not indicated any increase in the number of sites closed per year.)

Conflicting Regulatory Requirements

Responsible parties like the Navy are faced with multiple regulatory problems. A plethora of federal, state, and local agencies are responsible for the protection of public health and the environment. Empowered by different legislative mandates, each operates with a program- or agency-specific bias. Environmental statutes and regulations are inconsistent across the nation, often differing between agencies within a state. For example, each of the nine Regional Water Quality Control Boards in California operates as an independent regulatory body with its own cleanup criteria for contamination from underground storage tanks.

The result is a conflicting regulatory maze for the regulated community. Responsible parties operating at the national level, like the Navy, would benefit greatly from a consistent risk assessment process and risk management strategy that could be modified to satisfy the various oversight agencies. Adoption of a carefully designed risk-based methodology could be one way of providing such consistency.

Conservative Regulatory Approaches

Some of the regulatory agencies responsible for cleanup oversight at waste sites use conservative assumptions regarding the level of cleanup. This conservatism stems partially from uncertainties in the risk assessment process that force the agencies to adopt safety margins. One result of this conservatism, however, is that responsible parties may feel they are being asked to continue cleanup beyond that required to achieve maximum risk reduction. Responsible parties may also perceive the conservatism of regulatory agencies as being inconsistent with the current limitations in cleanup technology.

Complexity of Naval Facilities

Chapter 1 described many of the features of Navy bases that differentiate them from a typical hazardous waste site. The magnitude of the Navy's environmental liability is extremely high because of the tremendous complexity associated with its installations. Most Navy facilities are large and contain multiple types of hazardous waste sites. In individual sites there may be a variety of toxic

The coastal location of the recently capped McAllister Point Landfill in Newport, Rhode Island, aptly demonstrates it susceptibility to multiple contaminant migration pathways and ecological receptors. Courtesy of the U.S. Navy.

substances, many unidentified and most in unknown quantities because of accidents, outdated management practices, or a lack of recordkeeping. The location of many naval facilities along coastlines introduces potential pathways of contaminant migration and potential human and ecological receptors that are not characteristic of inland facilities. The complexity of most naval facilities suggests that the cleanup of waste at these facilities will be difficult, potentially expensive, and time consuming.

ELEVEN CRITERIA FOR A RISK-BASED METHODOLOGY

The Navy's request for this study reflected the challenges outlined above. The perception by many involved in the environmental cleanup business is that CERCLA is slower and more expensive than other risk-based approaches to cleanup. The committee recognizes the attraction of a new risk-based approach to the Navy Environmental Restoration Program, but remains cautious in recommending its use at Navy facilities. This is because risk-based approaches are more likely than source removal or technology-based approaches to result in remedies that leave contamination in place. The committee agrees that risk-based solutions can have significant short-term benefits. However, it does not believe that the long-term ramifications of leaving contamination in place are sufficiently considered in the methodologies that were reviewed. If a risk-based approach to environmental remediation is to be used at naval facilities, it must overcome the weaknesses that characterize solutions in which contamination is left in place.

Based on its review of federal, state, and other risk-based methodologies, interviews with and presentations from Navy personnel, previous NRC reports, and the expertise of its members, the committee has identified 11 important criteria for a risk-based methodology that addresses hazardous waste sites at Navy facilities. These criteria outlined below take into account the complex characteristics that distinguish Navy facilities from other types of hazardous waste site complexes.

1. An effective risk-based methodology should facilitate prioritization of contaminated sites at individual installations. One of the strengths of a risk-based approach noted in Chapter 3 is the ability to prioritize sites based on their relative risk. This feature is especially important at facilities harboring multiple waste sites. Ranking of sites based on their relative risk can help determine which sites pose immediate threats to human health and the environment, which sites should be cleaned up first, and how much money should be devoted to individual sites. This process should be relatively simple so that its use early in the remediation process can be expedited. Thus, prioritization does not have to occur with the same risk assessment and risk management paradigms that characterize a comprehensive methodology. However, initial data collected for the priority-setting analysis should be easily incorporated into an expanded framework.

2. It should provide a consistent mechanism for addressing all types of sites. The Environmental Restoration Program of the Navy must be able to encompass low risk sites that contain simple, well identified chemicals, as well as high risk sites characterized by multiple, recalcitrant chemicals and unfavorable hydrogeological conditions. Thus, if the Navy adopts a risk-based methodology for environmental remediation, it must include a systematic approach for conducting site investigations of differing complexity.

A risk-based methodology that facilitates the evaluation of both simple and complex sites should allow for the replacement of conservative, generic cleanup goals with less conservative but more site-specific cleanup goals when appropriate. Site-specific cleanup goals ensure that carefully considered and effective solutions are brought to bear on well-defined problems, minimizing the potential for the misallocation of limited resources. On the other hand, when time and resources cannot allow for protracted studies to generate site-specific information, generic cleanup goals should be available that reflect a level of conservatism consistent with the lack of knowledge about the site.

3. It should provide guidance on data collection needed to support the development of site-specific cleanup goals. Because risk-based approaches may suggest remedies in which some contamination is left in place, extensive site characterization and data collection must accompany their use to ensure that they are truly protective of human health and the environment. Currently, there are methods to characterize sources and pathways with known levels of confidence that will bolster the scientific defensibility of the resulting risk estimate. A satisfactory risk-based methodology will provide guidance for setting data collection methods and data quality objectives. It will suggest ways to conduct an initial site assessment that will aid in prioritization of sites, as well as methods of site characterization that can be used to generate site-specific cleanup goals. Consistency in the methods for conducting site characterization is essential for multistate responsible parties like the Navy.

4. It should provide for integrated assessment of sites affecting the same human or ecological receptors. At large facilities containing multiple hazardous waste sites with complex chemical mixtures, such as military bases and Superfund sites, the risk from exposure to contamination may derive from multiple sources. A risk-based methodology must be able to assess quantitatively all of the sources that affect individual human or ecological receptors. First, it must include cumulative risk assessment, which evaluates the effects on potential target receptors of multiple chemicals and multiple exposure pathways originating from a single waste site. Second, an integrated assessment of sites must be conducted to determine the overall facility-wide risk encountered by potential target receptors. As discussed in Box 5-1, an integrated assessment of the potential risks posed by multiple waste sites has not traditionally been performed at naval facilities.

5. It should encourage early action at sites (a) where the risk to human health and the environment is imminent and (b) for which the risks are demonstrably low and remediation is likely to be more rapid and inexpensive. A risk-based methodology will allow for source removal and pathway interruption to eliminate risk to potential receptors before the remedial option has been chosen. It will also facilitate rapid action at sites that are easy and inexpensive to remediate, as defined by the nature of the contaminants present and the affected subsurface (NRC, 1994).

If all contamination is not removed as a result of these early actions, the methodology should evaluate the long-term consequences of removal actions and pathway interruptions with long-term monitoring. If such monitoring shows that contamination remains above acceptable risk levels, further remedial action, such as the implementation of engineering or institutional controls, may be necessary. Although interim removal was never intended to bypass the normal timeline for cleanup under either the EPA or ASTM RBCA methodologies, in practice removal actions often become the only actions taken at a site because of time and money constraints (see Criterion 8).

6. It should consider relevant uncertainties. This report has emphasized the significant uncertainties in risk-based approaches to remediation, e.g., model and data uncertainty, lack of understanding concerning ecological or environmental risk, uncertainty in dose-toxicity relationships, and incomplete knowledge about the enforceability of institutional controls. This uncertainty directly translates to uncertainty in risk estimates, associated cleanup levels, and the effectiveness of the proposed solutions. A quantitative risk-based methodology will allow for the explicit consideration of these uncertainties and suggest options for reducing these uncertainties. For uncertainties that cannot be reduced, the methodology should allow for the use of stochastic modeling approaches, such as the Monte Carlo simulation, rather than deterministic models, in order to represent the degree of uncertainty associated with the risk estimates.

7. It should provide a mechanism for integrating the selection of the remedial option with the establishment of remedial goals. It should also provide quantitative tools for developing risk management strategies. A risk-based methodology provides guidance for calculating the risk of a hazardous waste site (with risk assessment), setting goals for the cleanup process, and determining methods for meeting those goals. This process is sometimes conducted sequentially, with the setting of cleanup goals preceding the selection of a remedial option. In many instances, however, there are no remedies technologically capable of meeting those goals, which can significantly confound the process if cleanup goals are immutable. A risk-based methodology should allow flexibility in setting cleanup goals and selecting remedies by using an iterative approach during which the responsible party and oversight agencies cycle back and forth between these issues.

Currently, the selection of remedial options is qualitative, and relies on the limited guidance embodied by the nine criteria in the NCP (or other similar criteria, as found in the ASTM RBCA standard guides). At least three of the nine criteria, short- and long-term effectiveness of the remedy and cost, are amenable to quantitative analyses. The committee acknowledges that "cookbook" solutions for conducting remedy selection are not workable. However, it believes that quantitative tools for evaluating multiple remedial options can be developed to improve the remedy selection process. Such tools are likely to balance effectiveness and cost and consider risk reduction per dollar of expenditure.

8. It should have options to revisit sites over the long term. Risk-based approaches to the management of contaminated sites must have the ability to quantify and control future risks, both short-term and long-term. Thus, a risk-based methodology may call for future evaluations of risk if site conditions change

BOX 5-1
Using Risk for the Cleanup of USTs at North Island Naval Air Station

A type of risk-based methodology, the Risk-Based Cleanup Index, was prepared for the Navy by Bechtel National, Inc., to address closure of underground storage tanks (USTs) at North Island Naval Air Station (Bechtel National, Inc., 1997). A general description of North Island Naval Station can be found in Box 1-1. A total of 190 individual USTs have been identified at North Island, including tanks currently in use, closed and abandoned tanks, and tanks planned for upgrading or replacement. This index addressed the closure of petroleum tank sites containing gasoline, diesel fuel, marine diesel, and the jet fuels JP-4 and JP-5. It expressly excluded tanks containing chlorinated compounds, acids, metals, and non-petroleum products that met the criteria for classification as non-RCRA hazardous waste. A detailed description of this study is beyond the scope of this report. However, a summary of the key points is relevant to Criterion 4 of a risk-based methodology.

- Because the ground water beneath North Island has been declared unsuitable for drinking water, human exposure to contamination was limited to inhalation of volatile organics and to exposure from dissolved contaminants that migrate to San Diego Bay or to the Pacific Ocean. Calculations of environmental risk indicated little potential exposure of human occupants to volatile organic contaminants present in ground water. Thus, the methodology focused on ecological receptors in the waters surrounding North Island.

over time. Internal DOD and Navy guidance, as well as CERCLA and the other regulatory processes that govern Navy cleanup, are flexible enough to allow site decision makers to adapt to changing site conditions. But the standard practice, encouraged by the pressure to close out sites, is not sufficiently flexible. In the committee's experience, many remedies consist of single actions, such as one remedial action or removal action. This approach may be acceptable when the source of contamination can be completely removed with currently available technologies. However, it is likely to be inappropriate when contamination remains on site after the remedy is in place. The affected public and regulatory agencies may be more willing to accept short-term decisions that appear to leave sources in place if they believe responsible parties are willing to take additional future action. Therefore, the Navy would be best served by a flexible risk-based method-

BOX 5-1 continued

- Contaminant transport by ground water to the marine environment was the main pathway by which pollutant sources were assumed to reach potential receptors. Ground water flow models and estimated biodegradation rates were used to calculate allowable concentrations (cleanup goals) for target indicator compounds present in petroleum at the individual UST locations (BTEX, naphthalene, and polynuclear aromatic hydrocarbons). These allowable concentrations were back calculated from compliance limits set for San Diego Bay and the Pacific Ocean by regulatory authorities. The net outcome of this approach was to provide a risk-based cleanup level for petroleum-based contaminants in the North Island aquifer.

- In determining these cleanup levels, the Navy did not analyze the cumulative impacts of all USTs on potential receptors, but instead examined each tank in isolation. This runs counter to the committee's recommendation that any risk-based methodology used by the Navy should perform an integrated risk assessment of all sites affecting the same human or ecological receptors. It is not known whether an integrated assessment of sites would have made a difference in the cleanup levels generated at North Island. However, considering each site separately may lead to situations where no action is taken at individual sites even though the overall facility-wide risk is significant.

ology that simultaneously addresses short-term and long-term risk. Box 5-2 presents two common scenarios at Navy facilities that illustrate why risk-based approaches should include options to revisit sites over the long term.

This criterion for revisiting sites over the long term applies to both active and BRAC facilities. It should be noted that in some circumstances, current DOD policy relieves the Navy of responsibility for performing additional cleanup activities on BRAC facilities that have been transferred to the private sector. For example, a future change in land use by the new owner, if it goes against a stated deed restriction or institutional control, does not require the DOD to return and provide additional cleanup. However, the military will return to conduct additional cleanup if (1) the selected remedy is no longer protective (because of its failure), (2) new contamination is discovered, or (3) regulatory agencies require

BOX 5-2
Revisiting Sites over the Long Term

Dense nonaqueous phase liquids

A frequent scenario at Navy facilities is ground water contaminated with dense nonaqueous phase liquids (DNAPLs). Existing technologies, such as pump-and-treat systems, are robust enough to control plume migration, but in most cases they cannot bring contamination down to risk-based regulatory goals. In such cases, remedies should be designed to accomplish short-term goals, such as containment, while the responsible parties and others support the research and development of remedial technologies that can more completely or more cost-effectively reduce contamination to acceptable risk levels (NRC, 1994).

Landfills

A typical problem at most Navy bases is the presence of one or more landfills, usually an unlined pit containing household garbage, landscape refuse, construction debris, and industrial waste. There may be unknown quantities of containerized industrial chemicals, such as waste oils or paints in 55-gallon drums. Often very little is known about what was buried and what remains that could potentially pose a threat if a drum were to start leaking. A "one-shot" solution might have to be extremely costly or intrusive to guard against that worst case scenario. However, an approach that allows sites to be revisited over time could guard more effectively against evolving risks. If regulators and the public are confident that the Navy (or other responsible party) is monitoring such sources as leaking drums and pathways of contaminant migration (or other new signs of risk), and has a plan in place to respond quickly to such evidence, the response can be both more protective and less costly.

additional cleanup (Department of Defense, 1997). Any risk-based methodology adopted by the Navy should contain provisions for revisiting sites under these circumstances.

9. It should be implemented in a public setting with all stakeholders involved. Implementation of any risk-based methodology adopted by the Navy should take place in a public forum. The assumptions and relevant science used during the risk assessment process and the proposed remedies, along with all relevant value judgments, must be presented to and understood by interested stakeholders. To facilitate public scrutiny and debate, the methodology must be explicit, scientifically defensible, and traceable. Fortunately, the Navy already has policies requiring public involvement in its remediation activities through Restoration Advisory Boards (though some stakeholders feel these policies are unevenly implemented). This criterion for a risk-based methodology should not be as difficult for the Navy to implement as it could be for other responsible parties.

10. Its guidance document should undergo both external, independent scientific peer review and public review. Any proposed risk-based methodology must be the product of rigorous and broad external scientific peer review. All interested stakeholders must be allowed to review the risk-based approach, and supporting policies, during a public comment period prior to its implementation. Adoption of any methodology developed by a limited stakeholder group will insert potentially misleading biases into the remediation process. It also discourages (perhaps inadvertently) the pursuit of improved risk-based methodologies.

11. It should comply with relevant state and federal statutory programs for environmental cleanup. Cleanup of contaminated Navy sites is governed by a variety of regulatory agencies and state and federal environmental statutes. Any risk-based methodology adopted by the Navy must comply with relevant laws and regulations, including CERCLA and RCRA. The methodology must be flexible enough to incorporate the regulatory policies of the states and the EPA, including all relevant generic cleanup criteria that have been developed.

COMPARING ASTM RBCA TO THE ELEVEN CRITERIA

The Navy asked that the ASTM Risk-Based Corrective Action standard guides be evaluated for possible implementation at Navy facilities. The committee has reviewed the documents (Chapter 2) and discussed their strengths and weaknesses (Chapter 3). This section reviews ASTM RBCA with respect to the specific criteria outlined above.

The following assessment of the ASTM publications is based on a strict reading of the guides. It does not imply that the RBCA approach could not be modified to take some of these criteria into account. Most states have modified the ASTM petroleum RBCA standard guide to some extent prior to implementation for cleanup of USTs.

Prioritization of Sites

ASTM RBCA allows for the ranking of sites by risk. As stated in Chapters 2 and 3 in this report, prioritization is accomplished during the initial site assessment and classification. Table 1 in petroleum RBCA describes the necessary site characteristics that lead to classifications of immediate threat, short-term threat, long-term threat, or no demonstrable threat. This information can be used to direct immediate response actions and prioritize sites for cleanup. The ASTM document stresses that Table 1 is only an example. The prioritization method can be modified according to the user, and it may include additional levels of prioritization.

Consistent Mechanism for Addressing All Site Types

The tiered approach of ASTM RBCA is a systematic mechanism that is applicable to both low and high risk sites. In addition, generic cleanup standards can be replaced with site-specific cleanup levels given the appropriate data collection. The tiered approach expedites the closure of low risk sites that are relatively simple, while allowing high risk sites to undergo more intensive site characterization.

Data Collection and Site Characterization

At many Navy facilities, there are hazardous waste sites with unknown types of contaminants. Any risk-based methodology adopted by the Navy should require data collection sufficient to delineate unidentified sources of contamination. Petroleum RBCA lists the types of data that may be collected as part of a tier 1 or tier 2 evaluation, but it does not require that these data be collected. Chemical RBCA greatly improves on petroleum RBCA by (1) adding to the types of data that are collected; (2) making data collection mandatory; and (3) requiring the development of data quality objectives. Users are referred to other ASTM documents and EPA guidance for developing data quality objectives. The discussion of site characterization in chemical RBCA is only minimally adequate. Users would greatly benefit from more information on data quality objectives, monitoring methods, appropriate sample size, and performance criteria for data collection methods.

Integrated Risk Assessment

The petroleum RBCA standard guide makes no mention of either cumulative risk assessment or integrated risk assessment. Chemical RBCA calls for cumulative risk assessment during a tier 2 evaluation; however, the standard guide does not define cumulative risk. It is not clear whether both multiple exposure pathways and multiple chemicals are considered and whether their effects are additive or combined in some other fashion. An integrated assessment of multiple sites that affect target receptors is not part of either RBCA standard guide. This type of analysis is likely to increase considerably the complexity of any risk-based methodology.

Early Action

ASTM RBCA does allow for source removal actions and actions to interrupt pathways of contaminant migration. Once an early action is completed, the user returns to Site Classification and Initial Response Action, and then to a tier 1 evaluation (see Figure 2-3). This refunneling of sites back into the main cleanup process ensures that early actions do not lead directly to site closure. Care must be taken by oversight agencies to ensure that the methodology is not abused by allowing interim remedial actions to lead directly to site closure.

For low risk sites for which remediation is expected to be inexpensive and timely, the tier 1 evaluation can expedite site closure. If chemical concentrations at such sites are below generic cleanup levels found in the look-up table, a tier 1 evaluation can lead directly to site closure.

Uncertainty

The ASTM RBCA methodology does not adequately consider uncertainty in the data and the models of fate and transport used in the risk assessment process. This pertains to data on the concentrations of the chemicals of concern, data used to develop the dose-response models, and the actual models of fate and transport. The standard guides do not require that the user determine the uncertainty of the data collected; all data are assumed to be error-free. An assessment of the variability of certain parameters, such as hydraulic conductivity and individual response to toxicants, is not required.

The ASTM RBCA approach to modeling is inherently deterministic and ignores the myriad of very real uncertainties associated with subsurface modeling that are enumerated in Chapter 4. The use of conservative model parameters in no way characterizes the uncertainty in model output. Uncertainty in transport model parameters due to soil heterogeneity could be incorporated into ASTM RBCA by using a Monte Carlo analysis. The ASTM documents do suggest using Monte Carlo techniques as part of a tier 3 analysis. Evidence from state programs implementing the petroleum RBCA standard guide indicates that most contaminated sites never reach tier 3 because of the costs associated with conducting extensive site characterization, so this suggestion is rarely realized. Monte Carlo analysis should be suggested for tier 2 evaluations as well as tier 3.

None of the qualitative uncertainties associated with risk management are mentioned in ASTM RBCA. Chapter 4 in this report discusses several important unknowns in both technical and nontechnical remedial options that can seriously hamper remedy selection. A more thorough discussion of these uncertainties and suggestions for assessing and reducing them are needed.

A comprehensive assessment of uncertainty will increase the complexity of a risk-based methodology, and a high degree of expertise may be required to adequately implement such a methodology. Nonetheless, given the pervasiveness of uncertainty in risk assessment and risk management, a quantitative risk-based methodology must incorporate a more thorough evaluation of uncertainty than can be found in the ASTM RBCA methodology.

Linking Cleanup Goals and Remedial Options

ASTM RBCA is a flexible, iterative risk-based methodology that allows the user to cycle between deciding on the cleanup level and choosing the remedial option. Under RBCA, remedial options can be considered at each tier evaluation. If remedial options are not technically capable of reaching the cleanup levels developed for that tier, then more site-specific cleanup goals are generated as part of a higher tier evaluation.

ASTM RBCA lacks a quantitative, consistent method for choosing remedial options based on their effectiveness and cost. The petroleum RBCA standard guide provides virtually no guidance on choosing the remedial option, while chemical RBCA states only what criteria must be considered (similar to the nine criteria of the NCP). It should be noted that ASTM is producing other documents relating to specific remedial options, such as a standard guide for the use of natural attenuation at petroleum release sites. In addition, the RBCA standard guides specifically discuss the use of institutional controls as remedial options. While similar guidance for the other types of remedial options would be beneficial, what is needed most is a quantitative method for analyzing various remedial options during each tier evaluation.

Revisiting Sites over the Long Term

Petroleum RBCA provides almost no guidance on how long monitoring should be conducted to ensure protection of public health, nor does it discuss how the risk at a hazardous waste site can be assessed at a later date. This stems from the long-held assumption that petroleum products biodegrade relatively quickly in the natural environment (Bouwer and Zehnder, 1993). However, the discovery of MTBE in many petroleum mixtures has demonstrated the fallacy of this assumption. The absence of wording about long-term monitoring in petroleum RBCA is a significant weakness.

Chemical RBCA, on the other hand, addresses each of these issues in a more satisfactory manner. The purpose of long-term monitoring is clearly stated as "(1) demonstrating the effectiveness of the chosen remedial option, (2) confirming an improvement in conditions over time, and (3) verifying model assumptions and conditions."

Chemical RBCA discusses the very real possibilities of ineffective remedial

In preparation for transfer of the property to the private sector, considerable cleanup was conducted at the Derecktor's Shipyard located at the Newport Naval Education and Training Center. Courtesy of the U.S. Navy.

options and future changes in land use, although the wording is not as strong as might be desired. If long-term monitoring demonstrates that the remedial option is ineffective, the user should either reevaluate the remedy or return to the applicable tier evaluation. Similarly, if future land use changes during the implementation of a remedial option, the user may return to the applicable tier evaluation. Chemical RBCA does not, however, mention what to do when changes in land use occur after the remedial action is complete and after site closure.

A somewhat surprising feature of chemical RBCA related to long-term considerations of risk is the inclusion of Figure 2 (see Figure 2-5 in Chapter 2) in a tier 1 evaluation. This figure allows for a preliminary assessment of the completeness of the pathways connecting sources to receptors. Depending on how the figure is interpreted, demonstrating a break in that pathway can lead to site closure before concentrations of chemicals of concern are compared to generic cleanup levels. This is problematic because in the absence of any control strategies, currently incomplete exposure pathways may be completed at some point in the future. If interpreted in this way, this figure negates many of the improvements of this document over the petroleum RBCA standard guide.

Broad Stakeholder Participation in Implementation

Public involvement during implementation of petroleum RBCA is minimal. During the site classification, petroleum RBCA requires that the appropriate authorities, property owners, and potentially affected parties be notified of the risk posed by the contamination. Chemical RBCA, on the other hand, mentions public involvement during the collection of site assessment information, following site classification, and during remedy selection (although public involvement still does not appear at explicit points in the RBCA flowchart). The appendixes of chemical RBCA contain detailed information on potential public involvement activities.

External Scientific Peer Review and Public Review

Both ASTM standard guides were designed and approved by a limited group of stakeholders. Petroleum RBCA was the product of negotiations between the oil industry, state regulatory programs, members of ASTM, and the EPA. Chemical RBCA was created by oil and chemical industries, a small number of state regulatory agencies, members of ASTM, and the EPA (which officially abstained from voting for approval of the standard guide). Environmental advocacy organizations were not involved in the design of either standard guide. Nor did the ASTM RBCA standard guides undergo external scientific peer review, although they did win approval in the ASTM consensus balloting. Because the general public and the scientific community were not given an opportunity to comment on the standard guides before being approved by ASTM, it is likely that the methodologies reflect biases that might not have been present if these groups had been involved at an earlier stage.

Compliance with Current Statutory Guidelines

Both of the ASTM RBCA standard guides outline a framework that encompasses all aspects of the cleanup process, from initial site discovery to eventual site closure. Depending on the particular regulatory environment, only portions of the methodology may be amenable to adoption by state and federal environmental cleanup programs. The ASTM petroleum RBCA standard guide is being adopted by many states as the regulatory framework for their UST programs. Because USTs are regulated primarily under RCRA, which does not mandate any specific cleanup framework, integration of petroleum RBCA has been successful in many states. Most states have made modifications to the RBCA framework that reflect particular state laws and regulations regarding cleanup of USTs.

The implementation of chemical RBCA for contaminated sites regulated under RCRA may be accomplished with similar ease. Especially for Brownfields sites and voluntary cleanup efforts, the chemical RBCA framework may be an attractive way for state hazardous waste programs to become more standardized.

At 66 percent of its hazardous waste sites the Navy uses CERCLA, a federal statute that dictates a specific cleanup framework. The integration of RBCA into the CERCLA framework is not at all clear. For example, in circumstances where ground water must be restored to drinking water quality because of other statutes (ARARs), the tiered approach of RBCA could not be used to generate site-specific cleanup levels that were greater than MCLs.

State environmental laws would also have to be consulted prior to the use of chemical RBCA. Some state laws are more stringent than the corresponding federal laws and contain non-degradation or resource conservation provisions that would eliminate any risk-based methodology from consideration.

To its credit, the chemical RBCA standard guide, unlike the petroleum RBCA standard guide, repeatedly stresses that it is a voluntary methodology meant to complement state and federal regulatory programs rather than replace them. It suggests strongly that the appropriate regulatory authorities should be contacted to assist users with a myriad of technical policy decisions that would have to precede its use at the state level. Unfortunately, the standard guide does not present an example of how the methodology could be integrated with existing regulations, suggesting that this is a formidable task.

RECOMMENDATIONS

The committee recognizes that consideration of risk as well as resource conservation is an important element of environmental remediation. The high costs associated with environmental remediation combined with limited financial resources mean that all sites cannot be cleaned up to background levels. A consideration of risk is an important and pragmatic way to help determine which sites should be cleaned up.

Risk-based approaches are more likely than source removal or technology-based approaches to result in remedies that leave contamination in place. This can lead to a variety of problems that have been described in detail, including the appearance of previously unidentified compounds or pathways after site closure, less interest in the development of innovative technologies for source removal, a reliance on institutional controls, and a loss of public support and trust. Unless a risk-based approach is formulated to prevent these problems, the committee does not believe that such an approach can provide a long-term solution to environmental contamination at Navy facilities.

Use of the ASTM RBCA Standard Guides

The ASTM RBCA standard guides are a strong attempt to provide a uniform risk-based approach to environmental remediation. The chemical RBCA standard guide is an improvement over the petroleum RBCA standard guide because of the increased attention given to ecological risk assessment, cumulative risk, the selection of the remedial option, long-term monitoring, and the establishment of a RBCA program at the state level. In fact, if the Navy currently were using RBCA programs based on the petroleum standard guide, the committee would recommend that it adopt the chemical standard guide in its place.

Despite these improvements, however, **the committee does not recommend the adoption of either the petroleum or chemical RBCA standard guides at Navy facilities unless they are modified to satisfy the 11 criteria outlined above.** As currently written, the ASTM RBCA methodology does not satisfy all 11 criteria listed above as characteristics of an effective risk-based methodology. Petroleum and chemical RBCA fall short in their guidance on site characterization and cumulative risk assessment. The methodology does not integrate the effects of multiple sites on individual receptors. Although some consideration of uncertainty is present in the methodology, an explicit assessment of uncertainty is suggested only during a tier 3 evaluation, which would encompass very few cleanups. Uncertainties associated with remedial options are not discussed at all. Chemical RBCA includes a preliminary assessment of source, pathways, and receptors that might allow site closure prior to any tier evaluation. Although criteria for remedy selection are provided in chemical RBCA, no quantitative framework is suggested for balancing those criteria. ASTM RBCA was drafted by a limited group of stakeholders and did not undergo independent, external scientific peer review or public review. Finally, its successful integration into such existing statutory programs as CERCLA is unclear.

There are several practical reasons to recommend against the use of ASTM RBCA at Navy facilities. One of the advantages of ASTM RBCA is the perceived time and cost savings associated with its use at petroleum USTs. It may be true that minimal treatment of low risk sites, such as leaking petroleum USTs, could generate cost savings. These benefits of ASTM RBCA are less likely to accrue to the Navy because of the complexity of its hazardous waste sites. Navy sites contain mixtures of such contaminants as fuels, chlorinated solvents, metals, and other organic compounds. Often, neither the quantity nor the type of contamination is known, especially for landfills. The array of potential receptors surrounding naval facilities is particularly broad because of their proximity to coastlines and their location in densely populated areas. Navy facilities are located throughout the country, and are thus subject to oversight by a wide range of regulatory agencies, many of which may have inconsistent requirements for environmental remediation. These complexities make it unlikely that significant time and cost savings would follow implementation of ASTM RBCA.

Two other practical considerations are: (1) Federal Facilities Agreements at naval facilities on the National Priorities List would have to be altered to reflect the use of ASTM RBCA. This reopening of a negotiated legal document could delay cleanup efforts and introduce considerable public opposition; and (2) the use of a new methodology will involve retraining personnel. Earlier attempts to use ASTM RBCA were opposed by some Navy personnel, who described the methodology as too complicated for widespread implementation. However, this challenge will accompany the adoption of any legitimate risk-based approach, not just the ASTM standard guides.

Although not necessarily the intention of its authors, it is clear that the ASTM RBCA approach is attractive because it is perceived by responsible parties to be a short cut to cleanup that will lead to faster site closure. This perception is partially due to examples in both ASTM standard guides in which site closure is obtained relatively quickly and with minimal cleanup efforts. Our analysis indicates that most (not all) of the states have developed a short-term view of risk, increasing the possibility that ASTM RBCA might be misinterpreted to allow for premature site closure. The committee is reluctant to advocate fully a risk-based methodology that is perceived as supporting a no-cleanup alternative.

A Risk-Based Approach

After reviewing the problems in its Environmental Restoration Program, it is clear that the Navy would benefit from a consistent approach to environmental cleanup at all sites across the country. The committee's evaluation of existing risk-based approaches, the type of approach specifically desired by the Navy, did not reveal a methodology the committee could fully endorse for use at Navy facilities. Recognizing the merits of risk-based environmental remediation and a significant increase in its use across the country, **the committee recommends that the Navy develop a risk-based methodology for its Environmental Restoration Program that incorporates the following 11 criteria:**

1. Prioritization of contaminated sites at individual installations.
2. Provision of a consistent mechanism for addressing all types of sites.
3. Guidance on data collection needed to support the development of site-specific cleanup goals.
4. Integrated assessment of sites across entire installations affecting the same human or ecological receptors.
5. Early action at sites (a) where the risk to human health and the environment is imminent and (b) for which the risks are demonstrably low and remediation is likely to be more rapid and inexpensive.
6. Consideration of relevant uncertainties.
7. Integration of the selection of the remedial option with the establishment of remedial goals. Provision of quantitative tools for developing risk management strategies.
8. Revisiting of sites over the long term.
9. Implementation in a public setting with all stakeholders involved.
10. Both external, independent scientific peer review and public review for the guidance document.

11. Compliance with relevant state and federal statutory programs for environmental cleanup.

These criteria overcome many of the weaknesses associated with the use of risk-based methodologies. In particular, if a risk-based methodology gives sufficient attention to long-term risks (Criterion 8), the presence of potentially dangerous unidentified compounds and the use of institutional controls become less problematic. Public trust in such an approach is likely to be greater because of the continued involvement of the responsible party in long-term monitoring and enforcement of institutional controls. The development of innovative technologies for removing sources of contamination may still be slowed, but risk-based methodologies have been shown to spur the development of other technologies that accomplish pathway interruption and long-term monitoring.

Because of the diversity of Navy facilities and sites within those facilities, the committee suggests developing a broad framework that can be customized for use at individual facilities. A possible starting point for constructing this framework could be the ASTM RBCA methodology, but this is not a requirement. If the ASTM RBCA methodology is used as a guide, care should be taken to avoid the weaknesses currently found in the ASTM standard guides. The framework must be flexible enough to work with existing state and federal environmental statutes. Any risk-based approach must be capable of gaining the approval of the EPA and its state counterparts. To identify weaknesses and make improvements, the committee recommends pilot testing the methodology at one facility before commencing its widespread use.

The 11 criteria identified as important for any risk-based approach to environmental remediation, as well as the problems identified by Navy personnel, point to several avenues for further study. First, the process by which the remedial option is chosen requires significant analysis, explanation, and refinement. One possible study could expand on Criterion 7. The goal of this study would be to develop quantitative analytical tools to assist with remedy selection by evaluating the cost and effectiveness of remedies (including long-term maintenance of engineering and institutional controls). As currently envisioned by the committee, one tool would be based on the paradigm of optimizing risk reduction per dollar spent for a suite of available remedial options.

Another important aspect of an effective risk-based approach is its ability to assess risk over the long term. Improving long-term monitoring at sites in which contamination is left in place will be critical to the use of a risk-based approach. Such monitoring is critical to ensure the effectiveness of chosen remedies and to reduce uncertainty in risk assessment. Techniques that allow for successful, efficient monitoring of the site's responses to natural processes, treatment technologies, containment technologies, and institutional controls should be the focus of such efforts.

Assessing and reducing uncertainties in both risk assessment and risk management should accompany the implementation of a risk-based approach to environmental remediation. Formal considerations of uncertainty must be incorporated into a risk-based methodology in an understandable and convenient way. It will be important for the Navy to develop guidelines aimed at remedial project managers for (1) using more sophisticated analytical techniques during risk assessment, (2) reducing the uncertainty associated with site characterization and treatment technologies, (3) conducting uncertainty analyses when appropriate, and (4) enforcing a wide variety of institutional controls.

Success Metrics

The committee has observed that on-site project managers in the Environmental Restoration Program often strive to meet vague or inconsistent goals regarding the level of cleanup required to close a site. This is partly because, until recently, few people in management positions in regulated or regulatory agencies had spent much time determining what site completion actually meant. As described in Chapter 1 and in Figure 1-3 of this report, the Defense Environment Security Office has recently clarified "terminology for work after remedial design" (Office of the Deputy Under Secretary of Defense, 1998). This apparently new terminology represents a step forward compared to the vague concepts of "completion" and "close-out." The definition of "response complete" makes it clear that monitoring is often required beyond the operation and maintenance stage. The DOD's recent clarification of site completion milestones is a significant step in the right direction. **The committee recommends that the interagency task force on site completion (Air Force/Army/Navy/EPA, 1998) reach consensus on processes that use or adapt that terminology. It further recommends that project managers for regulatory agencies and the military be quickly apprised of the terminology and associated goals.**

As currently employed, the site completion track of the DOD's cleanup program focuses too heavily on site closeout as its metric of success. **The committee feels that metrics of success should reflect the characteristics of individual sites**. For those sites where closeout may never be feasible because of the type of contaminants present and the ineffectiveness of source removal technologies, the committee recommends that the Navy put more emphasis on "response complete" as the most important metric of success. "Response complete" more adequately addresses progress at sites where contamination remains in place by rewarding the effective operation of the remedial option(s). The military might even consider developing multiple "response complete" milestones or replacing "response complete" with one or more "response taken" milestones. In this way, progress toward long-term monitoring, containment, and enforcement of institutional controls would be considered an achievement, even though additional responses would still be recognized as necessary. Developing improved metrics of success for sites in which contamination remains in place could go a long way toward increasing the public acceptance of risk-based approaches to environmental remediation.

REFERENCES

Air Force/Army/Navy/EPA Working Group. 1998. The Road to Site Close-out (Working Draft). Washington, D.C.

Bechtel National, Inc. 1997. Risk-Based Cleanup Index for the Closure of Underground Storage Tanks at Naval Air Station, North Island, San Diego County, California.

Bouwer, E. J., and A. J. B. Zehnder. 1993. Bioremediation of Organic Compounds—Putting Microbial Metabolism to Work. Trends Biotechnol. 11:360-367.

Department of Defense. 1997. Responsibility for Additional Environmental Cleanup after Transfer of Real Property. Memorandum dated 7/25/97 from R. Noel Longuemare, Acting Under Secretary of Defense, to the Assistant Secretary of the Army, the Assistant Secretary of the Navy, the Assistant Secretary of the Air Force, the Deputy Under Secretary of Defense, (Environmental Security), the Deputy Under Secretary of Defense (Industrial Affairs and Installations), and the Director of the Defense Logistics Agency. Washington, D.C.

Department of the Navy. 1998. Department of the Navy Environmental Restoration Plan for Fiscal Years 1998-2002. Chief of Naval Operations, Arlington, Va.

Eikenberry, S. 1998. Naval Facilities Engineering Service Center. Personal communication.

Environmental Information, Ltd. 1997. Underground Storage Tank Cleanup. Environmental Information Ltd. Minneapolis, Minn.

General Accounting Office (GAO). 1998. Superfund: Times to Complete Site Listing and Cleanup. GAO/T-RCED-98-74.

National Research Council (NRC). 1994. Alternatives for Ground Water Cleanup. National Academy Press. Washington, D.C.

Office of the Deputy Under Secretary of Defense (Environmental Security). March 1998. Management Guidance for the Defense Environmental Restoration Program.

Appendix A

Survey of State Risk-Based Decision Making

STATE: ______________________

1. How is it determined which state agency/department/division regulates a release to the environment?
    - a.) By contaminant
    - b.) By industry
    - c.) By geographical area
    - d.) By media impacted
    - e.) Other, explain

2. Does your state allow any flexibility in the establishment of cleanup levels? On what basis?
    - Soil?
    - Ground water?

3. With regard to petroleum-impacted sites, do your state's rules ________ risk-based decision making?
    - a.) forbid
    - b.) allow
    - c.) encourage
    - d.) require

4. Is an evaluation of the risk of MTBE required?

5. Is an evaluation of the risk of Total Petroleum Hydrocarbons (TPH) required and, if so, how is that accomplished?

6. With regard to **non**petroleum-impacted sites, do your state's rules _____ risk-based decision making?

    a.) forbid
    b.) allow
    c.) encourage
    d.) require

7. Does your state have a nondegradation policy?

    Soil?
    Ground water?
    Surface water?

8. Is all ground water considered a drinking water supply?

9. Is all ground water considered a receptor?

10. Is risk a factor in prioritizing impacted sites in your state?

11. Even if risk-based decision making is not used to establish cleanup levels, can a case be closed by risk assessment?

    Petroleum-impacted sites?
    Nonpetroleum-impacted sites?

12. Do background concentrations affect the cleanup levels set for a site?

13. How familiar are you with ASTM's RBCA methodology?

    a.) no familiarity
    b.) a little familiarity
    c.) some familiarity
    d.) very familiar

14. How does your state's risk-based decision making differ from ASTM's RBCA methodology?

15. What is the acceptable target risk level for carcinogens?

    Current conditions?
    Future conditions?

16. What is the acceptable hazard quotient for toxins?

17. Are the risks for exposure to carcinogens or toxins considered additive?

18. Are there any pathways that are not considered viable conduits in your state?

19. Have criteria been established for evaluating risks to ecological receptors?

20. Has your state been divided into different hydrogeological regions for the application of certain fate and transport parameter values?

21. Do your rules set any minimal requirements for a[n ASTM RBCA] Tier I or Tier II evaluation?

22. Can off-site cleanup levels vary from what are established on site?

23. Has your state developed any software for its risk-based decision making?

24. Is commercial software acceptable?

25. Is this software applicable to more than just petroleum releases?

26. Under what conditions is natural attenuation an acceptable remediation strategy?

27. Can cases with free product be closed under your state's risk-based decision-making rules?

28. At what step is public notification required?
    a.) at case activation
    b.) prior to setting cleanup levels
    c.) anytime, but prior to case closure
    d.) not required

29. Is notification of more than current or identifiable future potential receptors required?

30. When evaluating for completed vapor pathways, is there a practical depth limit below which the pathway is no longer considered complete?

31. What happens to a case where the best available technology has failed to reduce contaminant concentrations to below established cleanup levels?

32. Pump-and-treat systems often discharge treated ground water into a surface waterbody. Soil vapor extraction systems discharge vapors into the atmosphere.

Considering that most engineered remediation efforts involve transferring the contaminant from one media (soil, water, air) to another, is there any formal mechanism for comparing the risks to receptors if such a remediation system's treatment breaks down versus not implementing the system at all?

33. Are there any proposed rules that will change any of the answers to the prior questions? If so, please elaborate and give an estimated date of implementation.

To be completed by the person who completed this survey:

Name:
Title:
Affiliation:
Telephone No.:
Date:

Appendix B

Acronyms

ARARs	Applicable or Relevant and Appropriate Requirements
ASTM	American Society for Testing and Materials
BRAC	Base Realignment and Closure
BTEX	Benzene, toluene, ethylbenzene, and xylene(s)
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CoC	Chemical(s) of Concern
DNAPL	Dense Nonaqueous Phase Liquid
DOD	Department of Defense
DSMOA	Defense State Memoranda of Agreement
EPA	Environmental Protection Agency
ESSRA	Enhanced Site-Specific Risk Assessment
FFA	Federal Facilities Agreement
FHC	Fuel Hydrocarbons
FS	Feasibility Study
HEAST	Health Effects Assessment Summary Tables
HOC	Hydrophobic Organic Compounds
HQ	Hazard Quotient
HRS	Hazard Ranking System
IRA	Interim Remedial Action
IRIS	Integrated Risk Information System
LLNL	Lawrence Livermore National Laboratory
LTM	Long-Term Monitoring
LUFT	Leaking Underground Fuel Tank
MCL	Maximum Contaminant Level

MTBE	Methyl Tertiary Butyl Ether
NAPL	Nonaqueous Phase Liquids
NAS	Naval Air Station
NCP	National Contingency Plan
NPL	National Priorities List
NRC	National Research Council
NSB	Naval Submarine Base
PA	Preliminary Assessment
PCB	Polychlorinated Biphenyls
PCE	Perchloroethene
POL	Petroleum, Oil, and Lubricants
PRG	Preliminary Remediation Goal
RA	Remedial Action
RA-C	Remedial Action-Construction
RA-O	Remedial Action-Operations
RAB	Restoration Advisory Board
RAGS	Risk Assessment Guidance for Superfund
RBCA	Risk-Based Corrective Action
RBDM	Risk-Based Decision Making
RBSL	Risk-Based Screening Level
RC	Response Complete
RCRA	Resource Conservation and Recovery Act
RD	Remedial Design
RESC	Relevant Ecological Screening Criteria
RI	Remedial Investigation
RIP	Remedy in Place
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act
SI	Site Inspection
SSEC	Site-Specific Ecological Criteria
SSG	Soil Screening Guidance
SSL	Soil Screening Level
SSTL	Site-Specific Target Level
TAC	Technical Advisory Committee
TPH	Total Petroleum Hydrocarbons
UST	Underground Storage Tank
WSTB	Water Science and Technology Board

Appendix C

Biographical Sketches of Committee Members and Staff

EDWARD J. BOUWER is a professor of environmental engineering at the Johns Hopkins University. His research interests include biodegradation of hazardous organic chemicals in the subsurface, biofilm kinetics, water and waste treatment processes, and transport and fate of bacteria in porous media. He is on the Research Advisory Council for the American Water Works Association Research Foundation, the editorial boards of the *Journal of Contaminant Hydrology* and *Environmental Engineering Science,* and the managing editorial board for *Biodegradation*. He received a Ph.D. in environmental engineering and science from Stanford University in 1982. Dr. Bouwer has served on several NRC committees, including the U.S. National Committee for SCOPE, the Steering Committee on Building Environmental Management Science Programs, and the Committee on Groundwater Cleanup Alternatives.

GENE F. PARKIN is a professor of civil and environmental engineering at the University of Iowa, where he was chairman from 1990 to 1995. He earned a B.S. and an M.S. in civil engineering from the University of Iowa and a Ph.D. from Stanford University. His teaching interests include biological wastewater treatment, environmental chemistry, and remediation of hazardous wastes. He has conducted research in bioremediation, the fate and effects of toxic chemicals (including metals) in the subsurface and above-ground treatment systems, anaerobic biological treatment, and biological nitrogen removal. In 1989, Dr. Parkin was awarded the Hancher-Finkbine Medallion for Outstanding Professor at the University of Iowa. He recently published the fourth edition of Chemistry for Environmental Engineering with Perry McCarty. He serves as the director of the Center for Health Effects of Environmental Contamination at the University of Iowa. He is a registered professional engineer in Iowa.

Michael J. Barcelona is a research professor in civil and environmental engineering and director of operations at the National Center for Integrated Bioremediation Research and Development at the University of Michigan. He received his Ph.D. in marine chemistry and chemical oceanography from the University of Puerto Rico in 1977. His research focuses on developing methods for estimating the distribution, speciation, and transformation potential of contaminants in sedimentary and aquatic geochemical environments, with particular emphasis in the development of improved analytical and statistical interpretative tools for remediation technology performance measures. Since 1992, he has been editor of *Ground Water Monitoring and Remediation.*

Lawrence W. Barnthouse is president of LWB Environmental Sciences, Inc. He was formerly a principal scientist in the ChemRisk division of McLaren/Hart, Inc. and manager of the ChemRisk office in Oak Ridge, Tennessee. As a senior research staff member in Oak Ridge National Laboratory's Environmental Sciences Division, he was involved in dozens of environmental research and assessment projects involving development of new methods for predicting and measuring environmental risks of energy technologies. He has authored and co-authored more than 70 publications on ecological risk assessment, covering such topics as population modeling techniques and problems involving cooling systems, toxic chemicals, and watershed management. He has served on numerous NRC committees and was a recent member of the Board on Environmental Studies and Toxicology. Dr. Barnthouse received his Ph.D. in biology from the University of Chicago in 1976.

John C. Chambers is a partner with the law firm of Arent, Fox, Kintner, Plotkin, & Kahn in Washington, D.C. His practice involves litigation, counseling, and lobbying on such environmental issues as hazardous waste management, remediation, recycling and corrective action; Clean Air Act permitting; and environmental justice. Mr. Chambers frequently lectures at environmental forums and appears as a television and radio commentator. He was featured in the 1994 *International Corporate Law Magazine's* "Guide to Leading Environmental Lawyers." Mr. Chambers is also founder of the Brownfields Business Information Network and currently serves as the president of the Washington Government Relations Group. He received his B.A. from the University of Pennsylvania and his J.D. from the Washington College of Law, American University.

Francis H. Chapelle is a research hydrologist at the U.S. Geological Survey in Columbia, South Carolina. He received a Ph.D. in geology in 1984 from George Washington University. He also holds a B.A. in music and a B.S. in geology from the University of Maryland. His research interests focus on the impact of microbial processes on ground-water chemistry in contaminated and pristine environments. He is the author of *Ground-Water Microbiology and Geochemistry,* a textbook that explains how microorganisms affect ground-water chemistry, and *The Hidden Sea*, a book describing ground-water systems and ground-water contaminants throughout the United States. Dr. Chapelle was a member of the NRC Committee on In Situ Bioremediation.

Neil R. Garrett is currently a project environmental analyst supervisor with the Oklahoma Corporation Commission, where he has worked since 1994. His duties include regulating the investigation, risk assessment, and remediation of chemical (mostly fuel) releases from underground storage tanks. He has helped to implement risk-based corrective action at all commission-regulated facilities in Oklahoma. He has previously been a hydrogeologist at environmental consulting firms, and RCRA-related investigations have taken him to several states. Previous petroleum-related work has been conducted in the south-central United States, Gulf of Mexico, and the Persian Gulf. Mr. Garrett received his B.S. in geology from the University of Oklahoma, his M.Ed. from the University of Central Oklahoma, and a Hydrogeology Certificate from Oklahoma State University.

Franklin W. Schwartz received his Ph.D. in geology in 1972 from the University of Illinois. He is currently the Ohio eminent scholar in hydrogeology at Ohio State University. His research interests concern contaminant transport in mixed convective systems and oxidation schemes for DNAPL remediation. Dr. Schwartz has been an active consultant to government and private industry since 1972, with most of his work involving project management, report review, technical advice, development and application of computer models, and field investigations. He is an editor-in-chief of the *Journal of Contaminant Hydrology* and co-author of the textbook *Physical and Chemical Hydrogeology*. He has served on several NRC committees and is a former member of the Water Science and Technology Board.

Lenny M. Siegel is the director of the Center for Public Environmental Oversight, a project of San Francisco State University's Urban Institute. He has been director of the Pacific Studies Center since 1970. He is one of the environmental movement's leading experts on military base contamination and has worked as a consultant to a wide range of organizations. Mr. Siegel is or was recently a member of several government advisory committees, including the Defense Science Board Task Force on Unexploded Ordnance, the Federal Facilities Environment Restoration Dialogue Committee, the Subcommittee on Waste and Facility Siting of the National Environmental Justice Advisory Committee, the Peer Review Panel for the VOC Historical Case Initiative, and the Moffett Field Restoration Advisory Board. Mr. Siegel edits the *Citizens Report on the Military and the Environment,* and his organization runs Internet forums on military environmental issues and Brownfields.

Alice D. Stark is the director of the Bureau of Environmental and Occupational Epidemiology at the New York State Department of Health. She has conducted health assessments in populations exposed to toxic substances from hazardous waste sites and other sources of environmental exposure. Dr. Stark is also an adjunct professor of anthropology at State University of New York, Albany, where she was formerly an associate professor of environmental health and toxicology and epidemiology. Dr. Stark is conducting a follow-up health study at Love Canal and a Farm Family Health and Hazard Survey. She is a member of the Board of Scientific Counselors, Agency for Toxic Substances and Disease Registries. She has recently served on two National Cancer Institute committees, one of which investigated the role of xenobiotic chemicals in causing cancer. She received her B. S. in chemistry from the City College of New York and her MPH and Ph.D., from Yale University in environmental epidemiology.

Samuel J. Traina is a professor of soil physical chemistry at Ohio State University. His research is focused on surface, colloidal, and complexation chemistry in soils, and includes studying the chemical fate of organic and inorganic contaminants in soils, sediments, and aquifer materials. Recent work has examined the chemical speciation and bioavailability of lead in soil, the reactions of organic bases with clay minerals, the geochemistry of arsenic and chromium in hyperalkaline environments, and biotic and abiotic transformations of chlorinated pesticides in soils and sedimentary environments. Dr. Traina received his Ph.D. from the University of California at Berkeley in soil chemistry in 1983 and has been a faculty member at OSU since 1985.

Albert J. Valocchi is a professor in the Department of Civil and Environmental Engineering at the University of Illinois, where he has taught since 1981. His research interests include modeling fate and transport of reactive contaminants in the subsurface and mathematical modeling applications in environmental and hydrological sciences. Several research projects reflecting those interests are currently being conducted in his lab, including numerical simulation of reactive transport at Yucca Mountain, transport of complex mixtures of radionuclides and organics, and a stochastic analysis of reactive transport in heterogeneous aquifers. Dr. Valocchi is an associate editor of the *Journal of Contaminant Hydrology* and the American Society of Chemical Engineers *Journal of Hydrologic Engineering*. He received his Ph.D. in civil engineering from Stanford University in 1981.

Brian J. Wagner is a research hydrologist in the U.S. Geological Survey's National Research Program. His research interests include data network design for environmental monitoring and assessment, experimental design for understanding contaminant fate and transport, and optimization and decision analysis for water resources management. He received a B.S. in civil engineering from Drexel University and an M.S. and Ph.D. in applied hydrology from Stanford University.

Dr. Wagner was a member of the National Research Council's Committee on Innovative Remediation Technologies.

Claire Welty is associate professor of civil and environmental engineering at Drexel University. Her research interests broadly include development and application of mathematical models to predict groundwater flow and solute transport in aquifers. Her current research interests focus on using a stochastic approach to predict virus transport through aquifers; interpretation of observations of density-coupled transport; and prediction of contaminant transport in fractured rock aquifers. Dr. Welty is also involved in establishing a porous media observational facility at the University of Kassel in Germany. She is an associate editor of *Water Resources Research* and served as the 1996-1998 chair of the American Geophysical Union's Groundwater Committee. Dr. Welty received her Ph.D. in civil engineering from the Massachusetts Institute of Technology in 1989. Prior to graduate school, she was an environmental scientist in the Hazardous and Industrial Waste Division at U.S. EPA.

Jeffrey J. Wong is chief of the Human and Ecological Risk Division of the California Environmental Protection Agency. He is responsible for (1) assessment of public health and environmental effects due to exposure to hazardous materials, (2) development and formulation of risk management and reduction strategies, and (3) analysis of policy implications of risk control options. Dr. Wong received his Ph.D. in pharmacology and toxicology from the University of California, Davis, in 1981. He currently teaches undergraduate courses in environmental toxicology and risk assessment modeling at UC Davis, and he has conducted short courses on similar topics for environmental professionals. He was a member of the NRC Committee on Remedial Action Priorities for Hazardous Waste Sites.

Laura J. Ehlers is a staff officer of the National Research Council's Water Science and Technology Board and the study director for this report. She is also the study director for the Committee to Review the New York City Watershed Management Strategy. In 1998, she received a Certificate of Appreciation for Outstanding Service from the Commission on Geosciences, Environment, and Resources of the National Research Council. Dr. Ehlers received her B.S. in biology and engineering and applied science from the California Institute of Technology and her M.S.E. and Ph.D. degrees in environmental engineering from the Johns Hopkins University.

Kimberly A. Swartz is a project assistant with the National Research Council's Water Science and Technology Board. She assisted the staff and committee in producing the final draft of this report. She has a B.S. in sociology from Virginia Polytechnic Institute and State University.