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Risk Assessment Guidance for Superfund:

Volume I - Human Health Evaluation Manual (Part C, Risk Evaluation of Remedial Alternatives)

Interim

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NOTICE

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This guidance is based on policies in the Final Rule of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), which was published on March 8, 1990 (55 *Federal Register 8666).* The NCP should be considered the authoritative source.

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CONTENTS (Continued)

EXHIBITS

DEFINITIONS

Term	Definition
Applicable or Relevant and Appropriate Requirements (ARARs)	"Applicable" requirements are those clean-up standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site. "Relevant and appropriate" requirements are those clean-up standards which, while not "applicable" at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well-suited to the particular site. ARARs can be action-specific, location-specific, or chemical-specific.
Exposure Pathway	The course a chemical or physical agent takes from a source to an exposed organism. An exposure pathway describes a unique mechanism by which an individual or population is exposed to chemicals or physical agents at or originating from a site. Each exposure pathway includes a source or release from a source, an exposure point, and an exposure route. If the exposure point differs from the source, a transport/exposure medium (e.g., air) or media (in cases of intermedia transfer) also would be indicated.
Exposure Point	A location of potential contact between an organism and a chemical or physical agent.
Exposure Route	The way a chemical or physical agent comes in contact with an organism (i.e., by ingestion, inhalation, dermal contact).
Final Remediation Levels	Chemical-specific clean-up levels that are documented in the Record of Decision (ROD). They may differ from preliminary remediation goals (PRGs) because of modifications resulting from consideration of various uncertainties, technical and exposure factors, and all nine selection-of-remedy criteria outlined in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP).
Long-term Risks	Risks that remain after remedy implementation is complete (i.e., residual risks).
Preliminary Remediation Goals (PRGs)	Initial clean-up goals that (1) are protective of human health and the environment and (2) comply with ARARs. They are developed early in the process based on readily available information and are modified to reflect results of the baseline risk assessment. They also are used during analysis of remedial alternatives in the remedial investigation/feasibility study (RI/FS).

DEFINITIONS (Continued)

Term	Definition
Remedial Alternative	An action considered in the feasibility study intended to reduce or eliminate significant risks to human health and/or the environment at a site. A range of remedial alternatives are considered in detail by the FS while the selection of a specific remedial alternative over others is documented in the ROD.
Remedial Action	The selected alternative that is documented in the ROD.
Risk-based Concentrations	Concentration levels for individual chemicals that correspond to a specific cancer risk level (e.g., 10^{-6}, 10^{-4}) or hazard quotient (HQ) or hazard index (HI) (e.g., less than or equal to 1). They are generally selected as preliminary or final remediation goals when ARARs are not available.
Short-term Risks	Risks that occur during implementation of a remedial alternative. Some "short-term" risks can occur over a period of many years (e.g., risk associated with air stripper emissions).

ACRONYMS/ABBREVIATIONS

Acronym/ Abbreviation	Definition
ACGIH	American Conference of Governmental Industrial Hygienists
AIC	Acute Inhalation Criteria
APCD	Air Pollution Control Device
ARARs	Applicable or Relevant and Appropriate Requirements
ATSDR	Agency for Toxic Substances and Disease Registry
CEGL	Continuous Exposure Guidance Level
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
ECAO	Environmental Criteria and Assessment Office
EEGL	Emergency Exposure Guidance Level
EPA	U.S. Environmental Protection Agency
HEAST	Health Effects Assessment Summary Tables
HHEM	Human Health Evaluation Manual
HI	Hazard Index
HQ	Hazard Quotient
IDLH	Immediately Dangerous to Life and Health
IRIS	Integrated Risk Information System
LOAEL	Lowest-observed-adverse-effect-level
MCL	Maximum Contaminant Level
MRL	Minimal Risk Level
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NIOSH	National Institute for Occupational Safety and Health
NOAEL	No-observed-adverse-effect-level
NRC	National Research Council

ACRONYMS/ABBREVIATIONS (Continued)

Acronym/ Abbreviation	Definition
ORD	Office of Research and Development
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Level
POTW	Publicly Owned Treatment Works
PPE	Personal Protective Equipment
PRG	Preliminary Remediation Goal
QA/QC	Quality Assurance/Quality Control
RAGS	Risk Assessment Guidance for Superfund
RCRA	Resource Conservation and Recovery Act
REL	Recommended Exposure Level
RfC	Reference Concentration
RfD	Reference Dose
RI/FS	Remedial Investigation/Feasibility Study
RME	Reasonable Maximum Exposure
ROD	Record of Decision
RPM	Remedial Project Manager
RQ	Reportable Quantity
RREL	Risk Reduction Engineering Laboratory
SARA	Superfund Amendments and Reauthorization Act
SPEGL	Short-term Public Emergency Guidance Level
TLV-C	Threshold Limit Values - Ceiling
TLV-STEL	Threshold Limit Values - Short-term Exposure Limit
TLV-TWA	Threshold Limit Values - Time-weighted Average
TSC	Superfund Health Risk Technical Support Center

ACRONYMS/ABBREVIATIONS (Continued)

Acronym/ Abbreviation	Definition
TSCA	Toxic Substances Control Act
VOCs	Volatile Organic Compounds

ACKNOWLEDGEMENTS

This manual was developed by the Toxics Integration Branch (TIB) of EPA's Office of Emergency and Remedial Response, Hazardous Site Evaluation Division. A large number of EPA regional and headquarters managers and technical staff (see below) provided valuable input regarding the organization, content, and policy implications of the manual throughout its development.

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PREFACE

Risk Assessment Guidance for Supetund: Volume I — Human Health Evaluation Manual (RAGS/HHEM) Part C is one of a three-part series. Part A addresses the baseline risk assessment; Part B addresses the development of risk-based preliminary remediation goals. Part C provides guidance on the human health risk evaluations of remedial alternatives that are conducted during the feasibility study, during selection and documentation of a remedy, and during and after remedy implementation. Part C provides general guidance to assist in site-specific risk evaluations and to maintain flexibility in the analysis and decision-making process. This guidance does not discuss the evaluation of ecological effects that takes place during remedy selection and implementation, nor does it discuss the risk management decisions that are necessary at a CERCLA site (e.g., selection of final remediation goals). The potential users of Part C are persons involved in the remedy selection and implementation proms, including risk assessors, risk assessment reviewers, remedial project managers, and other decision-makers.

This manual is being distributed as an interim document to allow for a period of field testing and review. RAGS/HHEM will be revised in the future, and Parts A, B, and C will be incorporated into a single final guidance document. Additional information for specific subject areas is being developed for inclusion in a later revision. These areas include:

- development of short-term inhalation toxicity values;
- short-term worker health and safety issues; and
- determination of attainment of final remediation goals.

Comments addressing usefulness, changes, and additional areas where guidance is needed should be sent to:

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CHAPTER 1

INTRODUCTION

This guidance has been developed by the U.S. Environmental Protection Agency (EPA) to assist remedial project managers (RPMs), risk assessors, site engineers, and others in using risk information at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites to both evaluate remedial alternatives during the feasibility study (FS) and to evaluate the human health risk associated with the selected remedial alternative during and after its implementation. Part C provides general guidance to assist in site-specific risk evaluations and to maintain flexibility in the decision-making process.

Risk assessment is one of many tools that RPMs use in selecting the best remedy for a site. Other important tools (not addressed in this guidance) involve the assessments of technical feasibility, applicable or relevant and appropriate requirements (ARARs), cost, and implementability.

This guidance is the third part (Part C) in the series *Risk Assessment Guidance for Superfund: Volume Z — Human Health Evaluation Manual* (RAGS/HHEM). Part A of this guidance (EPA 1989g) describes how to conduct a site-specific baseline risk assessment; the information in Part A is necessary background for Part C. Part B (EPA 1991c) provides guidance for calculating risk-based concentrations that may be used, along with ARARs and other information, to develop preliminary remediation goals (PRGs) during project scoping. PRGs (and final remediation levels set in the Record of Decision [ROD]) can be used throughout the analyses in Part C to assist in evaluating the human health risks of remedial alternatives. Exhibit 1-1 illustrates the major correspondence of RAGS/HHEM activities with the steps in the CERCLA remedial process.

The steps for conducting a risk evaluation of remedial alternatives are discussed in general terms in Chapters 2 and 3; more detailed guidance for conducting short-term evaluations is provided in Appendices A through D. (See the box in the next column for a description of how the terms short-term risk and long-term risk differ in this guidance.) The remainder of this chapter:

SHORT-TERM RISK VS. LONG-TERM RISK

For the purposes of this guidance, short-term risks are those that occur during implementation of a remedial alternative. Some "short-term" risks can occur over a period of many years (e.g., risk associated with air stripper emissions). In contrast, long-term risks are those that remain after remedy implementation is complete (i.e., residual risks).

- presents the scope and an overview of Part C;
- discusses the statutes, regulations, and guidance relevant to the evaluation of remedial alternatives;
- describes appropriate levels of effort for risk evaluations of remedial alternatives;
- discusses the importance of risk communication;
- addresses the role of the RPM and the need for documentation; and
- presents the organization of the remainder of this document.

1.1 SCOPE AND OVERVIEW OF PART C

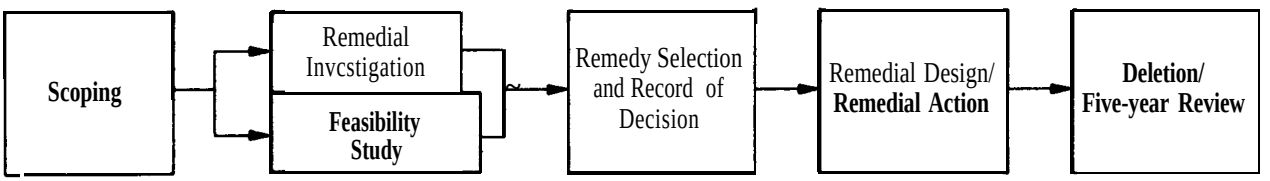
1.1.1 SCOPE

As discussed in Section 1.2 below, some of the nine criteria that are described in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) and that are used to evaluate remedial alternatives during the remedial investigation/ feasibility study RI/FS), involve a direct use of risk-related information. Several aspects of these criteria (e.g., short-term risks to workers and

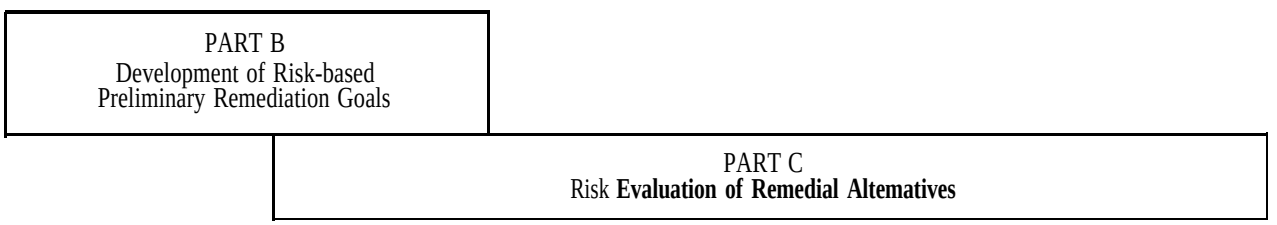
EXHIBIT 1-1

RELATIONSHIP OF THE HUMAN HEALTH EVALUATION TO THE CERCLA PROCESS

CERCLA REMEDIAL PROCESS



HUMAN HEALTH EVALUATION MANUAL



surrounding community, long-term effectiveness) are discussed in detail in this guidance. Other criteria that do not directly involve health risk (e.g., implementability, cost) – with the exception of community acceptance — are mentioned briefly but are not discussed in detail.

Remedial alternatives, in addition to being evaluated for the degree to which they protect human health, are evaluated for their potential to protect ecological receptors. RAGS/HHEM Part C does not address ecological risk assessment (see the next box). However, ecological guidance specific to evaluating remedial alternatives in the CERCLA program will be developed following finalization of Agency guidance on ecological risk assessment.

EVALUATING ECOLOGICAL EFFECTS OF REMEDIAL ALTERNATIVES

Remedial actions, by their nature, can alter or destroy aquatic and terrestrial habitat. This potential for destruction or alteration of habitat and subsequent consequences must be evaluated so that it can be considered during the selection of a remedial alternative and during its implementation.

This document does not address the evaluation of ecological risks. Future guidance for ecological evaluations is planned, however. At present, ecological evaluations should be based on the best professional judgment of experienced ecologists and/or aquatic or environmental toxicologists.

The guidance in this document applies to sites contaminated with non-radioactive hazardous substances and those contaminated with radionuclides. Appendix D Provides additional guidance specific to radionuclide sites.

Note that this guidance is limited to the use of risk assessment in evaluating remedial alternatives. Part C does not provide guidance on the risk management decisions that must be made when evaluating alternatives and selecting a remedy (e.g., balancing of the nine NCP criteria, selection of final remediation goals and levels) or engineering judgments that affect the evaluation of alternatives (e.g., determining whether an alternative is likely to achieve remediation goals). These issues are addressed in other guidance or in guidance that currently is being developed.

1.1.2 OVERVIEW

The process of evaluating remedial alternatives begins in the development and screening stage of the FS and extends into the detailed analysis stage. The major goal for the risk evaluation during these steps is to provide decision-makers with specific information that they may need in choosing among alternatives. Additional risk evaluations may need to be conducted during the proposed plan, during the design and implementation of the remedy, and after the remedy is complete (e.g., during "five-year reviews"). These activities are discussed below and throughout this guidance.

Exhibit 1-2 summarizes the levels of effort and purposes of the risk evaluations of remedial alternatives, while Exhibit 1-3 illustrates when these activities take place within the context of the CERCLA remedial process.

Identification and Screening of Technologies and Alternatives. During this stage, a range of remedial alternatives is identified, if necessary, and each alternative is evaluated with respect to effectiveness, implementability, and cost. This process may consist of two steps: (1) identification and screening of technologies and (2) development and screening of alternatives. These steps are often combined into a single step (as reflected in this guidance). Those alternatives that are clearly unfavorable relative to other alternatives in terms of effectiveness (e.g., very high perceived risk) or implementability, or that are grossly excessive in cost are dropped from consideration after this screening. Part of the evaluation of effectiveness involves human health risk (e.g., risks to the community and remediation workers), and Chapter 2 of this document provides guidance on evaluating these factors. RAGS/HHEM Part C does not discuss evaluating factors such as implementability and cost.

Detailed Analysis of Alternatives. During the detailed analysis stage, alternatives are evaluated according to each of the nine NCP evaluation criteria, and then are compared to each other. Both long-term effectiveness (i.e., residual risk) and short-term effectiveness (i.e., risk to the community and remediation workers during remedy implementation) are evaluated during the detailed analysis. Chapter 2 and Appendices A

EXHIBIT 1-2

SUMMARY OF RISK EVALUATIONS OF REMEDIAL ALTERNATIVES

STAGE	LEVEL OF EFFORT		PRIMARY PURPOSE OF RISK EVALUATION[b]	
	Short -term Risk[c]	fang-term Risk	Short-term Risk'	Long-term Risk
Screening of Alternatives (Section 2.1)	Qualitative	Qualitative	Identify (and eliminate from consideration) alternatives with clearly unacceptable short-term risks.	Identify (and eliminate from consideration) alternatives with clearly unacceptable long-term risks.
Detailed Analysis of Alternatives (Section 2.2)	Qualitative or Quantitative[d]	Qualitative or Quantitative[d]	Evaluate short-term risks of each alternative to community and on-site remediation workers during implementation so that these risks can be compared among alternatives.	Evaluate long-term (residual) risk of each alternative and its ability to provide continued protection over time so that these risks can be compared among alternatives.
Proposed Plan (Section 3.1)	Qualitative or Quantitative[d]	Qualitative or Quantitative[d]	Refine previous analyses, as needed, based on newly developed information.	Refine previous analyses, as needed, based on newly developed information.
Record of Decision (Section 3.2)	Qualitative or Quantitative[d]	Qualitative or Quantitative[d]	Document short-term risks that may occur during remedy implementation.	Document risks that may remain after completion of remedy and determine need for five-year reviews.
Remedial Design (Section 3.3)	Qualitative or Quantitative[d]	Qualitative or Quantitative[d]	Refine previous analyses, as needed, and identify need for engineering controls or other measures to mitigate risks.	Refine previous analyses, as needed, and identify need for engineering controls or other measures to mitigate risks.
Remedial Action (Section 3.3)	Quantitative	Quantitative	Ensure protection of workers and community by monitoring emissions or exposure concentrations, as needed.	Evaluate whether remediation levels specified in ROD have been attained and evaluate residual risk after completion of remedy to ensure protectiveness.
Five-year Review (Section 3.4)	Generally not applicable	Quantitative	Generally not applicable.	Confirm that remedy (including any engineering or institutional controls) remains operational and functional and evaluate whether clean-up standards are still protective.

[a] Level of effort (i.e., qualitative or quantitative) refers only to the level of risk evaluation that is generally expected. Levels other than those presented here, or combinations of levels, are possible. See the main text of this document for additional discussion on level of effort.

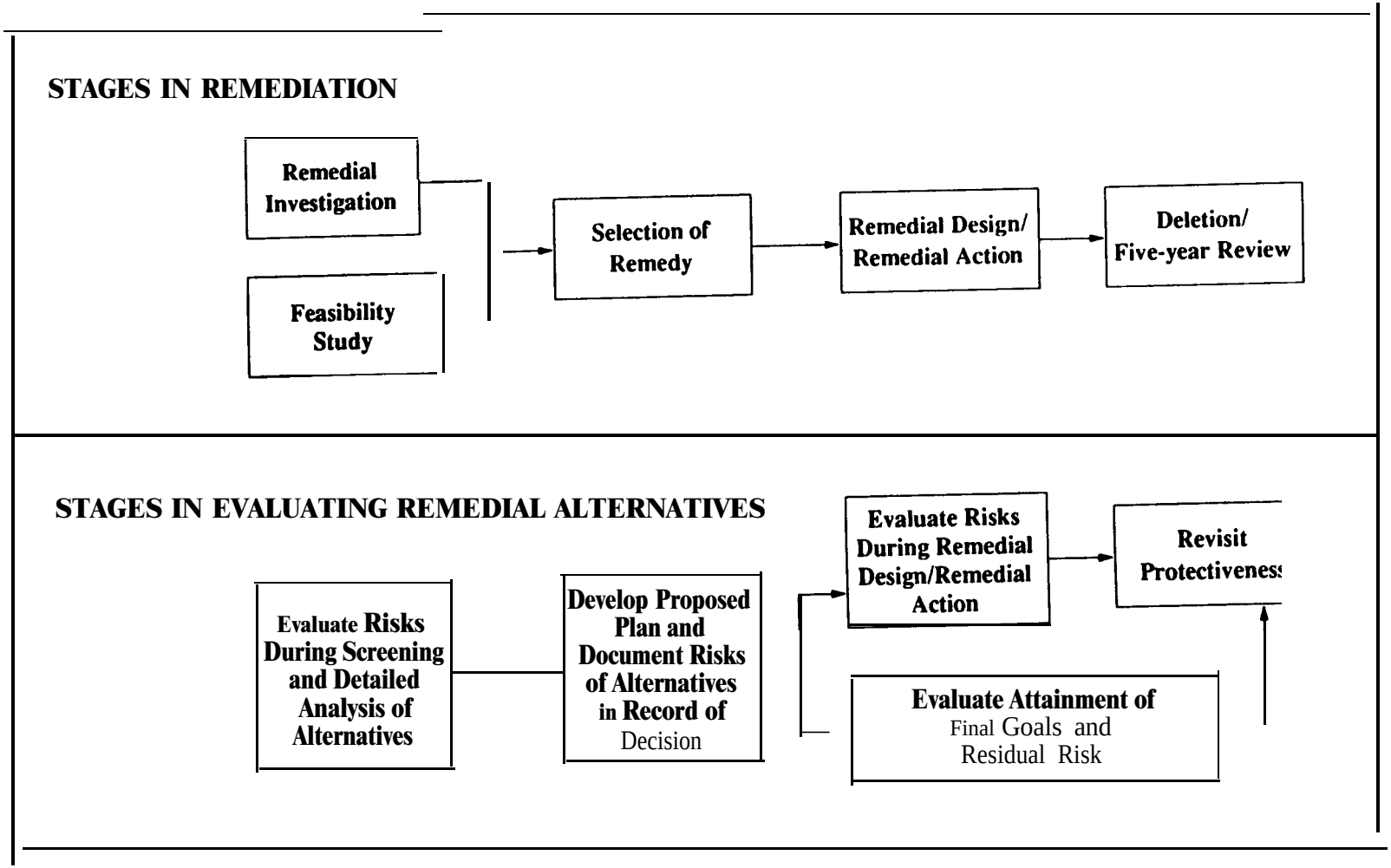
[b] Purpose presented in this exhibit for each stage is only the primary purpose; other purposes may exist. See the main text of this document for additional information.

[c] Short-term risk refers to risks that occur during remedy implementation.

[d] Text box in Section 2.2 lists considerations for deciding whether a qualitative or quantitative risk evaluation is needed for these stages.

EXHIBIT 1-3

RISK EVALUATION OF REMEDIAL ALTERNATIVES IN THE CERCLA PROCESS



through D of this document provide guidance on the evaluation of the risk-related aspects of long-term effectiveness (residual risk and permanence), and short-term effectiveness. (As with the screening of alternatives, Chapter 2 generally does not discuss evaluation of the other criteria, which do not directly involve human health risk considerations.) The resulting risk information is incorporated into the overall detailed analysis process described in the *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (RI/FS Guidance; EPA 1988c).

Proposed Plan and ROD. Risk evaluations are generally conducted during the development of the proposed plan and ROD only when new information concerning risks of the remedial alternatives is generated. Chapter 3 provides guidance on the evaluation of risks for the proposed plan and ROD stage.

Remedial Design/Remedial Action (RD/RA). Risk-related evaluations may also be conducted for some sites during implementation of the selected remedy. These activities, discussed briefly in Chapter 3, include: (1) refining risk evaluations as necessary when designing the remedy; (2) monitoring potential short-term health impacts on the community and workers; (3) assessing attainment of final remediation levels selected in the ROD; and (4) evaluating residual risk.

Five-year Review. Under the NCP, five-year reviews are required for sites as long as hazardous substances remain onsite above levels that allow unlimited use and unrestricted exposure, and are also conducted as a matter of policy for long-term remedial action sites even if no hazardous substances are expected to remain after completion of the action. Chapter 3 briefly addresses the consideration of risk during five-year reviews.

1.2 RELEVANT STATUTES, REGULATIONS, AND GUIDANCE

As discussed in RAGS/HHEM Part A, there is a hierarchy of requirements and guidance in CERCLA, beginning with the laws enacted by Congress, followed by the regulations, and then the guidance developed by EPA. This section addresses this hierarchy within the context of the risk evaluation of remedial alternatives.

1.2.1 CERCLA/SARA

CERCLA, commonly called Superfund, was enacted by Congress in 1980 in response to the dangers posed by sudden or otherwise uncontrolled releases of hazardous substances, pollutants, or contaminants into the environment. The Superfund Amendments and Reauthorization Act (SARA) was enacted in 1986. (All references to CERCLA in this guidance should be interpreted as "CERCLA as amended by SARA.")

Section 121 of CERCLA requires that remedies be protective of human health and the environment, satisfy ARARs, be cost-effective, and utilize permanent solutions and alternative treatment technologies to the maximum extent practicable. Section 121(c) of CERCLA requires a periodic review of remedial actions, at least every five years after initiation, for as long as hazardous substances that may pose a threat to human health or the environment remain at the site. The information in this manual provides guidance for evaluating the protectiveness of remedial alternatives at a site in terms of the human health-related aspects of these CERCLA requirements. Some considerations include protectiveness, effectiveness in terms of risk reduction, and degree of hazard for substances remaining at the site.

1.2.2 NCP

The NCP is the main set of regulations developed by EPA to implement CERCLA. The most recent NCP was published on March 8, 1990 (55 *Federal Register 8666-8865)* and is codified at 40 Code *of Federal Regulations* (CFR) Part 300. Section 300.430(e)(l) of the NCP describes a two-stage evaluation of remedial alternatives: a screening evaluation of a range of alternatives, if necessary, followed by a detailed analysis of the most promising alternatives. The NCP also describes activities that follow selection and implementation of the selected remedial alternative.

Screening. NCP section 300.430(e)(7) indicates that, if necessary and to the extent sufficient information is available, alternatives should be screened out if determined to be ineffective, not implementable, or grossly excessive in cost. Some aspects of effectiveness involve considerations of human health risk and are discussed in this guidance.

Detailed Analysis. The NCP establishes nine criteria in section 300.430 (e)(9) (iii) to use in evaluating alternatives in detail and in selecting a remedy. Parts of three of these criteria — overall protection of human health and the environment, long-term effectiveness and permanence, and short-term effectiveness – directly relate to risks and therefore are the focus of this guidance. The actual selection of a remedy for any given site ultimately is based on consideration of the nine criteria. This guidance also discusses the importance of risk communication to the community as it relates to the criterion of community acceptance.

Five-year Reviews. NCP section 300.430(f)(4)(ii) provides that if a remedial alternative is selected that results in hazardous substances (or pollutants or contaminants) remaining at the site above levels that allow for unrestricted exposure and unlimited use, such remedy should be reviewed at least every five years after initiation of the selected remedial alternative.

1.2.3 OTHER RELEVANT GUIDANCE

Three CERCLA program documents are important background for the guidance presented in this document – RAGS/HHEM Parts A and B (EPA 1989g; EPA 1991c), and the RI/FS Guidance (EPA 1988c). Parts A and B provide guidance on conducting a baseline risk assessment and on developing risk-based concentrations, respectively, that should be used in evacuating remedial alternatives. The activities conducted during a risk evaluation of remedial alternatives are somewhat similar to the activities conducted during a baseline risk assessment. (Chapter 2 discusses in more detail the similarities and differences.) The RI/FS Guidance describes the major activities and analyses that are conducted during the RI/FS. See the references at the end of this document for other relevant background guidance.

1.3 LEVEL OF EFFORT

The level of effort for risk evaluations of remedial alternatives depends primarily on the site-specific (questions that must be answered in order to select and implement a remedy. In addition, site-specific factors such as the complexity of the site, the number of alternatives considered for the site, the available resources, and the amount of available data may affect the level of effort. In most cases, a qualitative rather than a detailed quantitative evaluation of both long-term and short-term risks is all that is needed to select the most appropriate alternative. A quantitative risk evaluation of remedial alternatives will not need to be conducted for all sites. In all cases, the baseline risk assessment provides much of the risk-related information needed for the detailed analysis of alternatives, especially for those alternatives that involve limited or no action.

For many sites, the risk evaluations of remedial alternatives during the FS are conducted in a qualitative manner. That is, the risk evaluations during both the screening and detailed analysis stages for these sites will not be at all quantitative. At other sites, a more quantitative analysis of the long-term and/or short-term risks associated with the remedial alternatives may be needed during the detailed analysis. In these situations, the risk evaluation generally needs to incorporate more site-specific information.

A guiding principle is that the risk evaluation should be tailored to provide the RPM with specific information that he or she needs for supporting the selection or design of a remedy (e.g., the relative risks associated with alternatives, the alternatives that best meet the remediation goals). Because of the differences in information needs and available data for sites, in the complexity of sites, and in available methods, models, and resources for evaluation, all of the components of this guidance will not be applicable to all sites.

Chapter 2 provides some additional factors to consider when deciding on the level of effort to use for the risk evaluation of remedial alternatives.

1.4 IMPORTANCE OF RISK COMMUNICATION

As noted earlier, while overall protection of human health and the environment is one of the threshold criteria established by the NCP for use in evaluating alternatives and selecting a remedy, community acceptance of the remedy is a modifying criterion (NCP section 300.430(e)(9) (iii)). The CERCLA program encourages and promotes public participation during all phases of the decision-making process at CERCLA sites. Just as risk information is used by RPMs and other EPA staff to assist in evaluation of remedial alternatives during the FS and to evaluate the selected remedial alternative during and after its

implementation, risk information also will be employed by the public in their acceptance of a selected remedy. Good communication of the risks of the remedy to the public is crucial to the community's acceptance of the remedy.

There is no single procedure for good risk communication. The actual mechanism used and the messages delivered will vary from site to site and will depend upon the public, their level of concern, the complexity of the site, the contaminants of concern, and the proposed remedial alternative. RPMs are encouraged to work with the risk assessor and community relations coordinator for the site to develop the appropriate means to communicate risks from the remedial alternative or any residual risks. RPMs should consider using fact sheets, public meetings, and the release of draft documents or "risk communication" summaries as vehicles for risk communication. *Communiy Relations in Superfund: A Handbook* (EPA 1988a) offers guidance on planning and conducting CERCLA community relations activities.

Regardless of the vehicles chosen for risk communication, the following rules, from *Seven Cardinal Rules of Risk Communication* (EPA 1988f), should be kept in mind.

- Accept and involve the public as a legitimate partner.
- Plan carefully and evaluate your efforts.
- Listen to the public's specific concerns.
- Be honest, frank, and open.
- Coordinate and collaborate with other credible sources.
- Meet the needs of the media.
- Speak clearly and with compassion.

As provided under the NCP, risk communication, public participation, and community relations at CERCLA sites begin well before the remedy selection phase. This is important, as communities near CERCLA sites may begin with a degree of outrage that must be addressed before effective communication can begin. Community relations, public involvement, and good risk communication continue throughout the RI/FS process. A well-informed public will be better able to comment on — and provide input to — technical decisions. Establishing credibility through community relations, public participation, and effective risk communication practices early in the CERCLA process leads to greater community acceptance of the selected remedy.

1.5 MANAGEMENT AND DOCUMENTATION

One role of an RPM in the risk evaluation of remedial alternatives is to make risk management decisions. The RPM must have a comprehensive understanding of the risk evaluation in order to make these decisions. The first box on the next page provides questions that RPMs and other decision-makers should ask about the risks of remedial alternatives at their sites. The second box provides guidance on where to document the evaluations addressed in RAGS/HHEM Part C.

1.6 ORGANIZATION OF THE DOCUMENT

The remainder of this guidance is organized into two additional chapters and four appendices, as follows:

- Chapter 2: Risk Evaluation During the Feasibility Study;
- Chapter 3: Risk Evaluation After the Feasibility Study;
- Appendix A: Selected Remediation Technologies and Associated Potential Releases;
- Appendix B: Guidance for Quantifying Potential Releases from Selected Remediation Technologies;
- Appendix C: Short-term Toxicity Values; and
- Appendix D: Radiation Remediation Technologies.

In addition, several boxes, such as those below, provide useful information. A second kind of box, a "shadow" box, provides case studies. These boxes are presented at the end of Chapter 2.

QUESTIONS RPMs SHOULD ASK ABOUT HUMAN HEALTH RISKS OF REMEDIAL ALTERNATIVES

- Which technologies can readily achieve all preliminary remediation goals (PRGs) in a given medium? What uncertainties are involved in this determination?
- Which alternatives will clearly not address the significant human exposure pathways identified in the baseline risk assessment ?
- Are the expected residual risks or short-term risks from one alternative significantly different from another?
- What other risk-based benefits (e.g., shorter time to achieving goals) are realized by selecting one alternative over another?
- Will implementation of specific technologies create new chemicals of concern or new significant exposures or risks for the surrounding community?
- Is there a need for engineering controls or other measures to mitigate risks during implementation? Are such controls available? How reliable are these controls?
- Does the remedial alternative result in hazardous substances remaining at the site such that a five-year review or reviews would be required?

DOCUMENTATION OF RISK EVALUATIONS

- The risk evaluation conducted during the development and screening of alternatives (Section 2.1) and during the detailed analysis of alternatives (Section 2.2) should be documented in the FS.
- The proposed plan (Section 3.1) should contain a summary of the risk evaluations for the alternatives, including any new risk information identified during development of the proposed plan.
- The ROD (Section 3.2) should contain the results of the risk evaluations of the alternatives and the preferred alternative, including any results developed since the proposed plan.
- Any significant changes identified during RD/RA (Section 3.3) in the risk evaluations should be documented (e.g., in a memorandum).
- Each five-year review (Section 3.4) should contain a statement on protectiveness and, if necessary, a recalculation of risk and/or a new risk assessment.

CHAPTER 2

RISK EVALUATION DURING THE FEASIBILITY STUDY

The FS generally is a two-step process of evaluating remdial alternatives: (1) screening, if necessary, and (2) a more detailed analysis for those alternatives that pass the screening. The RI/FS Guidance provides information on conducting the FS and describes all of the evaluations that are performed. Some of these evaluations pertain to human health risk, and the guidance *in* this chapter assists in these evaluations. (Ecological effects of remedial alternatives — not discussed in RAGS/HHEM Part C – also must be considered during the FS.)

2.1 RISK EVALUATION DURING DEVELOPMENT AND SCREENING OF ALTERNATIVES

The overall objective of the development and screening of alternatives is to identified an appropriate range of waste management options, some of which will be analyzed more fully in the detailed analysis phase. This process usually takes place relatively early in the RI/FS process, during project scoping (before the baseline risk assessment is completed).

The NCP specifies that the long-term and short-term aspects of three criteria — effectiveness, implementability, and cost - should be used to guide the development and screening of remedial alternatives. At screening, those alternatives that are clearly unacceptable in terms of effectiveness or implementability or are grossly excessive in cost may be eliminated from further consideration.

Consideration of effectiveness involves evaluating the long-term and short-term human health risks — among other factors - associated with a remedial alternative. The criteria of implementability and cost are not related to risk and, therefore, are not discussed in this document.

2.1.1 CONSIDERATION OF LONG-TERM HUMAN HEALTH RISKS

The long-term human health risks associated with a remedial alternative are those risks that will remain after the remedy is complete (i.e., residual risks). Evaluating long-term risks might ideally include an assessment of the risks associated with treatment residuals and untreated wastes (for a treatment-based remedy), or an evaluation of the remedy's ability to provide protectiveness overtime (for a containment-based remedy). This approach might simply involve comparing estimates of the final concentrations that a remedy is expected to achieve in a medium with the PRGs for those chemicals in that medium. At the screening stage, however, this evaluation typically is based on professional judgment and the experience of the CERCLA program staff. Quantifying residual risks during screening generally is not necessary. For example, a technology may be evaluated during screening for its potential to treat the classes -or treatability groups — of chemicals present at the site (e.g., volatile organics, halogenated organics, non-volatile metals) rather than its ability to meet chemical-specific PRGs. See Section 2.2.1 for additional information on long-term risks associated with remedial alternatives.

2.1.2 CONSIDERATION OF SHORT-TERM HUMAN HEALTH RISKS

The short-term human health risks associated with a remedial alternative are those risks that occur during implementation of the remedial alternative (e.g., risks associated with emissions from an onsite air stripper). Because some remedies may take many years to complete, some "short-term" risks may actually occur over a period of many years. Populations that maybe exposed to chemicals during remedy implementation include: (1) people who live and work in the vicinity of the site and (2) workers who are involved in site remediation. As with the consideration of long-term risks, this evaluation is based primarily on

many simplifying assumptions and on professional judgment at the screening stage and is intended to identify alternatives with clearly unacceptable short-term risks. See Section 2.2.2 and Appendices A and D for additional information on evaluating alternatives for short-term risks during screening and development of alternatives.

2.2 RISK EVALUATION DURING DETAILED ANALYSIS OF ALTERNATIVES

The overall objective of the detailed analysis of alternatives is to obtain and present the information that is needed for decision-makers to select a remedial alternative for a site. This detailed analysis usually takes place during the later stages of the RI/FS process (i.e., near the end of or after the baseline risk assessment, when PRGs may have been modified). As discussed previously, two of the balancing criteria assessed during the detailed evaluation — long-term effectiveness and short-term effectiveness — involve an evaluation of risk. In addition, these criteria are considered in evaluating the criterion of overall protection of human health and the environment.

The risk evaluations of remedial alternatives involve the same general steps as the baseline risk assessment: exposure assessment, toxicity assessment, and risk characterization. The box on this page discusses the connection between the baseline risk assessment and the risk evaluations of remedial alternatives.

The guidance provided in this section assists in assembling and using available site-specific information for the purpose of completing the detailed analysis of remedial alternatives, specifically the evaluation of criteria that pertain to human health risks. The box on the next page lists several sources of information that can be used in the risk evaluations that are conducted during the RI/FS. The box on page 14 addresses the question of whether a quantitative evaluation is needed. The case studies at the end of this chapter provide examples of a qualitative and a quantitative evaluation of long-term and short-term risks during the detailed analysis.

CONNECTION BEIWEEN THE BASELINE RISK ASSESSMENT AND THE RISK EVALUATION OF REMEDIAL ALTERNATIVES

A risk evaluation of remedial alternatives follows the same general steps as a baseline risk assessment. Detailed guidance on each step is provided in RAGS/HHEM Part , which must be reviewed and understood by the risk assessor before a risk evaluation of remedial alternatives is conducted. Note, however, that the baseline risk assessment typically is more quantitative and requires a higher level of effort than the risk evaluation of remedial alternatives. Other differences (and similarities) are listed below.

Evaluate Exposure (Part A – Chapter 6)

- The source of releases for the baseline risk assessment is untreated site contamination, while the source of releases for the evaluation of remedial alternatives is the remedial action itself (plus any remaining waste).
- Exposure pathways associated with implementation of remediation technologies may include some pathways and populations that were not present (or of concern) under baseline conditions.
- The evaluation of short-term exposures associated with remedial alternatives may consider a number of different releases that occur over varying durations.

Evaluate Toxicity (Part A – Chapter 7)

- The risk evacuation of remedial alternatives often involves less-than-lifetime exposures that require appropriate short-term toxicity values to characterize risk or hazard.
- The risk evaluation of remedial alternatives may include an analysis of chemicals that were not present under baseline conditions (i.e., created as a result of the remedial alternative).

Characterize Risks (Part A – Chapter 8)

- A risk evaluation of remedial alternatives generally considers risks to onsite workers, as well as risks to the surrounding community.
- There are additional uncertainties involved in evaluating risks of remedial alternatives that are not considered in the baseline risk assessment (e.g., confidence in performance of remedies and patterns of predicted releases, confidence in attainment of clean-up levels).

SOURCES OF INFORMATION FOR RISK EVALUATIONS DURING THE FS

Baseline Risk Assessment. Much of the data collected during the baseline risk assessment can also be used to calculate the long-term residual risk associated with a remedial alternative. Some of the data may be applicable to calculation of risks during the remedial action. Some of the information from the baseline risk assessment that may be useful for analyzing the risks associated with the remedial alternative includes:

- exposure setting, including exposed populations and future land use (RAGS/HHEM Part A, Section 6..2);
- exposure pathways, including sources of contamination, chemicals of concern, fate and transport of chemicals after release, and exposure points (RAGS/HHEM Part A, Section 6.3);
- general exposure considerations, including contact rate, exposure frequency, and duration (RAGS/HHEM Part A, Section 6.4);
- exposure concentrations, including monitoring data, modeling results, and media-specific results (RAGS/HHEM Part A, Section 6.5);
- estimates of chemical intake (RAGS/HHEM Part A, Section 6.6);
- toxicity information (e.g., changes/additions to Integrated Risk Information System [IRIS] and Health Effects Assessment Summary Tables [HEAST]) (RAGS/HHEM Part A, Chapter 7);
- quantitation of risks (RAGS/HHEM Part& Section 8.6); and
- uncertainties associated with toxicity assessment, exposure assessment, and baseline risk characterization (RAGS/HHEM Part A, Sections 6.8, 7.6, and 8.5).

Treatability Studies. Treatability investigations are site-specific laboratory or field studies, performed either with laboratory screening, bench-scale, or pilot-scale study (see Section 5.3 of the RI/FS Guidance). Generic studies for technologies (e.g., those performed by a vendor) can also contain useful information. Treatability studies may provide risk-related data such as (1) information on short-term emissions and (2) information on removal efficiencies of a technology. This information may be especially useful when considering innovative technologies. *Guide to Conducing Treatability Studies under CERCLA* (under development by EPA's Risk Reduction Engineering Laboratory) provides a three-tiered approach to conducting treatability studies during screening, selection, and design of rernedial alternatives. Chapter 5 of the RI/FS Guidance, especially Section 5.6, provides information on evaluating the applicability of the treatability study results (e.g., determination of usefulness, documentation, usefulness of residual information, application of laboratory/ bench/pilot studies to full-scale system).

Feasibility Studies or Other Analyses for Comparable Sites. If a risk evaluation of one of the alternatives being considered was conducted during the FS (or later stages) for a site with similar wastes and similar conditions, some of the information that was developed may be helpful in characterizing the short-term or long-term risks associated with that alternative. This type of information should be examined carefully to determine whether the analyses are appropriate for the site currently being evaluated. Differences in the types of hazardous substances present, characteristics of environmental media, meteorological conditions, locations of receptors, or other factors could result in large differences in the risk evaluation.

The Engineering and Technical Support Center of EPA's Risk Reduction Engineering Laboratory (513-569-7406 or FTS 684-7406) can provide information concerning treatability studies and evaluations of remedial technologies.

FACTORS TO CONSIDER WHEN DECIDING WHETHER A QUANTITATIVE RISK EVALUATION IS NEEDED

The decision of whether to conduct a quantitative or qualitative risk evaluation depends on (1) whether the relative short-term or long-term effectiveness of alternatives is an important consideration in selecting an alternative and (2) the "perceived risk" associated with the alternative. The perceived risk includes both the professional judgment of the site engineers and risk assessors and the concerns of neighboring communities. Some factors that generally lead to a higher perceived risk are as follows:

- close proximity of population,
- presence of highly or acutely toxic chemicals
- technologies with high release potential, either planned or "accidental";
- high uncertainties in the nature of releases (e.g., amount or identity of contaminants released) such as might exist with use of certain innovative technologies;
- multiple contaminants and/or exposure pathways affecting the same individual
- multiple releases occurring simultaneously (e.g., from technologies operating in close proximity);
- multiple releases occurring from remedial actions at several operable units in close proximity and
- releases occurring over long periods of time.

If consideration of these (or other) factors leads to a high perceived risk for an alternative, a more quantitative evaluation, including emission modeling and/or detailed treatability studies, may be helpful in the decision-making process. For example, if one alternative considered for a site involves extensive excavation in an area that is very close to residential populations, then a more quantitative evaluation of short-term risks maybe needed to evaluate this alternative. In addition, other factors, such as available data and resources, may affect the level of detail for these risk evaluations.

2.2.1 EVALUATION OF LONG-TERM HUMAN HEALTH RISKS FOR DETAILED ANALYSIS

Evaluation of the long-term human health risks associated with a remedial alternative involves: (1) evaluating residual risk and (2) evaluating the alternative's ability to provide protection over time.

Evaluate Residual Risk. Because PRGs generally are based on chronic human health risk considerations (e.g., ARARs such as maximum contaminant levels (MCLs), or risk-based concentrations), they usually provide the standard to use to evaluate long-term health risks. When site engineers are developing alternatives and determining whether a technology is capable of achieving PRGs, they are in effect evaluating residual risk. (Therefore, the results from using RAGS/HHEM Part B and other guidance on remediation goals are very important for this part of the analysis.)

Most of the time it will be sufficient for the detailed analysis to indicate whether or not an alternative has the potential to achieve the PRGs, rather than to quantify the risk that will remain after implementation of the alternative. If more detailed information concerning long-term risk is needed to select an alternative (e.g., to determine the more favorable of two otherwise similar alternatives), then it may be useful to determine whether one alternative is more certain to achieve the PRGs than the other, whether (or to what extent) one may be able to surpass (i.e., achieve lower concentrations than) the PRGs, or whether one may be able to achieve the goals in a shorter time.

Certain remedial technologies (e.g., incineration) may produce new contaminants that were not present at the site under baseline conditions. The risks associated with these additional substances generally should be evaluated. Another consideration in evaluating the residual risk associated with some alternatives is the level of confidence in the ability of the remedy as a whole to achieve the site engineers' predictions. For some technologies (e.g., ground-water extraction and treatment technologies), past experience has indicated that, in some situations, it may be difficult or impossible to achieve the predicted goals. This information on the

uncertainty associated with an alternative may be an important factor in selecting a remedy.

After the individual technologies comprising a remedial alternative have been examined separately, then the alternative as a whole should be examined to determine the extent to which it meets the PRGs for all of the contaminated media and all of the contaminants of concern. Even if PRGs will be met, potential cumulative effects on human health due to multiple contaminants, media, or exposures may need to be considered. If an alternative will not meet the PRGs for all media or contaminants of concern or if cumulative effects are a concern, this information should be highlighted in the presentation of the results of the detailed analysis.

Evaluate Protectiveness Over Time. Evaluating whether an alternative is likely to maintain the specified level of protectiveness over time (often referred to as "permanence") involves using expert engineering judgment. In particular, if an alternative relies on engineering or institutional controls to reduce or eliminate exposure to contaminated media, then the ability of these controls to maintain protectiveness should be considered. These types of remedies provide protection by reducing or eliminating exposure to hazardous substances rather than eliminating the hazardous substances or reducing their concentrations, volumes, or toxicity. Failure of such remedies could lead to an increase in exposure and therefore an increase in risk. For example, if a remedy includes the capping of contaminated soils, then the potential future exposures due to cap failure include direct contact with soils and the leaching of contaminants to ground water. The worst-case situation of complete containment system failure is unlikely to occur, however, because five-year reviews (see Section 3.4) are conducted at all sites where wastes are managed onsite above concentration levels that allow for unrestricted use and unlimited exposure.

2.2.2 EVALUATION OF SHORT-TERM HUMAN HEALTH RISKS FOR DETAILED ANALYSIS

Short-term health risks generally include any current baseline risks plus any new risks that would occur while implementing the remedy. As discussed previously, the evaluation of potential short-term risks involves the same general steps as in the baseline risk assessment. These steps, however, generally will not be conducted in the same level of detail for the FS.

Other important points concerning level of effort should be emphasized here. For example, the Resource Conservation and Recovery Act (RCRA) has performance standards for many commonly used CERCLA remedial technologies (e.g., incineration). The risks associated with many of these technologies were analyzed in developing these standards, and the standards were set such that the risks associated with operation of the technology would be acceptable. Therefore, a detailed evaluation of the risks associated with RCRA-regulated technologies generally would not be necessary. On the other hand, depending on site-specific factors such as the toxicity of site contaminants and the proximity of populations, a more detailed evaluation of short-term risks may indeed be appropriate.

Detailed analyses may also be appropriate for less-characterized technologies (e.g., innovative technologies). In addition, alternatives with multiple short-term releases or substantial baseline risks may need a more detailed evaluation to determine whether cumulative risks are expected to be within acceptable levels.

Of special note is that the short-term risk evaluation for remedial alternatives during the detailed analysis includes an evaluation of the potential for short-term risks to two groups of individuals: (1) neighboring populations (which include onsite workers not associated with remediation) and (2) onsite workers associated with remediation.

Appendices A through D Provide information that can be used when a more quantitative evaluation of short-term risks is needed to support the selection of a remedy. Chapter 8 of RAGS/HHEM Part A also provides guidance on characterizing short-term risk.

Evaluate Short-term Exposure. A qualitative exposure assessment for remedial alternatives during the detailed analysis generally involves — just as in the baseline risk assessment, but in a less quantitative manner – using the concept of reasonable maximum exposure (RME) to evaluate release sources, receiving media, fate and transport, exposure points, exposure routes, and receptors associated with a particular alternative.

An important difference between the baseline risk assessment and the risk evaluation of remedial alternatives involves exposure sources. For the baseline risk assessment, the source of exposure is untreated site contamination. For remedial alternatives, however, the potential sources of exposure are the releases that result from the implementation of remedial technologies. In addition, some remedial alternatives (e.g., incineration, biodegradation) may result in new chemicals that were not previously assessed for the site.

The first step of the exposure assessment involves identifying the types of releases associated with a particular waste management approach. During the detailed analysis, methods for mitigating potentially significant short-term releases should be examined, and releases that are expected to be most difficult to control should be highlighted.

Appendices A and D of this guidance each contain two matrices that should assist in characterizing the releases that may occur during remedy implementation. Exhibit A-1 provides a brief description of common remedial technology processes, and Exhibit A-2 summarizes potential releases to different media during the normal operation of various technologies. Exhibit D-1 provides a summary of releases associated with radiation remedial technologies, and Exhibit D-2 includes a qualitative estimate of the potential short-term risks posed by a radiation remedial technology.

After the releases and their receiving media have been identified, the next step of the exposure assessment is to determine whether major exposure pathways exist. Characterizing site-specific exposure pathways involves identifying:

- the general fate and transport of the contaminants that are released from the technology (e.g., downwind transport);
- the potential exposure points and receptors (e.g., nearby downwind residents); and
- potential exposure routes (e.g., inhalation).

Exhibit 2-1 illustrates an example of an exposure pathway for a remedial alternative. More detailed information concerning exposure pathways is available in Chapter 6 of RAGS/HHEM Part A. The flow charts contained in Exhibit 6-6 of Part A are particularly useful in determining the populations potentially exposed by releases into a particular medium. Transfers of contaminants from one medium to other media also are addressed.

At this point, a quantitative exposure assessment — if needed — would involve (in addition to identifying release sources, exposure routes, and exposure points):

- quantifying releases;
- evaluating environmental fate and transport;
- determining exposure point concentrations; and
- calculating intakes.

All of these steps are discussed in Chapter 6 of RAGS/HHEM Part A.

Throughout the short-term exposure assessment, the assessor must continually ask whether the potential exposure warrants the level of quantitation being used. At times, the answer may not be known until the end of the exposure assessment. For example, if short-term exposure was estimated to be very similar to long-term exposure, it would not be necessary to expend resources to obtain the short-term toxicity information needed to quantitatively characterize risk.

A major difference between the exposure assessment conducted during the baseline risk assessment and the one conducted during the risk evaluation of remedial alternatives is the evaluation of the timing and duration of releases. Because a number of different activities will take place during implementation, it is likely that the quantities of hazardous substances released to the environment will vary over time. For example, as seen in Exhibit 2-2, one remedy can have several distinct phase.., each with different exposure potentials. It may be important to determine the sequence of events and likely activities at each phase of the remediation, so that the exposure point can be evaluated for each phase. This will also ensure that appropriate short-term exposure durations are identified and that the potential for releases to occur simultaneously and thus result in cumulative risk is considered. As seen in

EXHIBIT 2-1

ILLUSTRATION OF AN EXPOSURE PATHWAY FOR A REMEDIAL ACTION

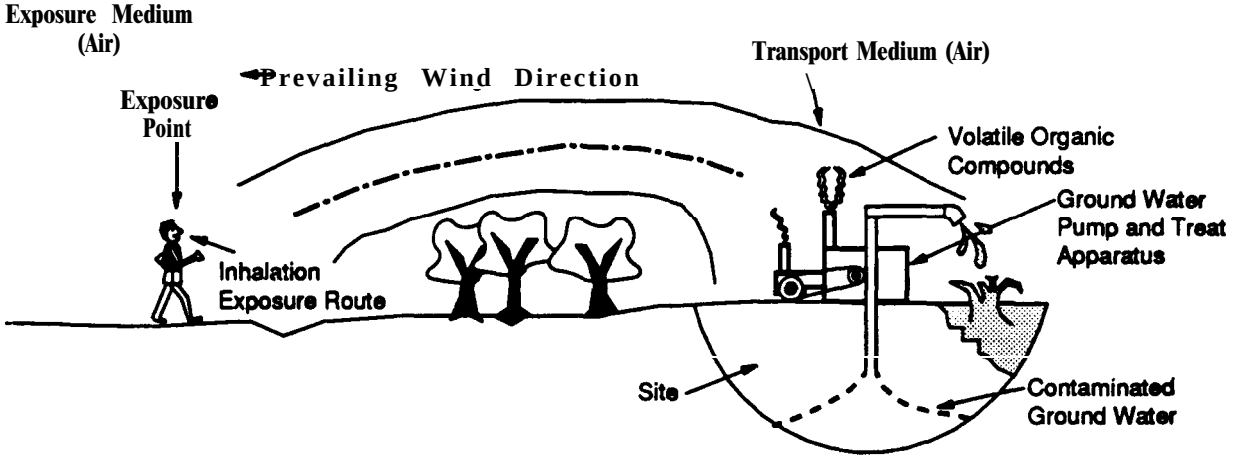


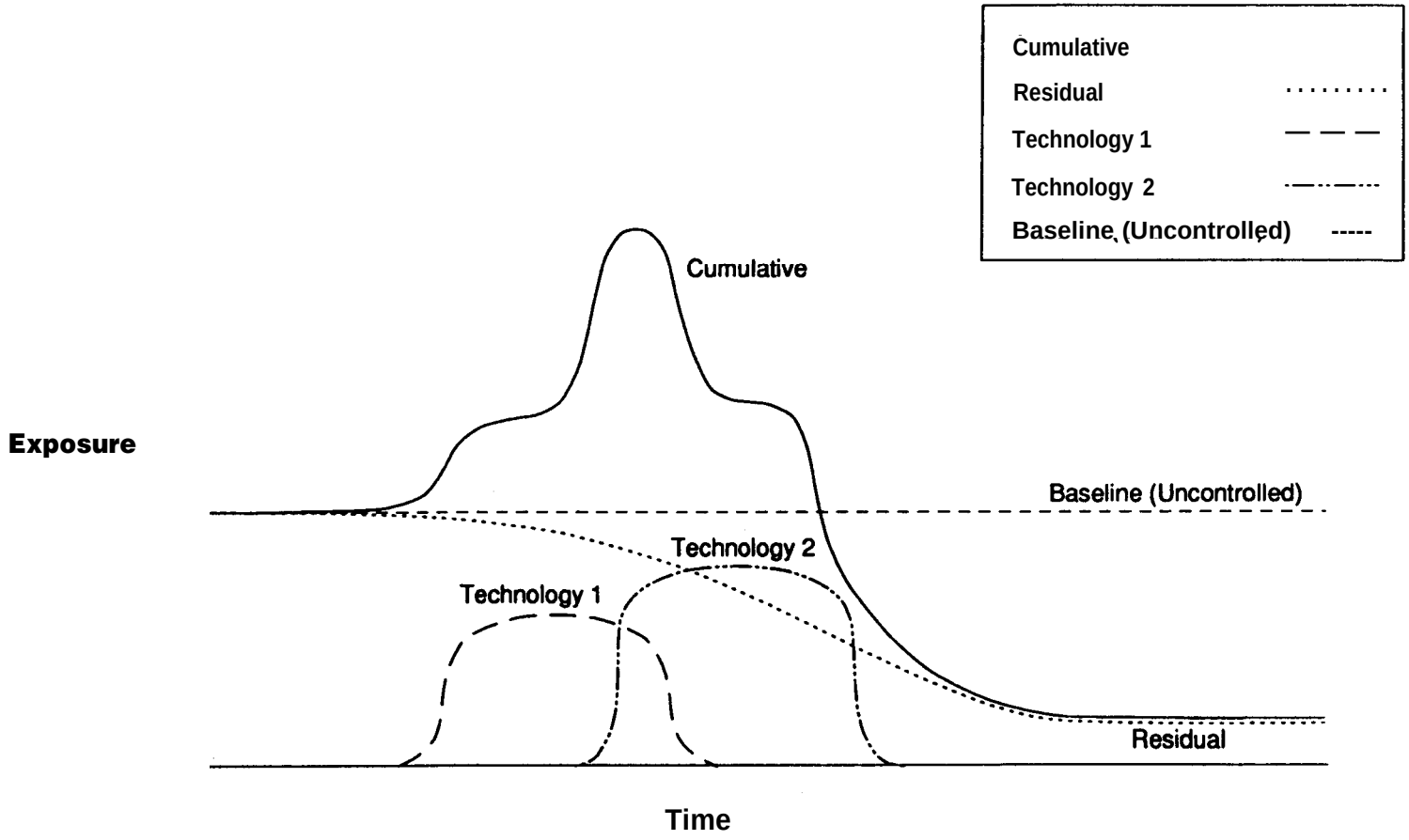
Exhibit 2-2, this issue is complicated by the possible presence of baseline exposures.

Appendix B provides references — organized based on several important categories of remedial technologies — that can be consulted to quantify the release of and therefore exposure to contaminants. The information in Appendix B includes a brief discussion of considerations in release modeling and monitoring, a list of key technology-related parameters generally needed as inputs for models (e.g., meteorological conditions, operation characteristics, soil/media characteristics), an annotated list of primary references, and a list of additional references.

Evaluate Short-term Toxicity. The releases that may occur during implementation of a remedial alternative, and hence the exposure-point concentrations, generally last for varying durations and correspond m less-than-lifetime exposures. Consequently, any toxicity values used to evaluate the risks from these shorter exposures must correspond to the duration of the release (or exposure). Three exposure durations, in addition to longer-term exposures, may be of concern at CERCLA sites undergoing remediation: single exposure events (minutes, hours, or single day), very short-term exposures (up to two weeks), and short-term exposures (two weeks to seven years). Note that the chronic toxicity values for noncarcinogenic effects used most frequently in the baseline risk assessment may not be appropriate without modification for exposures of less than seven years (otherwise they may be unnecessarily conservative).

EXHIBIT 2-2

ILLUSTRATION OF CUMULATIVE EXPOSURE FROM MULTIPLE RELEASES



Note: The graph illustrates how nearby populations at some sites could be exposed to both residual risks and risks from remediation technologies. The cumulative exposure illustrated is the sum of residual exposure ad exposures associated with releases from Technologies 1 and 2. This exhibit is for illustration purposes only and is not meant to imply that this level of quantitation is neccesary or even desired.

Appendix C contains information concerning the use of short-term toxicity values. RAGS/HHEM Part A provides additional information on assessment of contaminant toxicity. As discussed in Appendix C, the Superfund Health Risk Technical Support Center (TSC) should be consulted in all cases where short-term toxicity values are needed.

Characterize Short-term Risks to the Community. During risk characterization, exposure and toxicity information is brought together to provide a measure or indication of the magnitude and timing of short-term health risks (if any) from the remedial alternatives. As discussed previously, risk assessors may choose to characterize the short-term risks to the community (i.e., persons who live or work in the vicinity of the site) quantitatively for some sites and qualitatively for others. When short-term risks are not expected to be a problem for a site, a more qualitative evaluation generally is appropriate. In these cases, a qualitative evaluation of the magnitude, duration, and/or likelihood of the exposures and risks should be conducted, and assessors could describe short-term risks in a qualitative manner relative to the results of the baseline risk assessment.

A quantitative evaluation of short-term risks is most likely to be useful when the types, levels, and/or availability of hazardous substances are expected to change significantly as a result of remediation. If quantitative exposure estimates and toxicity data are available, then a more quantitative risk characterization may be conducted. The quantitative method that is used to characterize these risks depends in part on the toxicity values that have been identified. Some of these toxicity values (e.g., subchronic reference doses) must be combined with the results of the exposure assessment (i.e., intakes). The results of risk characterizations using this type of toxicity value will be of the same type as those generated in the baseline risk assessment: hazard quotients (or indices) or excess individual lifetime cancer risks. If the toxicity values incorporate exposure assumptions (e.g., as in one- and ten-day health advisories), then these values are compared with exposure concentrations to determine whether the risks are above acceptable levels. Appendix C provides additional information on short-term toxicity values.

Cumulative effects from multiple releases or multiple chemicals should also be considered, if possible. If the risk characterization is qualitative, then a discussion of the potential for cumulative risks from multiple chemicals and/or exposure pathways (e.g., due to simultaneous implementation of several remedial technologies) should be provided. If the results of the risk characterization are more quantitative (e.g., cancer risks and hazard quotients), then the information concerning duration and timing of releases can be used to calculate the cumulative risks or hazard indices for those releases that will occur at the same time and affect the same populations. If the results of the quantitative risk characterization are comparisons with short-term toxicity criteria, then the total exposure concentrations can be calculated for releases that occur at the same time and affect the same populations. These total exposure concentrations then can be compared to the short-term toxicity criteria. See Chapter 8 of RAGS/HHEM Part A for additional guidance on characterizing short-term human health risks.

Characterize Short-term Risks to Workers. Worker health and safety issues should also be considered during the development of the FS. The Worker Protection Standards for Hazardous Waste at 40 CFR 311 and 29 CFR 1910.120 establish requirements for worker protection at CERCLA sites, including requirements for planning (i.e., health and safety plans, and emergency response plans), training, and medical surveillance. Although the standards encompass areas that are not directly related to worker risk (e.g., illumination and sanitation), they also specify requirements in areas that are directly relevant to worker health risks. Specifically, once a remedy is selected, the Worker Protection Standards require that implementation of that remedy proceed with the following risk-related considerations:

- site characterization and analyses prior to commencing remedial activities, specifically risk identification (see 29 CFR 191O.12O(c));
- proper use of engineering controls, work practices and personal protective equipment (PPE) for employee protection (see 29 CFR 1910.120(g)); and
- preparation of emergency response plans that specify how the site employees will be protected while responding to onsite

emergencies that may occur (see 29 CFR 1910.120(1)).

It is important to note, however, that factors not associated directly with hazards particular to a given site (e.g., risk of accidents during offsite motor vehicle transport) are not usually considered during the FS, but instead should be addressed prior to remediation in the site health and safety plan.

The exact nature of the assessment of worker safety issues for a remedial alternative will vary with each site. For many types of sites and remedial alternatives, the risks to workers will be well-characterized and will not require much additional site-specific analysis. These issues will be addressed in more detail in the site-specific health and safety plan. Thus, a qualitative assessment of worker risk is appropriate for most sites during the FS and can be based on three types of risk.

- Potential for exposure to hazardous substances during onsite remedial activities. The most significant factor determining the potential for exposure to hazardous substances is the nature of the onsite contamination. Because onsite remediation workers are equipped with the appropriate PPE and are required to use appropriate engineering controls, their risk generally should be minimal. Factors that affect the potential for exposure, however, include the likelihood of PPE failure. In general, more restrictive PPE is more likely to fail due to considerations such as worker mobility and visibility constraints, and potential for worker heat stress.

- Potential for injury due to Physical hazards. Onsite remediation workers maybe exposed to hazards other than exposure to hazardous substances. Hazards such as explosion, heat stress, and precarious work environments may also pose threats to workers.

- Potential for exposure during emergency response activities (assuming the need arises for onsite emergency response). Part of the design of a remedial alternative should consider the potential for worker exposure during emergency responses that may be required in the event of remedy failure. For some remedial alternatives, it is possible that emergency assistance would be handled in part by onsite workers, with offsite assistance (e.g., county HAZMAT teams) as required.

Alternatively, it is possible that an emergency response plan would require the evacuation of onsite remediation workers and use of offsite emergency responders.

2.3 CASE STUDIES

The following two case studies provide examples of the evaluations of long-term and short-term risks that are conducted during the detailed analysis. Both case studies present an evaluation of only one technology for one of several alternatives that are considered for the hypothetical site. An actual detailed analysis would include a similar evaluation for other technologies and alternatives as well. The two sites considered in the case studies are identical in all respects, except one: the XYZ Co. site considered in Case Study #1 is distant from residential or worker populations, while the ABC Co. site considered in Case Study #2 is adjacent to a residential neighborhood. A more quantitative analysis was conducted in Case Study #2 because of concern for potential short-term exposures to the neighboring community.

The sites presented in these case studies are abandoned industrial facilities that are contaminated with various volatile organic compounds (VOCs) and heavy metals. VOCs contaminate both the soil and ground water at the sites, while metals are found in the soil only. A number of leaking drums were stored above ground at the sites and were removed prior to the RI. There are also two lagoons filled with hazardous sludges. City ground-water wells are located approximately 1/4 mile from the" sites. VOCs have been detected in the wells at levels high enough to force the city to use an alternate water source.

CASE STUDY #1:
QUALITATfVE EVALUATION DURING DETAILED ANALYSIS

[Note: This case study presents an evaluation of only one technology for only one of several remedial alternatives; an actual detailed analysis would address other technologies and alternatives as well. All data in this ease study are for illustration purposes only.]

Remedial Altematives

Based on the results of the development and screening of alternatives, the site engineers have identified five alternatives (A through E) to be evaluated for use as remedies at the XYZ Co. site. One of the technologies included in Alternative C is ground-water pumping and air stripping for the VOCs in ground water.

Evaluation of Long-term Risks

Meeting PROS for all contaminants in ground water is uncertain at this point due to the complex nature of the contaminated aquifer. If after remedy implementation it is determined that Alternative C does not meet PRGs for all contaminants in ground water, then the residual risk remaining after implementation will be examined to determine whether other measures need to be taken to assure protectiveness. There are no residual risks for media other than ground water for the pump-and-treat/air stripping component of Alternative C.

Evaluation of Short-term Risks

The time-frame for air stripping of VOCs from ground water at the XYZ Co. site - and therefore the time frame considered for evaluating short-term risks – is at least 20 years, and possibly as many as 50, depending on factors such as the specific aquifer characteristics.

Releases and Receiving Media. The most likely release of concern from an air stripper is the release of air contaminated with VOCs. The type of air stripper being considered for the XYZ Co. site generally achieves 99 percent or better removal of VOCs from water. The vapor phase VOCs contained in the air stripper off-gases then can be removed if necessary using air pollution control devices such as granular activated carbon columns or an afterburner, which generally achieve 90 to 99 percent destruction or removal of contaminants from the vapor phase. However, there will still be some small release of contaminants that may need to be examined further during the design stage of this remedy (if selected). Also, air pollution control devices will produce residues that in turn may need to be treated. Other releases associated with air stripping include treated water containing residual organic contaminants that will be released to surface water, and, possibly, fugitive air emissions due to leaky valves and fittings.

Fate and Transport, Exposure Points and Expos ure Routes. The release of VOCs into the air during air stripping at the XYZ Co. site could result in inhalation of volatiles transported through the air. However, the nearest target population is over one mile from the site. Long-term average concentrations may be a concern, as well as shorter-term or peak concentrations that may occur under certain conditions (e.g., temperature inversions).

Short-term Risks. The time period of exposure to air stripper Off-gases (20 to 50 years) is a significant portion of a human lifetime. However, because the concentrations of VOCs in ground water are not unusually high, the releases associated with the air stripper are weli-characterized, and there is no nearby target population, quantitation of these risks is not needed to select a preferred alternative.

CASE STUDY #2:
QUANTITATIVE EVALUATION DURING DETAILED ANALYSIS

[Note: This case study presents an evaluation of only one technology for only one of several remedial alternative an actual detailed analysis would address other technologies and alternatives as well. All data in this case study are for illustration purposes only.]

Remedial Alternatives

Based on the results of the development and screening of alternatives, the site engineers have identified five alternatives (A through E) to be evaluated for use as remedies at the ABC Co. site. One of the technologies included in Alternative C is ground-water pumping and air stripping for the VOCs in ground water. [For this case study, only benzene from the pump-and-treat component of the remedial alternative will be analyzed in detail. In an actual analysis, each contaminant of concern and each component of the remedy may need to be analyzed in a similar fashion.]

Evaluation of Long-term Risks

The RI has shown that the organic contaminants in the ground water are adsorbed to the aquifer material and are also dissolved in the ground water. The rernediation goal for benzene will be readily met in the treated water, which will subsequently be discharged into the nearby surface water. Remediation of the water remaining in the aquifer, however, is much less certain. The residual concentration of benzene in this remaining water will depend on several factors, including the adsorptive characteristics of benzene with the aquifer material, the specific pumping regimen, and the length of time that this technology is implemented. If, at a later stage (e.g., during the five-year review), it is determined that the contaminants are not being extracted at the desired levels, the pumping regimen may need to be modified (or some other approach may be needed). At a minimum, the pumping of ground water is expected to be an effective barrier against further contaminant migration. Due to the uncertainty regarding the residual concentration of contaminants that may remain in ground water, the permanence of the pump-and-treat technology, in terms of future risks, is unknown at this time.

Evaluation of Short-term Risks

Short-term impacts due to air emissions from air stripping are expected to be the most significant risks from the pump-and-treat component of the remedy at ABC Co. site. [This case study does not consider fugitive emissions from sources "upstream" of the air stripper (e.g., separators, holding tanks, treatment tanks), although these sources may have been evaluated in an actual risk assessment.] In order to assess these risks during the detailed analysis stage, exposure concentrations from the ABC Co. site will be estimated by combining emissions modeling with dispersion modeling. Before proceeding with this analysis, the following steps were taken.

- An appropriate atmospheric fate and transport model, derived from the SCREEN model developed by EPA's Office of Air Quality and Planning Standards was chosen. (A more complete listing and comparison of atmospheric fate models is given in Table 3-2 of the *Superfund Exposure Assessment Manual* [EPA 1988e].)

- Required inputs for the atmospheric fate and transport model were obtained. These inputs included the emission rate of contaminants from the air stripper into the atmosphere (based on contaminant concentrations in ground water, system flow rate efficiency of the air stripping process, and efficiency of the air pollution control device); atmospheric dispersion factors for contaminant and meteorological data (wind speed, prevalent direction, stability, mixing height, and temperature). More detailed parameters, such as surface roughness height and specific topographic features, were not required for the model that was chosen.

(Continued)

CASE STUDY #2:
QUANTITATIVE EVALUATION DURING DETAILED ANALYSIS
(Continued)

- The population that will be affected by short-term releases was identified. This information was obtained from the baseline risk assessment, and was based on the population distribution and density of the surrounding community, and meteorological data such as the prevailing wind direction.

- The toxicity characteristics of the contaminants were obtained from the baseline risk assessment.

Exposure Assessment. Releases are expected to occur during both the construction and the implementation stages of the pump-and-treat technology. The time frame for each of these stages varies and, therefore, the release and exposure potential also will vary. The most probable release of concern from implementation of the air stripper [the focus of this case study] has been identified as the release of air contaminated with volatile organic chemicals (VOCs) from the stripping tower to the atmosphere. Benzene is one of the volatile contaminants in the ground water being treated, and is expected to be present as a residual in the stripper off-gases. The following equation (EPA *Emission Factors for Superfund Remediation Technologies,* Draft, Office of Air Quality Planning and Standards, 1990) was used to calculate the benzene emission rate into the air stripper off-gases

$$ER\ (g/s) = C \times Q_{in} \times (SE/100) \times K$$

where ER = emission rate of benzene (g/s)
C = concentration of benzene in water = 2.5 mg/L
Q_{in} = influent water flow rate = 1700 L/rein
SE = stripping efficiency of tower for benzene = 99.99%
K = constant to convert units = 1.67×10^{-5} (g-min/mg-s)

An SE of 99.99 percent is used in these calculations to determine the reasonable maximum emission rate of benzene into the air. Actual SEs would be between 90 and 99.99 percent, depending on several operating parameters. Solving this equation, ER = 0.071 g/s.

Because this system will use an air pollution control device (APCD) such as granular activated carbon (GAC) columns to remove contaminants from gases released to the atmosphere, ER is the rate of release of benzene from the ground water into the stripper off-gases rather than the rate of release of benzene directly to the atmosphere. The release rate of benzene to the atmosphere, therefore, can be calculated using the following equation

$$q = ER \times (1 - DRE/100)$$

where q = mass release rate to atmosphere (g/s)
ER = emission rate from air stripper to APCD = 0.071 g/s
DRE = destruction/removal efficiency of APCD = 95%

A DRE of 95 percent is used to obtain a reasonable maximum release rate to the atmosphere. Applications of similar APCDs achieve 95 to 98 percent destruction and removal efficiency for benzene in air. Solving for the atmospheric release rate of benzene, q = 0.0035 g/s.

Using fate and transport modeling [analysis not shown], the atmospheric release rate of benzene is converted to an exposure point concentration at a residence 250 m downwind of the site. The short-term air concentration (24-hour average) of benzene is estimated to be 6×10^{-4} mg/m3. The average annual longer-term concentration of benzene in air at the site boundary, as determined by the same model, is estimated to be 3.4×10^{-4} mg/m^3.

(Continued)

CASE STUDY #2:
QUANTITATIVE EVALUATION DURING DETAILED ANALYSIS
(Continued)

The only potential exposure pathway identified for releases from the air stripper is the air (inhalation) pathway. Because the toxicity criterion used to characterize short-term risk is a threshold concentration (see Toxicity Assessment below), a short-term intake does not need to be calculated. The longer-term intake is needed to evaluate the cancer risk associated with inhalation of benzene. This intake is calculated by first obtaining the long-term site-specific exposure duration of 30 years from the baseline risk assessment. (An exposure duration of 30 years is used because, while the time for implementation of the pump and air stripping technology maybe up to 50 years, an individual is not expected to stay in the community for more than 30 years. If the maximum time for Implementation were less than the exposure duration identified in the baseline risk assessment, then exposure would be computed using the maximum implementation time as the exposure duration.) Using other exposure values obtained from the baseline risk assessment (e.g., inhalation rate of 20 m^3/day), the longer-term (lifetime average) intake of benzene due to the air stripper is approximately 73 x 10^{-5} mg/kg-day.

These concentrations and intakes are based on conservative steady-state assumptions regarding atmospheric conditions. Therefore, there is uncertainty surrounding the atmospheric data (which are inputs to the model) that could lead to higher (but probably lower) concentrations. For example, variations in wind speed and direction will result in different contaminant concentrations for both maximum short-term and long-term exposure point concentrations. Some amount of published research data is available (mainly from water treatment plant studies) on the reliability of the APCDs used in air stripping. This information, combined with data from previous program experience, indicates that the uncertainty associated with the effectiveness of the APCDs is low.

Toxicity Assessment. To assess risk from exposure to the short-term benzene concentration (24-hour average), a toxicity criterion corresponding to a similar exposure duration is used. One such criterion, identified through consultation with the TSC, is EPA's acute inhalation criteria (AIC). The AIC provides a threshold level above which acute inhalation exposure to benzene could result in toxicity to the most sensitive target organ (bone marrow and the immune system). The AIC for benzene is 190 ug/m^3. [In this case study, the AIC for benzene was assumed to be readily available. In an actual risk evaluation, this may not always be the case. When toxicity information is not readily available — especially when, as in this case study, the longer-term exposure point concentration is not significantly different from the shorter-term point concentrate ion (and the longer-term has toxicity information) — then either delaying the assessment or expending resources to obtain the shorter-term toxicity information is not recommended.]

To assess risk from exposure to the longer-term benzene concentration (annual average) for the 30-year exposure duration, the inhalation cancer slope factor for benzene of 0.029 $(mg/kg\text{-}day)^{-1}$ is identified from the baseline risk assessment.

Risk Characterization. Short-term risk to the community from benzene is determined by comparing the short-term concentration of 6 x 10^{-4} mg/m^3 (i.e., 0.6 ug/m^3), with the AIC of 190 ug/m^3, to result in a ratio of 0.003. Because this ratio is less than 1, short-term risk to the community solely from benzene is considered to be unlikely.

Using the longer-term intake of 7.3 x 10^{5} mg/kg/day, and the slope factor of 0.029 $(mg/kg/day)^{-1}$, the upper-bound excess individual lifetime cancer risk to the community from long-term exposure to benzene in the atmospheric releases from the air stripper is approximately 2 x 10^{-6}, within EPA's acceptable risk range.

[Uncertainties associated with the site-specific exposure information and the toxicity information, discussed in more detail in the baseline risk assessment, also are important to consider at this. stage of the analysis.]

CHAPTER 3

RISK EVALUATION AFTER THE FEASIBILITY STUDY

After the FS is completed, a remedy is proposed, and, if selected, is documented in the ROD. Following this, the remedy is designed and implemented, and then deletion/five-year reviews of the site take place. This chapter discusses the role of risk information during these activities. Note, however, that not all of these risk evaluations nor a significant level of quantitation may be needed for every site. The guiding principles is that risk evaluations after the FS should be conducted as necessary to ensure that the remedy is protective.

3.1 RISK EVALUATION FOR THE PROPOSED PLAN

The purpose of a risk evaluation during the proposed plan stage is to refine previous analyses conducted during the FS, as needed. If new information becomes available during the public comment period for the proposed plan, additional analysis of the alternatives may need to be conducted at this time. If additional analysis is conducted, it should be conducted for all the alternatives, as appropriate, and not just for the preferred alternative.

3.2 DOCUMENTATION OF RISKS IN THE ROD

Several risk-related analyses should be documented in the ROD. The comparative analysis section should include a discussion of risk as it pertains to the three risk-related criteria: long-term effectiveness, short-term effectiveness, and overall protection of human health and the environment. The discussion of overall protection of human health and the environment should include a discussion of how the remedy will eliminate, reduce, or control the risks identified in the baseline risk assessment and whether exposure will be reduced to acceptable levels. The discussion of long-term effectiveness (and permanence) should address, where appropriate, the residual risk from untreated waste remaining at the site. The part of the decision summary that focuses on the selected remedy should present:

- the chemical-specific remediation levels to be attained at the conclusion of the response action;
- the corresponding chemical-specific risk levels;
- the points (or areas) of compliance for the media being addressed; and
- the lead agency's basis for the remediation levels (e.g., risk calculation, ARARs).

In addition, the ROD should indicate whether the site will require five-year reviews (see Section 3.4). In some cases, additional risk information (e.g., anticipated post-remedy cumulative risk for an environmental medium or for a site) may need to be included in the ROD.

Interim Final Guidance on Preparing Superfund Decision Documents (EPA 1989f), *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions* (EPA 1991d), and RAGS/HHEM Part B provide additional information on documenting risks in the ROD.

3.3 RISK EVALUATION DURING REMEDIAL DESIGN/ REMEDIAL ACTION

The activities during remedy design and implementation that may involve consideration of risk include refining risk evaluations during remedial design, monitoring short-term risks, evaluating attainment of remedial levels in the ROD, and evaluating residual risk.

3.3.1 RISK EVALUATION DURING REMEDIAL DESIGN

The process of evaluating long-term and short-term risks, which began during the FS and may have continued during development of the proposed plan, also may continue during design of the selected remedy for some sites. The purpose for risk evaluations during the remedial design is to ensure that the selected remedy will be protective. These evaluations can be conducted by (1) refining previous analyses, as needed, and/or (2) identifying the need for engineering controls or other measures to mitigate risks. Methods for evaluating long-term and short-term risks are discussed in more detail in Chapter 2.

3.3.2 MONITORING SHORT-TERM HEALTH RISKS DURING IMPLEMENTATION

If the potential for short-term health effects due to releases during remedy implementation needs to be assessed (e.g., due to high uncertainty concerning predicted risks to communities or remediation workers), a sampling and analysis strategy to accurately determine exposure concentrations should be developed. This strategy may need to consider the following elements:

- location of sampling
- sample collection and handling procedures;
- chemicals to be monitored and methods used; and
- statistical considerations regarding the analysis of results.

The monitored exposure concentrations should be compared to short-term health-based benchmarks (see Appendix C) to help in determining whether the release presents a threat to human health.

3.3.3 ASSESSING ATTAINMENT OF SELECTED REMEDIATION LEVELS DURING IMPLEMENTATION

The RPM, risk assessor, and others should be involved in developing a sampling and analysis plan to measure whether the selected remedy has attained the remediation levels in the ROD. As in the baseline risk assessment, this sampling and analysis should provide data that can be used to develop RME estimates. This plan is site-specific and may need to consider the same elements presented in Section 3.3.2, plus the relevant remediation levels for the chemicals of concern.

The plan for measuring attainment should ensure that sufficient data to evaluate protectiveness of human health will be available. For example, at a minimum, those chemicals that contribute to major portions of the site risk should be selected for measuring attainment. The two-volume set *Statistical Methods for Evaluating the Attainment of Cleanup Standards* (EPA 1988d) outlines a number of statistical methods that can be used to measure attainment. EPA is developing additional guidance on this topic.

3.3.4 EVALUATION OF RESIDUAL RISK

This step – which may be conducted at completion of the remedy and perhaps during a five-year review (see next section) – may be needed to ensure that the remedy is protective. This step may be different from the assessment of attainment of remediation levels selected in the ROD because it may more closely consider the expected land use and cumulative effects (e.g., due to multiple chemicals or exposure pathways). Residual risk estimates can be conducted at any time after the remedy has commenced until the end of the remedy. Typically, a final evaluation of the cumulative site risk may be done following completion of the final operable unit to ensure that residual risks from multiple contaminants, pathways, and operable units that affect the same individuals are at protective levels.

In general, the same equations, exposure parameters, and toxicity values that were used to determine the baseline risk for a site can be used to assess the final clean-up (risk) level that a remedy has achieved. The concentrations that are used to calculate these risks, however, are the final measured concentrations of the contaminants that remain at the site, not the remediation levels in the ROD. The following are other potential differences between the baseline risk assessment and evaluation of residual risks.

- Significant levels of "new" chemicals (e.g., that were not identified during the baseline risk assessment but that may have resulted from the remedy or were not discovered until after remedy implementation) should be considered in evaluating residual risk.

- Changes in land use since the time of the baseline risk assessment may require changes in exposure parameters (e.g., contact rates, exposure frequency and duration).

- Toxicity values may have been updated since the baseline risk assessment. The most recent toxicity values in IRIS and HEAST should be used in calculating residual risk.

For some sites where engineering or institutional controls rather than treatment-based remedies are employed, the concentrations of chemicals in a contaminated medium may remain the same as the baseline concentrations. The risk will have been reduced or eliminated, however, by mitigation or elimination of the exposure pathway (e.g., by mitigating direct contact with soil by using a cap or institutional controls, or eliminating ingestion of contaminated drinking water by providing an alternate water supply). These risk reductions and associated exposure assumptions should be clearly presented.

3.4 RISK EVALUATION DURING FIVE-YEAR REVIEWS

Section 121(c) of CERCLA provides for reviews of remedies that result in hazardous substances remaining at the site no less often than every five years after the initiation of the remedies. The purpose of the reviews is to assure that human health and the environment are being protected by the remedial alternative that was implemented.

The remainder of this section briefly describes the purpose of five-year reviews, the sites for which five-year reviews are conducted, and the risk-related activities that may be conducted during five-year reviews. More detailed guidance regarding five-year reviews is available in *Structure and Components of Five-year Reviews* (EPA 1991e).

3.4.1 PURPOSE OF FIVE-YEAR REVIEWS

A five-year review is intended to ensure that a remedy remains protective of human health and the environment. The more specific goals of a five-year review are:

- to confirm that the remedy (including any engineering or institutional controls) remains operational and functional; and

- to evaluate whether clean-up standards (based on risk or ARARs) are still protective.

The first goal may be accomplished primarily through a review of the operation and maintenance records for a site and through a site visit and limited analysis. The second goal includes an analysis of requirements that have been promulgated by the federal or state governments since ROD signature to determine whether they are ARARs and whether they call into question the protectiveness of a remedy.

In addition to considering ARARs for substances designated as contaminants of concern in the ROD, the reviews may include changes in ARARs for substances not addressed under contaminants of concern. Where remediation levels in the ROD were based on risk calculations (rather than ARARs), then new information – such as revised toxicity values or exposure parameters – that could influence the protectiveness of the remedy should be considered. Based on this analysis, the reviewer can determine whether the original remediation levels set out in the ROD are still protective.

3.4.2 SITES THAT RECEIVE FIVE-YEAR REVIEWS

Two types of five-year reviews are conducted: statutory and policy. Statutory reviews are conducted for remedies selected after the enactment of SARA where, after the remedy is complete, hazardous substances are present above levels that allow for unlimited use and unrestricted exposure. These sites generally include: (1) sites with remedies requiring access or land-use restrictions or controls (i.e., remedies that achieve protectiveness through the use of engineering or institutional controls); and (2) sites with remedies that achieve protectiveness for the current use, but include restrictions on activities due to limits on exposure (i.e., sites cleaned up to levels that would be protective for a nonresidential land use, but would not be protective for residential or other land use). Policy reviews are conducted for: (1) sites with long-term remedial actions (LTRAs) or other remedies that require five years or longer to achieve levels that would allow for unlimited use and unrestricted exposure and (2) remedies selected before the enactment of SARA where hazardous substances are present above levels that allow for unlimited use and unrestricted exposure.

Statutory reviews may be discontinued only if levels of hazardous substances fall permanently to a point that would allow unlimited use and unrestricted exposure. Policy reviews for LTRAs should be discontinued when the remediation goals specified in the ROD are achieved, assuming these levels allow for unlimited use and unrestricted exposure. Achievement of these levels must be verified by an appropriate period of monitoring.

3.4.3 RISK-RELATED ACTIVITIES DURING FIVE-YEAR REVIEWS

Three levels of effort have been defined for five-year reviews. The following are risk-related activities conducted for the three levels.

- At Level I, the reviewer will consider the risk assessment information contained in the ROD and ROD summary.

- At Level II, the reviewer will conduct a recalculation of the original baseline risk assessment using information obtained during the review (e.g., new toxicity data). If appropriate, additional data may be collected. Ongoing monitoring may provide such data.

- At Level III, the reviewer will reevaluate the risk assessment, and, if appropriate, conduct a new risk assessment. Such an assessment may be appropriate in order to address a new site condition, such as a new exposure pathway. New data may be collected as necessary for the risk assessment. If possible, however, existing data should be used.

The appropriate level of review depends on site-specific conditions and the confidence level for the selected remedy. The proposed level of the first review is to be included in the ROD. A Level I review should be appropriate in all but a few cases where site-specific circumstances suggest another level either at the outset of the review or because findings of the review suggest the need for further analysis. A Level 111 review would not be proposed in the ROD, but would be initiated in response to specific concerns regarding the performance of the remedy or the risks at the site. The level of effort, particularly for subsequent reviews, also depends on the initial findings of the review. *Structure and Components of Five-year Reviews* (EPA 1991e) provides additional information concerning the appropriate level for reviews and the activities that are conducted at each level.

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APPENDIX A

SELECTED REMEDIATION TECHNOLOGIES AND ASSOCIATED POTENTIAL RELEASES

This appendix contains two exhibits designed to assist during the FS in identifying some of the potential releases that are associated with commonly used remediation technologies. Exhibit A-1 briefly describes each of the process options of each technology in Exhibit A-2. Exhibit A-2 summarizes several potential releases to air or water of common remedial technologies. Process variations for which potential releases are similar are combined under the technology category. Potential releases to surface water or ground water are included in the "water" column. "Other" releases include treatment residuals that need further treatment or proper disposal. In most cases, this column refers to sludge or solid residues that may also be hazardous.

Risk Reduction Engineering Laboratory (RREL; Cincinnati, Ohio) plans and conducts engineering, research, and development related to treatment of solid and hazardous wastes. RREL personnel provide site-specific technical services involving specific treatment technologies and CERCLA response processes including

- analysis of treatment alternatives,
- treatability studies,
- remedial design review,
- construction QA/QC methods, and
- contaminant source control and geotechnical test methods.

Regional EPA CERCLA staff should direct questions regarding evaluations of remediation technologies, previous experience with remediation technologies, and releases associated with remediation technologies to the Engineering and Treatment Technical Support Center, RREL at FTS 684-7406 or 513-569-7406.

EXHIBIT A-1

REMEDIATION TECHNOLOGY DESCRIPTIONS

Technologies	Description of Process
SOIL AND SLUDGE	
Soil Handling	
Soil Excavation, Transport, Dumping, and Grading	These processes use mechanized equipment to move contaminated soil. For some treatment techniques, soil must be removed from a contaminated site and be transported for treatment. Soil is then returned and replaced at either the original excavation or another disposal site. Grading is a technique which can reduce infiltration into contaminated soils and can also control runoff.
Thermal Destruction	These are destruction processes which control temperature and oxygen availability, and convert hazardous materials to carbon dioxide, water, and other products of combustion.
Circulating Bed Incineration	Wastes and auxiliary fuel are introduced into the combustion chamber. Air is forced up through the chamber from the bottom to promote mixing and complete combustion. Particulate and gaseous products of combustion exit from the top of the combustion chamber for treatment and disposal.
Rotary Kiln Incineration	The combustion chamber is a rotating, inclined cylinder which mixes combusting materials as it rotates. Wastes are fed into the chamber at the high end, along with air and auxiliary fuel. Exhaust gases are treated and released, and ash residue is collected on the low end of the kiln.
Fluidized Bed Incineration	A bed of inert particles (e.g., sand) lies at the bottom of the cylindrical combustion chamber. Air is forced up through the bed and the particles are fluidized (i.e., the particles "float" in the airstream). Wastes and fuel are injected at the top of the chamber, into the fluidized mass, where the mixture combusts. The turbulent atmosphere in the chamber provides good mixing of wastes to ensure complete combustion and efficient heat transfer.
Infrared Incineration	Waste materials are fed into the furnace on a conveyor belt, and pass through on a wire mesh belt. Heating elements provide infrared energy, oxidizing the materials. Waste gases are passed through a secondary combustion chamber; ash exits on the conveyor.
Pyrolysis	Organics are slowly volatilized at lower temperatures than incineration processes. Waste is fed into the primary combustion chamber and thermally treated without sufficient oxygen to completely combust. Volatilized organics pass to a secondary chamber and are incinerated. Solid residues from the primary chamber receive other treatment.

(Continued)

EXHIBIT A-1 (Continued)

REMEDIATION TECHNOLOGY DESCRIPTIONS

Technologies	Description of Process
Wet Air Oxidation	The high temperature and high pressure properties of water are utilized in destroying wastes. Contaminated solutions are treated at high temperatures (>600° C) and pressures (3400 psi to 3700 psi). Contaminants are oxidized to simple organic compounds as large amounts of oxygen are dissolved in solution.
Aqueous Thermal Decomposition	Aqueous thermal decomposition works on the same principles as wet air oxidation, without the addition of excess oxygen. ”
Dechlorination	
Glycolate Dechlorination	Using a specific solvent, chlorine atom(s) are removed from chlorinated hazardous materials, and toxic compounds are converted to less toxic, more water-soluble compounds. Reaction products are more easily removed from soil and more easily treated.
Biological Treatment	
Comporting	Contaminated material is mixed with bulking agents (e.g., sawdust, wood chips) and placed in reactor vessels or piles. Aeration, temperature, and nutrient levels are controlled to encourage microbial growth. Microorganisms then metabolize contaminants, breaking them down into less-harmful materials.
In-situ Biodegradation	Microorganisms are encouraged to decompose contaminants in soil without excavating the soil and placing it in a controlled reactor. Nutrients, oxygen, and other necessary materials can be injected into the contaminated area.
SIurry-phase Biodegradation	The wastes are mixed with water to achieve an aqueous mixture. The mixture is then treated in a bioreactor, where it is mixed continuously to contact microorganisms and contaminants. The bioreactor serves as a controlled environment for contaminant degradation.
Solid-phase Biodegradation	Soils are excavated and treated above ground so that treatment conditions can be closely monitored and adjusted to conditions that are ideal for biodegradation. Materials are treated in a prepared area which can include volatile emissions collection and leachate collection.

(Continued)

EXHIBIT A-1 (Continued)

REMEDIATION TECHNOLOGY DESCRIPTIONS

Technologies	Description of Process
Vacuum/Vapor Extraction, Thermal Desorption	
Low Temperature Thermal Stripping	Air, pressure, heat, and/or mechanical agitation provides a driving force for volatilizing and removing contaminants from soil into an airstream for further treatment. Separating contaminants from soil simplifies the final treatment of contaminants.
In-situ Vacuum/Steam Extraction	VOCs are removed from soil by applying a vacuum to wells that are placed in the contaminated soil. VOC vapors are collected and treated above ground. Some systems also inject hot air or steam into contaminated zones, raising temperatures and volatilizing organic chemicals.
Chemical Extraction & Soil Washing	
In-situ Chemical Treatment	Treatment chemicals are applied directly to contaminated soil. A variety of compounds can be applied, including neutralizing agents, oxidants, solidification/stabilization agents, and nutrients for biological treatment.
Chemical Extraction & Soil Washing	Contaminants are washed from the excavated soil into a chemical solvent. The liquid is treated to remove and destroy contaminants, and the solvent is reused.
In-situ Soil Flushing	Inorganic or organic contaminants are extracted from soil by washing the soil with solvents. Solvents are recovered, contaminants are extracted, and the solvents are recirculated through the soils.
Immobilization	
Capping	Contaminated soil is covered with low-permeability layers of synthetic textiles or clay. The cap is designed to limit infiltration of precipitation and thus prevent migration of contaminants away from the site and into ground water.
Solidification/Stabilization	Wastes are converted to chemically stable forms or are bound in a stable matrix. Chemical reactions are utilized to transform hazardous materials into new, non-hazardous materials. The goal is to prevent migration of contaminants.
In-situ Vitrification	Electrodes are placed vertically into the contaminated soil region, and an electrical current is applied. The soil is melted by the resulting high temperatures. When the melt cools and solidifies, the resulting material is stable and glass-like, with contaminants bound in the solid.

(Continued)

EXHIBIT A-1 (Continued)

REMEDIATION TECHNOLOGY DESCRIPTIONS

Technologies	Description of Process
GROUND AND SURFACE WATER	
Natural Attenuation	Contaminants in an aquifer disperse and dilute through natural ground-water transport. Some natural degradation may occur.
Aeration/Air Stripping	Contaminants, usually volatile organic compounds, are transferred from liquid phase to gaseous phase. By contacting contaminated water with clean air, dissolved VOCs are transferred to the airstream to create equilibrium between the phases. The process takes place in a cylindrical tower packed with inert material which allows sufficient air/water contact to remove volatiles from water. Contaminants are then removed from the. airstream.
Filtration	Filtration removes suspended solids from liquids by passing the mixture through a porous medium.
Sedimentation	Solids that are more dense than liquid settle by gravity and can be removed from the liquid. Chemicals to aid settling may be added. Settled solids result in a sludge which maybe treated further.
Granular Activated Carbon (GAC) Adsorption	GAC is packed in vertical columns, and contaminated water flows through it by gravity. GAC has a high surface area to volume ratio, and many compounds readily bond to the carbon surfaces. Contaminants from water are thus adsorbed to the carbon, and effluent water has a lower contaminant concentration. Water may be passed through several of these columns to complete contaminant removal. Spent carbon (i.e., carbon that has reached its maximum adsorption capacity) is regenerated by incineration.
Ion Exchange	**As** contaminated water flows through the reactor vessel, ions of contaminants are adsorbed to a synthetic resin in the vessel. The resin attracts and adsorbs contaminant ions, while releasing non-harmful ions into the treated water.
Chemical Treatment	Chemicals can be added to contaminated waters to chemically change or to remove constituents. Precipitation can be accomplished through pH control; solutions can be neutralized; contaminants can be oxidized; and solids can be settled out of solution.
Biological Treatment	Microorganisms in controlled-environment reactors are utilized to decompose contaminants in water. Nutrients, pH, temperature, and oxygen availability are controlled. The organisms degrade contaminants into simpler, safer compounds.

(Continued)

EXHIBIT A-1 (Continued)

REMEDIATION TECHNOLOGY DESCRIPTIONS

Technologies	Description of Process
Membrane Separation	
Reverse Osmosis	A semi-permeable rnembrane is used to separatc dissolved contaminants from liquids. High pressure is applied 10 the contaminated solution, which drives only the liquid through the membrane. The rcsult is a highly concentrated contaminated solution on the high pressure side of thc mcmbrane, and a purified liquid on the opposite side of the membrane.
Eleclrodialysis	This process concentrates ionic species that arc in aqueous solution. 'Ihe solution IS passed through alternate cation-permeable and anion-permeable membranes that have an applied electric potcntial. This potential provides a driving force or ion migration.

EXHIBIT A-2

REMEDIATION TECHNOLOGIES AND SOME POTENTIALLY SIGNIFICANT RELEASES

Technologies	Air	Water[a]	Other[b]
SOIL AND SLUDGE TECHNOLOGIES			
Soil Handling			
Soil Excavation, Transport, Dumping, Screening and Grading	• Fugitive emissions of particulate and volatiles	• Runoff or leaching of contaminants to surface or ground water	• Seepage or runoff to nearby soil
Thermal Destruction			
Incineration: Rotary Kiln, Fluidized Bed, Circulating Bed, and Infrared	• Fugitive and stack emissions of metal fumes; particulate, including metals and salts. and products of incomplete combustion, including organic compounds, acid gases, CO, NO_x and SO_x	• Discharge of scrubber liquor and blowdown	• Disposal of ash and other solid residues
Pyrolysis	• Fugitive and stack emissions of metal fumes; particulate, including metals and salts; and products of incomplete combustion, including organic compounds, acid gases, CO, NO_x and SO_x	• Discharge of scrubber liquor and blowdown	• Disposal of ash and other solid residues
Wet Air Oxidation	• Fugitive emissions of volatile organic compounds	• Discharge of metals and unoxidized organics	• Disposal of sludge residues
Aqueous Thermal Decomposition	• Fugitive emissions of volatile organic compounds	• Discharge of metals and unoxidized organics	• Disposal of sludge residues

(Continued)

EXHIBIT A-2 (Continued)

REMEDIATION TECHNOLOGIES AND SOME POTENTIALLY SIGNIFICANT RELEASES

Technologies	Air	Water[a]	Other[b]
Dechlorination			
Glycolate Dechlorination	• Fugitive emissions of volatile organic compounds	• Discharge of spent solvents and degraded contaminants to surface water, or leaching to ground water	
Biological Treatment			
Comporting	• Fugitive emissions of particulate and volatile organics	• Leaching of metals and/or organics	
In-situ Biodegradation	• Fugitive emissions of volatile organics	• Leaching of metals and/or organics • Discharge of treated water	
Slurry-phase or Solid-phase Biodegradation	• Fugitive emissions of volatile organics	• Discharge of non-degraded byproducts in slurry liquor and treated effluent • Runoff to surface water or to ground water (with solid-phase process)	• Disposal of residual biomass which may contain hazardous metals and refractory organics
Vacuum/Vapor Extraction, Thermal Desorption			
Low Temperature Thermal Stripping	• Stack emissions of volatile organics • Fugitive emissions of volatile organics	• Discharge of scrubber blowdown • Discharge of contaminant condensate	
In-situ Vacuum/Steam Extraction	• Fugitive emissions of volatile organics	• Discharge of contaminant or water condensate	• Disposal or regeneration of spent activated carbon

(Continued)

EXHIBIT A-2 (Continued)

REMEDIATION TECHNOLOGIES AND SOME POTENTIALLY SIGNIFICANT RELEASES

Technologies	Air	Water[a]	Other[b]
Chemical Extraction & Soil Washing			
In-situ Chemical Treatment	● Fugitive emissions of volatile organic compounds	● Runoff of uncontained treatment chemicals	● Possible solvent residuals in treated soil
Chemical or Solvent Extraction	● Fugitive emissions of volatile organic compounds	● Post-extraction discharge of wastewater with extracted contaminants	● Possible solvent residuals in treated soil
Soil Washing	● Fugitive emissions of volatile organic compounds	● Post-washing discharge of wastewater with extracted contaminants	● Discharge of foam with metals and organics ● Deposition of sedimentation sludge residuals . Deposition of untreated, contaminated fines
In-situ Soil Flushing	● Fugitive emissions of volatile organic compounds	● Leaching of contaminated flush water, acids, bases, chelating agents, or surfactants	
Immobilization			
Capping	● Fugitive emissions of particulate and volatiles during cap construction	● Leaching of contaminants to ground water	● Lateral movement of volatile organic compounds after capping
Solidification/Stabilization	● Fugitive emissions of particulate and volatiles	● None likely	● Potential leaching to soils and ground water of contaminants from deposited material over time

(Continued)

EXHIBIT A-2 (Continued)

REMEDIATION TECHNOLOGIES AND SOME POTENTIALLY SIGNIFICANT RELEASES

Technologies	Air	Water[a]	Other[b]
In-situ Vitrification	• Surface fugitive emissions of volatile organics and volatile metals during the process	• Discharge of scrubber solution • Possible contamination of ground water under the treatment area	• Potential lateral migration of vaporized or leached contaminants into the soil that surrounds the vitrified monolith
GROUNDWATER AND SURFACE WATER TECHNOLOGIES			
Non-Treatment Actions			
Natural Attenuation	• Emissions of volatile organic compounds	. Aquifer discharge to surface water • Continued aquifer transport of contaminants	
Pump without Treatment	• Emissions of volatile organic compounds	• Discharge of untreated water to surface water or Publicly Owned Treatment Works (POTW) • Seepage of untreated water	• Disposal of sludge residuals from POTW
Air Stripping	• Stack and fugitive emissions of volatile organics	• Discharge to surface water of effluent treated water with residual metals, particulate, or nonvolatile organics	• Disposal of backwash or cleaning residues
Filtration/Settling	• Fugitive emissions of volatile organic compounds from settling basin	• Discharge of effluent water containing dissolved solids or unremoved particles	• Disposal of filter cake or sludge containing organics, metals, or other inorganic
Granular Activated Carbon Adsorption	• None likely	• Discharge of effluent with non-adsorbable, low molecular weight compounds	• Disposal and/or regeneration of spent carbon

(Continued)

REFERENCES FOR APPENDIX A

Peavy, Howard S., Donald R. Rowe, and George Tchobanoglous. 1985. *Environmental Engineering.* McGraw-Hill, New York.

U.S. Environmental Protection Agency (EPA). 1987. *A Compendium of Technologies Used in the Treatment of Hazardous Wastes.* Center for Environmental Research Information. EPA/625/8-87/014 (NTIS PB90-274093/XAB).

EPA. 1988. *Technology Screening Guide for Treatment of CERCLA Soils and Sludges.* Office of Research and Development. EPA/540/2-88/004 (OSWER Directive 9380.0-25, NTIS PB89-132674).

EPA. 1989. *Summary of Treatment Technology Effectiveness for Contaminated Soil.* Office of Emergency and Remedial Response. EPA 540/2-89/-53.

EPA. 1990. *National Technical Guidance Series, Air/Superfund Manual, Volume 3.* Office of Air Quality Planning and Standards. EPA-450/l-89-003 (NTIS PB89 180061/AS).

EPA. 1990. *The Superfund Innovative Technology Evaluation Program, Progress and Accomplishments Fiscal Year 1989.* Office of Solid Waste and Emergency Response. EPA/540/5-90/001 (NTIS PB90-216516/XAB).

EPA 1991. Comments from Laurel Staley, Ed Bates, Ron Lewis, Teri Shearer, John Herrmann, Paul dePercin, Ed Barth. Coordinated by Mary Gaughan, Superfund Technology Demonstration Group, Cincinnati, "Ohio.

APPENDIX B

QUANTIFYING POTENTIAL RELEASES FROM SELECTED REMEDIATION TECHNOLOGIES

Remediation activities at hazardous waste sites have the potential to cause emissions and impacts in addition to those being addressed. Potential emission sources during remediation include point sources of treatment residuals such as incinerator stacks; fugitive emissions from treatment equipment leakage; and areal sources of volatile organics and fugitive dusts from the disturbed surface of a contaminated land area. Uncontrolled releases can result in exposures to contaminants in soils, surface water, ground water, and ambient air surrounding the treatment equipment. The following sections provide descriptions of several common remediation activities to serve as examples of the considerations involved in quantifying technology-specific releases. This appendix also contains a list of references that can be useful in quantifying potential air releases for a variety of remediation technologies,

B.1 SOILS HANDLING TECHNOLOGIES

Soils handling is a major component of nearly all ex-situ technologies for treating contaminated soils. Soil handling activities include excavation; transportation (e.g., to storage or treatment areas); dumping (e.g., onto trucks or piles); storage; and grading the treated or replaced soil. Any or all of these activities may result in fugitive dust emissions, the main type of release from soils handling. These emissions can carry organic and/or inorganic contaminants, which may be bound to soil particles, for great distances away from the site. Soil handling activities also can increase volatile organic emissions by exposing contaminated soil to the atmosphere, and through agitation of the soil.

Some of the important parameters that may affect the fugitive dust emissions potential at a contaminated site are listed in the box below. These parameters depend on site and remedial activity characteristics. Details can be obtained from onsite observation or from vendors and/or operators. Some or all of these parameters may already have been considered in the RI/FS. Fugitive dust emission factors (mass per unit operation) or rates (mass per unit time, derived from emission factors) for volatile organic, particulate and/or metal contaminants during each soil handling remedial activity can be estimated using equations and procedures outlined in the documents listed in Section B.4. These emission factors or rates can be used as inputs to fate and transport models, which are used to generate exposure point concentrations. Additional information on exposure assessment can be obtained from Chapter 2 of this guidance and Chapter 6 of RAGS/HHEM Part A.

KEY PARAMETERS AFFECTING RELEASES FROM SOILS HANDLING

- Area of working surface
- Agitation factor
- Drop height (when transferring soil)
- Storage pile geometry
- Soil moisture content
- Soil silt content
- Meteorological conditions
- Chemical characteristics

B.2 THERMAL DESTRUCTION TECHNOLOGIES

Thermal destruction uses high temperature and controlled conditions to oxidize and/or degrade a substance into simple combustion products such as $C0_2$, H_20 vapor, $S0_2$, NO_x, HCL gases, and ash. Thermal destruction methods can be used to destroy organic contaminants in liquid, gaseous, and solid waste streams. Incinerators are by far the best known and most studied thermal destruction devices. In many cases, thermal destruction techniques that do not have sufficient

emission data can be assumed to have emission characteristic similar to incinerators,

Emission sources from incinerators include process emissions and fugitive emissions. Incinerator process emissions include stack gas, bottom ash, and air pollution control device residuals. Fugitive emissions include uncontrolled or undetected equipment leakage. Process emission estimation methods for organic compounds, metals, particulate, and acid gases (HCL, $S0_2$, and HF) can be obtained from EPA (1985a) (see Section B.4.1). Fugitive emission sources and equations for estimating emissions are detailed in EPA (1989) (see Section B.4.1) and Holton and Travis (1984) (see Section B.4.3). Fugitive emissions from soils handling prior to incineration can be estimated using the guidance given in Section B.1 on soils handling.

Emissions from thermal destruction technologies generally can be estimated using any one of the approaches listed below. (These methods do not directly account for removal of contaminants by air pollution control devices that may be used to treat emissions from thermal destruction devices.)

- **Default approach:** Thermal destruction devices at most contaminated sites may be required to meet the requirements under federal regulations such as RCRA or the Toxic Substances Control Act (TSCA), since these requirements are generally considered ARARs. RCRA requires at least 99.99% destruction and removal of regulated organic constituents from wastes. TSCA requires 99.9999% destruction and removal for wastes containing PCBs and dioxins. Thus, organic emissions from thermal destruction of hazardous waste can be estimated by assuming that the above requirements of RCRA and TSCA will be exactly met, for pollutants covered by those regulations. Similar requirements can be used to estimate HC1 emissions, but this approach may not provide estimates for particulate or air emissions.

- **Trial run approach:** Federal regulations such as RCRA and TSCA require trial burns to demonstrate removal efficiencies. Whenever trial burn data for the waste in question exist they can be used to estimate the emissions that might occur during actual remedy implementation. Data obtained from trial burns at different sites or different operable units from the same site can be used for estimating emissions.

- **Theoretical or empirical approach** Theoretical or applicable empirical equations often called models — can be used to estimate emissions. These models correlate incinerator operating parameters and pollutant emission rates.

Some of the important parameters that may affect the emissions associated with thermal destruction technologies are listed in the box below. Many of these parameters are device dependent and can be obtained from onsite observation or from vendors and/or operators.

KEY PARAMETERS AFFECTING RELEASES FROM THERMAL DESTRUCTION

- Waste feed rate
- Burn temperature
- Residence time
- Excess air rate
- Facility size/type
- Atomization
- Control device efficiency
- Chemical characteristics

B.3 SOLIDIFICATION/ STABILIZATION TREATMENT TECHNOLOGIES

Solidification/stabilization technologies are used to immobilize the toxic and hazardous constituents in the waste by changing those constituents into immobile forms, binding them in an immobile, insoluble matrix, and/or binding them in a matrix that minimizes the material surface exposed to solvents. Except for emerging technologies that involve in-situ treatment, the implementation of stabilization or solidification generally involves several of the soils handling activities discussed in Section B. 1. The box below lists some of the key parameters affecting releases associated with solidification/ stabilization. These parameters depend on the specific

solidification/stabilization process. These can be obtained from onsite observation or from vendors and/or operators.

KEY PARAMETERS AFFECTING RELEASES FROM SOLIDIFICATION/STABILIZATION TREATMENT TECHNOLOGIES

- Binder type
- Batch size
- Waste/binding agent ratio
- Mixing time/efficiency
- Curing time
- Meteorological conditions
- Chemical characteristics

B.4 REFERENCES FOR DETERMINING RELEASES RESULTING FROM REMEDIAL ACTIVITIES

Provided below are references containing discussions of remedial activities and methodologies for determining releases associated with these activities. The references presented under the heading of various remedial activities contain information regarding the majority of remedial activities that may occur at a site (including soils handling, thermal destruction, and stabilization/solidification). The remaining references contain information specific to the activity listed in the heading. See the references provided for the main text of RAGS/HHEM Part C, especially, the RI/FS Guidance (EPA 1988c for additional references.

B.4.1 VARIOUS REMEDIAL ACTIVITIES

Primary References

Environmental Protection Agency (EPA). 1985a. *Handbook Remedial Action at Waste Disposal Sites* (Revised). Hazardous Waste Engineering Research Laboratory. EPA/625/6-85/O06 (NTIS PB87-201O34/XAB).

Provides information on remedial technologies, selection of appropriate remediation technologies for a given waste site, and planning remedial activities. Includes discussions of onsite and offsite disposal of wastes and soil, removal and containment of contaminated sediments, and in-situ treatments.

EPA. 1989. *Estimation of Air Emissions from Cleanup Activities at Superfund Sites.* Air/Superfund National Technical Guidance Study Series, Volume 3. Office of Air Quality Planning and Standards. EPA/450/l-89/003 (NTIS PB89-180061/XAB).

This document provides a step-by-step protocol for estimating air quality impacts resulting from site remediation. Presents emissions estimation techniques for thermal destruction devices, air stripping of ground water, in-situ venting, soils handling, and solidification/stabilization.

Additional References

EPA. 1990. *Emission Factors for Superfund Remediation Technologies.* Draft. Office of Air Quality Planning and Standards.

EPA. 1988. *Superfund Removal Procedures Revision Number Three.* Office of Emergency and Remedial Response. OSWER Directive 9360.03B.

EPA. 1986. *Superfund Remedial Design and Remedial Action* Guidance. Office of Emergency and Remedial Response. OSWER Directive 9355.O-4A.

B.4.2 SOILS HANDLING

Primary References

EPA. 1985b. AP-42: *Compilation of Air Pollution Emission Factors,* Fourth Edition. Office of Air and Radiation. NTIS PB86-124906.

This document contains emissions data obtained from source tests, material balance studies, engineering estimates, and other sources. Emission factors and equations are derived from sand and gravel processing (Section 8.19. 1), crushed stone operations (Section 8.19.2), surface coal mining (Section 8.2.4), and fugitive dust sources (Section 11.2).

EPA. 1985c. *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites. EPA/600/A-85/002.*

This document provides a methodology for rapid assessment of inhalation exposures to respirable particulate emissions from surface contaminated sites. The methodology consists of a site survey procedure and particulate emission factor equations for wind and mechanical entrainment processes.

EPA. 1990. *Development of Example Procedures for Evaluating the Air Impacts of Soil Excavation Associated with Superfund Remedial Actions.* Office of Air Quality Planning and Standards. EPA/450/4-90/014 (NTIS PB90-255662/XAB).

This document identifies and defines computational requirements for estimating air impacts from remediation of CERCLA sites. The estimation of air impacts from two example sites employing soil excavation are discussed. Modified Research Triangle Institute (RTI) land treatment equations are used for calculating emissions from excavations.

Additional References

Baxter, R.A. and D.M. Wilbur. 1983. *Fugitive Particulate Matter and Hydrocarbon Emission Factors from Mining Handling and Storing Diatomite.* AeroVironment, Inc. Pasadena, California.

EPA. 1977. *Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions.* Office of Air Quality and Planning Standards. EPA/450/3-77/010 (NTIS PB-272 288/-2).

EPA. 1985d. *Modeling Remedial Actions at Uncontrolled Hazardous Waste Sites.* Office of Emergency and Remedial Response, Office of Solid Waste and Emergency Response. EPA/540/2-85/001 (OSWER Directive 9355.0-8).

Orlemann, J.A. and G.A. Jutze. 1983. *Fugitive Particulate Dust Control Technology.* Noyes Publications. Park Ridge, New Jersey.

B.4.3 THERMAL DESTRUCTION

Primary References

Holton, G.A. and C.C. Travis. 1984. Methodology for Predicting Fugitive Emissions for Incinerator Facilities. *Environmental Progress 3:2.* Oak Ridge National Lab., Health & Safety Research Division. Oak Ridge, TN.

Error analysis and Monte Carlo modeling techniques are used to predict fugitive emissions caused by leaky pump fittings, sampling connections, flanges, storage tanks, and other non-stack equipment. Ten equations and three parameter value tables are provided for emission calculations.

Travis, C. C., E.L. Etnier, G.A. Holton, F.R. O'Donnel, and D.M. Hetrick. 1984. *Inhalation Pathway Risk Assessment of Hazardous Waste Incineration Facilities.* Oak Ridge National Lab. Oak Ridge, Tennessee. ORNL/TM-9096.

This report evaluates the relative importance of plant design and waste physiochemical variables on human inhalation exposure and health risk using two hypothetical incineration facility designs of three sizes each, burning three different generic wastes. Fugitive emissions are calculated using equations relating incinerator facility operation and configuration to fugitive emissions.

Trenholm, A. and D. Oberacker. 1985. "Summary of Testing Program at Hazardous Waste Incinerators." *Proceedings — Annual Solid Waste Research Symposium.* Environmental Protection Agency. Cincinnati, Ohio. Report No. CONF-8504112.

This article summarizes the results of tests conducted at eight full-scale hazardous incineration facilities.

Additional References

Cheremisinoff, P.N. 1986. "Special Report: Hazardous Materials and Sludge Incineration." *Journal of the Air Pollution Engineering 18:12(32-38).*

EPA. 1984. *Performance Evaluation Full-scale Hazardous Waste Incinerators.* (Five volumes.) Industrial Environmental Research Laboratory. Cincinnati, OH. EPA-600/2-84-181 a-e (NTIS PB85-129500).

Lee, C. C., G.L. Huffman, and D.A. Oberacker. 1986. "Hazardous/Toxic Waste Incineration." *Journal of the Air Pollution Control Association 36:8.*

Oppelt, E.T. 1987. "Incineration 01 Hazardous Waste, A Critical Review." *Journal of the Air Pollution Control Association. 37:5.*

Staley, L.J., G.A. Holton, F.R. O'Donnel, and C.A. Little. 1983. "An Assessment of Emissions from a Hazardous Waste Incineration Facility, Incineration and Treatment of Hazardous Waste." *Proceedings of the Eighth Annual Research Symposium. EPA-60/9-83/003.*

Wallace, D. D., A.R. Trenholm, and D.D. Lane. 1985. "Assessment of Metal Emissions from Hazardous Waste Incinerators." *Proceedings – 78th APCA Annual Meeting.* Paper 85-77. Air Pollution Control Association. Pittsburgh, Pennsylvania.

B.4.4 STABILIZATION/ SOLIDIFICATION

Primary References

Cullinane, M.J., L.W. Jones, and P.G. Malone. 1986. *Handbook for Stabilization/Solidification of Hazardous Waste.* Hazardous Waste Engineering Research Laboratory. EPA/540/2-86/001.

Hill, R.D. 1986. *Stabilization/Solidification of Hazardous Waste.* Hazardous Waste Engineering Research Lab. EPA/600/D-86/028.

This document discusses techniques such as sorption, lime-fly ash Pozzolan process, Pozzolan-Portland process, thermoplastic microencapsulation, and other techniques.

Additional References

Cullinane, M.J. and L.W. Jones. 1985. *Handbook for Stabilization/Solidification of Hazardous Waste.* Prepared for: Environmental Protection Agency, Hazardous Waste Engineering Research Laboratory. Office of Research and Development. EPA/540/2-86-001.

APPENDIX C

SHORT-TERM TOXICITY VALUES

The short-term effectiveness criterion for evaluating remedial alternatives includes an evaluation of the risks due to the short-term exposure of populations to contaminants during remedy implementation. Such short-term risks generally include both baseline risks from existing site contamination and new risks that would occur during the implementation of a remedy. In some cases, potential exposures and risks due to short-term exposures should be quantitatively assessed; however, there is no simple or widely accepted method for estimating such risks. Therefore, in all cases where short-term toxicity values are needed, TSC should be consulted. EPA's Environmental Criteria and Assessment Office (ECAO; where TSC is located) will maintain the data tiles for the most appropriate short-term toxicity values for evaluating risks from remedial alternatives. To obtain the most up-to-date information, regional EPA CERCLA staff must contact:

Superfund Health Risk Technical
Support Center
Environmental Criteria and Assessment Office
U.S. Environmental Protection Agency
Mail Stop 114
26 West Martin Luther King Drive
Cincinnati, OH 45268
Phone: 513-569-7300 (FWS-684-7300)
FAX: 513-569-7159 (FTS-684-7159)

Requests from others must be submitted to the TSC in writing and must contain the following information for consideration:

- CERCLA site name, site location, and 12-digit site number;
- name and phone number of the RPM; and
- detailed description of the risk assessment related question.

The remainder of this appendix provides some general background on exposure duration issues and an overview of some of the existing methods for deriving short-term human health toxicity values.

C.1 BACKGROUND ON EXPOSURE DURATION

In assessing short-term risks of remedial alternatives, the time frame (e.g., hours, days, weeks up to seven years) is generally of a much shorter duration than that identified in the baseline risk assessment. Nevertheless, there are a number of types of toxicity values that have been developed to characterize risk due to these short-term exposures. Some of these types depend on concentration- or dose-based threshold limits that are used as guidance levels for protection of specific populations from specific exposures (e.g., guidance levels intended to protect healthy workers from daily occupational exposure to chemicals in the workplace). In this section, the types of exposure durations commonly suggested or implied by the toxicity value types (discussed later) are presented.

Releases that may occur during remedy implementation could last for varying durations but are expected, in most if not all cases, to give rise to less-than-lifetime exposures. Furthermore, releases that occur during remediation may result in exposure levels much higher than those preceding remediation. Different risk levels may be associated with these different exposure durations (assuming the same dose rate) and with various exposure concentrations. Therefore, it is important that the dose- or concentration-based toxicity values that are chosen to characterize the short-term risks be based on appropriate exposure durations. Exposure durations associated with existing methods for characterizing short-term risks include hours, days, weeks, months, and years (generally up to seven years).

Currently, RAGS/HHEM part A defines three exposure durations, apart from long-term exposure, that may be of concern at CERCLA sites: single

exposure event, very short-term exposure, and short-term (subchronic) exposure.

- **Single Exposure Event.** The majority of chemicals are capable of producing an adverse health effect after a single exposure event, depending on the intensity of exposure. For developmental toxicants, irritants, and neurological poisons, a single, low level exposure event can result in effects after minutes, hours, or a day.

- **Very Short-term Exposure.** For some acute toxicants, multiple exposures over several days could result in an adverse effect. For these chemicals, the exposure is assessed over days or weeks (up to two weeks).

- **Short-term (Subchronic) Exposure.** Exposure lasting anywhere from two weeks to seven years to low concentrations of a chemical can also produce adverse effects; this exposure is assessed by averaging it over the specific duration.

During evaluations of remedial alternatives, it may be important to assess exposure (and risk or hazard) for all relevant exposure durations. Both the shortest time period of exposure, from peak or accidental releases, to the cumulative exposure over the entire time period of the remedy implementation, may need to be considered. Quantitative assessment is contingent, however, upon the availability of adequate exposure characterization. Exposure models used to predict concentrate ions have not for the most part been validated over the short durations considered for single exposure events (e.g., minutes to hours). At best, meteorological data are collected on an hourly basis at a site removed from the location of interest; using these data to derive a model to predict exposure concentrations for durations shorter than those for the meteorological data may produce results that could not be supported scientifically. In addition, the need to evaluate peak exposures as well as longer-term average exposures during remedy implementation depends on a number of considerations, including the degree of risk or hazard associated with the longer-term exposure and the difference between the predicted peak and average exposure concentrations.

A review of the types of (duration-specific) toxicity values that are available (discussed later in this appendix) indicates that a number of the types correspond to various durations that are relevant to releases during remedy implementation. Because a toxicity value generally is specific to a certain duration, however, risk may need to be characterized separately for the three short-term exposure durations.

C.2 EXISTING SHORT-TERM TOXICITY VALUES

In this section, commonly encountered short-term toxicity values are summarized. These values are: (1) concentration and dose threshold values primarily for noncarcinogenic effects; and (2) specific short-term carcinogenic risk values. A sect ion is provided on each of these toxicity value categories.

C.2.1 TOXICITY VALUES FOR ASSESSING RISK OF NONCARCINOGENIC EFFECTS FOR SHORT-TERM EXPOSURE

Toxicity values designed to characterize the risk of noncarcinogenic effects are summarized in the following subsections. Further information on the suitability of these values for various CERCLA exposure scenarios can be obtained from the TSC.

C.2.1. 1 Developmental Toxicant Reference Dose (RfD_{d1}) and Reference Concentration (RfC_{d1})

RfD_{dt}s and RfC_{dt}s are developed for chemicals that have been shown to cause adverse effects in a developing organism. EPA's Human Health Assessment Group of the Office of Health and Environmental Assessment is in the process of developing RfD_{dt} and RfC_{dt} values and the methodology for their derivation. As proposed by EPA (EPA 1989b), these values. will likely be derived from the no-observed-adverse-effect-level (NOAEL) or lowest-observed-adverse-effect-level (LOAEL) in a manner consistent with the derivation of reference doses (RfDs) and reference concentrations (RfCs), and without adjustment for short exposure duration. RfD_{dt}s are expressed in terms of dose and RfC_{dt}s are expressed as an air concentration. Additional information on these criteria is available in EPA's Proposed Amendments to the Guidelines for the Health Assessment of Suspected Developmental Toxicants (EPA 1989b), or by contacting the Reproductive

and Developmental Toxicology Branch of the Office of Health and Environmental Assessment at 202-260-7331 (FTS-260-7331).

Currently (i.e., at the date of publication of this guidance), developmental toxicity is considered in the derivation of EPA criteria for noncarcinogenic effects (including RfDs and RfCs for subchronic and chronic exposure and drinking water Health Advisories [HAs]). That is, these criteria are set at levels considered protective for developmental effects as well as for other noncarcinogenic effects.

C.2.1.2 Subchronic Reference Dose (RfDs) and Reference Concentration (RfCs)

RfDss and RfCss are developed by ECAO and are used to characterize potential noncarcinogenic effects associated with short-term exposures (two weeks to seven years as defined in RAG/HHEM Part A). To date, approximately 305 RfDss and 60 RfCss have been published. These RfDs and RfCs are developed based on NOAELS or LOAELS identified from subchronic (i.e., usually $\geq$ 90 days but less-than-chronic) toxicity studies. RfDss are expressed in terms of dose and RfCss are expressed as air concentrations. Subchronic RfDs and RfCs are available in HEAST. The derivation of RfDss is described in more detail in RAG/HHEM Part A.

C.2.1.3 One-day, Ten-day, and Longer-term Drinking Water Health Advisories (HAs)

Drinking water HAs developed by EPA provide guidance to assist state and local officials responsible for public health protection during emergency situations involving drinking water contamination. HAs are derived in a manner reasonably consistent with oral RfD methodology. Accordingly, these HA values constitute suitable criteria for evaluating short-term oral exposure. The HA concentrations include a margin of safety to protect sensitive members of the population (e.g., children, the elderly, pregnant women). "One-day HA" is the term used to describe the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects for one day of exposure, with a margin of safety. The "Ten-day HA" describes the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic health effects for two to ten consecutive days of exposure, with a margin of safety. The "Longer-term HA" is the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects up to approximately seven years of exposure. ("Lifetime HAs" that are protective for exposure over a lifetime are also developed based on chronic RfDs.)

In general, the HAs described here are protective of only noncarcinogenic effects. These values are expressed as concentrations in drinking water but can be converted to mg/kg/day doses by using the assumptions that were applied in their calculation: consumption of 1 L/day by a 10 kg child (one-, ten-, and longer-term HAs) and 2 L/day by a 70-kg adult (lifetime HA). Approximately 140 HAs have been developed by EPA for each exposure duration. (HAs are briefly described in RAGS/HHEM Part A.)

C.2.1.4 Acute Inhalation Criteria (AIC)

A report describing the derivation of AICs for benzene and beryllium is available through the TSC. AICs are derived as criteria for single, short-duration (up to an hour or a few hours) inhalation exposures, as may occur from releases during remediation. The AICs are based on noncancer endpoints and are expressed as air concentrations. AICs have been derived for a limited number of chemicals using EPA RfC methodology, modified as required for this acute exposure scenario. The modification consists of using the NOAEL (or LOAEL) as reported in the study without adjustment for exposure duration (hours/24 hours). Because these criteria are conceptually consistent with inhalation RfCs, they are a good basis for assessing short-term risks from single, very short exposures. The TSC should be contacted for additional AIC values.

C.2.1.5 Minimal Risk Levels (MRLs)

MRLs are derived by the Agency for Toxic Substances and Disease Registry (ATSDR) from human or animal studies for threshold effects on chemicals found at CERCLA hazardous waste sites. MRLs are developed for both inhalation and oral exposures; oral MRLs are expressed as doses and inhalation MRLs are expressed as concentrations in air. Estimates of exposure posing minimal risk to humans are made for the most sensitive noncarcinogenic endpoint (including developmental and reproductive endpoints) for three different exposure durations (i.e., acute,

intermediate, and chronic). These exposure durations for which MRLs are derived are as follows: acute MRL – 1 to 14 days; intermediate MRL – 15 to 364 days; chronic MRL – ≥ 365 days. MRLs are developed using an approach that is consistent with EPA RfD methodology (i.e., identification of a NOAEL or LOAEL and application of uncertainty factors to reflect human variability and, where appropriate, the uncertainty of extrapolating from laboratory animal data to humans).

Acute inhalation MRLs differ from AIC in regard to adjustment for exposure duration. The guidance for derivation of acute inhalation MRLs specifies that "exposure periods of less than 24 hours in the toxicity study from which the MRL is derived, can be adjusted to one day" (ATSDR 1991); this adjustment is commonly carried out. No such adjustment is carried out in the derivation of AICs, which are intended to serve as guidance for acute, very short, and single exposures (e.g., ranging from less than an hour to a few hours, perhaps as inadvertent releases during remediation).

MRLs can be found in the ATSDR Toxicological Profile documents in the Health Effects Summary section, on the Levels of Significant Exposure figure (graph). The bottom of the dotted line on the graph represents the MRL. Except in the earliest ATSDR Toxicological Profiles, MRL values and the endpoints on which they are based are also identified in the text accompanying the figure. To date, approximately 62 acute MRLs (38 oral, 24 inhalation) have been derived by ATSDR. As with other short-term toxicity values, guidance regarding use of the MRL must be sought from the TSC.

C.2.1.6 Emergency Exposure Guidance Level (EEGL), Short-term Public Emergency Guidance Level (SPEGL), and Continuous Exposure Guidance Level (CEGL)

EEGLs and CEGLs are exposure guidance levels developed by the National Research Council (NRC 1986) specifically for military personnel operating under emergency conditions. Therefore, setting of these levels involves consideration of various factors (such as age distribution, length of exposure, and susceptibility) that are different from those related to the general population. These guidance levels are published in the NRC (1984-1988) *Emergency and Continuous Exposure Guidance Levels for Selected Airborne Contaminants.* To date, 43 chemicals have been evaluated by NRC.

The EEGL is defined as the air concentration of a substance that is acceptable for the performance of specific tasks during rare emergencies usually lasting from 1 to 24 hours (i.e., it is a ceiling guidance level for a single emergency exposure) (NRC 1986). EEGLs are intended to prevent irreversible harm or serious impairment of judgment or performance. Exposure at an EEGL might produce reversible effects, and therefore should not be considered hygienic or safe. Acute toxicity is the primary basis for establishing an EEGL. However, even brief exposure to some substances might have the potential to increase the risk of cancer or other delayed effects. Derivation of an EEGL may involve application of an uncertainty factor of ten to extrapolate from animal data to humans, but no other species adjustments are applied. Some EEGLs are based on extrapolation of oral data. EEGLs are based on the most sensitive or most important noncarcinogenic health effects known. Because EEGLs are derived for healthy military personnel during rare emergencies, and are not intended to protect against reversible effects, they should not be applied directly to the general population (NRC 1986).

The SPEGL is defined as a suitable concentration for unpredicted, single, short-term emergency exposure of 1 to 24 hours of the general public. SPEGLs take into account the wide range of susceptibility of the general public. The SPEGL is generally estimated by applying an uncertainty factor of two to ten to the EEGL, to account for sensitive groups — such as children, the elderly, and persons with serious debilitating diseases. NRC (1986) suggests that a safety factor of two (i.e., EEGL x 0.5) is appropriate to protect more sensitive groups, such as children or the elderly, and that a safety factor of ten (i.e., EEGL x O. 1) is appropriate for fetuses or newborns. Because the SPEGL is derived from the EEGL, the considerations discussed above with regard to the EEGL also apply to SPEGLs.

The CEGL is defined as a ceiling concentration of a chemical in air to which military personnel can be exposed for up to 90 days without immediate or delayed adverse effects or degradation of performance (NRC 1986). CEGLs

are not derived for carcinogens. When data from chronic studies are available, they can be used to derive CEGLS. A CEGL is generally estimated, however, by applying an uncertainty factor of 10 to 100 to the EEGL (i.e., EEGL x 0.01 to 0.1), depending on the evidence for detoxification or accumulation of the substance in the body. Where there is evidence of substantial detoxification, a safety factor of ten is recommended by NRC (1986). If there is no evidence of detoxification or detoxification is slow, *a* safety factor of 100 might be more appropriate. If the substance accumulates in tissues, such as halogenated biphenyls and metals, even higher factors are recommended by NRC (1986). Other considerations discussed with regard to the EEGL also apply to CEGLs derived from EEGLs.

C.2.1.7 Threshold Limit Values — Short-term Exposure Limits (TLV-STELs), Threshold Limit Values — Time-weighted Averages (TLV-TWA), and Threshold Limit Values — Ceiling (TLV-C)

TLVs are concentrations developed by the American Conference of Governmental Industrial Hygienists (ACGIH) to protect workers from adverse effects of occupational exposure to airborne chemicals. However, because occupational exposure limits are not intended to protect sensitive workers or other populations, are not intended for the assessment of community air pollution or continuous exposure, may not incorporate the most recent toxicological data, may be based on unpublished documentation that is not available for review, and may differ from EPA derivations with respect to weight-of-evidence considerations and use of uncertainty factors, EPA does not endorse the general use of occupational exposure limits in deriving EPA criteria. In addition, it should be noted that the TLVs for a fair number of chemicals are derived by analogy to other chemicals because health effects data are inadequate or lacking.

The TLV-STELs are 15-minute time-weighted average (TWA) exposures that should not be exceeded at any time during the eight-hour work day/40-hour work week and should not occur more than four times a day, with at least 60 minutes between successive exposures in the STEL range (ACGIH 1990). The TLV-STEL is established to prevent workers from suffering irritation, chronic or irreversible tissue damage, or narcosis of sufficient degree to increase the likelihood of accidental injury. Use of the TLV-STEL should be limited to very short, single exposure events. STELs are recommended for substances with acute effects recognized from high short-term exposures in either humans or animals (ACGIH 1990). Approximately 115 TLV-STELs have been published by ACGIH.

The TLV-TWA is the time-weighted average concentration for a normal eight-hour workday/40-hour workweek to which nearly all workers maybe exposed, day after day, without adverse effects. The TLV-C is a concentration that should not be exceeded during any part of the working exposure. The ACGIH uses the TLV-C for substances that are particularly fast acting and hence are best controlled by a ceiling limit. In excess of 500 TLV-TWAs and fewer than 50 TLV-Cs have been published by ACGIH.

C.2.1.8 Permissible Exposure Levels (PELs) and Recommended Exposure Limits (RELs)

PELs are enforceable occupational exposure standards developed by the Occupational Safety and Health Administration (OSHA). They are meant to" protect workers against catastrophic effects (such as cancer; cardiovascular, liver, and kidney damage; and lung diseases) as well as more subtle effects resulting in central nervous system damage, narcosis, respiratory effects, and sensory irritation. The PELs are generally adopted from (existing) secondary guidance levels (e.g., ACGIH'S TLV-TWAs and TLV-STELs and the recommended exposure limits [RELs] developed by the National Institute for Occupational Safety and Health [NIOSH]), and nearly 400 are available from OSHA. EPA's reservations concerning the use of TLVs as the basis for criteria to protect the general population (see Section C.2.1.7) apply also to PELs and RELs.

C.2.1.9 Other Miscellaneous Methods

The following are some other methods that risk assessors or RPMs may encounter.

- **Immediately Dangerous to Life and Health (IDLH) Guidelines.** IDLH guidelines are developed by NIOSH. These air concentration limits are for 30-minute exposures under what are essentially emergency conditions, and generally far exceed corresponding TLV-TWA, TLV-STELs or PELs. IDLH guidelines were

determined only for the purpose of respirator selection. These guidelines are intended to be the maximum air concentration from which, in the event of respirator failure, a worker could escape within 30 minutes without experiencing any escape-impairing or irreversible health effects (NIOSH 1985). Many of the IDLH exposure levels are so high that they define levels at which severe toxic effects (unconsciousness, incapacitation, intolerable irritation or death) would be likely (Alexeef *et al.* 1989). Therefore, the IDLH guidelines are not suitable as benchmark guidelines for acute exposure and may be higher than would be useful even as a guideline for immediate evacuation.

- **CERCLA Section 102 (a) Reportable Quantities (RQs).** RQs are developed by EPA based on, among other factors, acute toxicity, chronic noncarcinogenic toxicity, and carcinogenicity. RQs define the quantity in pounds above which a release is considered potentially hazardous (or, at least, warrants reporting) under CERCLA section 102(a). The documentation for RQs may contain health effects information that would be useful in determining criteria for short-term exposure but are not by themselves useful in characterizing risks from releases that might occur at a CERCLA site.

C.2.2 SPECIFIC CARCINOGENIC RISK VALUES FOR SHORT-TERM EXPOSURES

There is relatively little guidance available on characterizing risks from short-term exposure to carcinogens. For cancer endpoints, most of the currently available values are specific to lifetime exposure. Many experimental investigations of carcinogenicity involve high-dose, long-duration exposure to compensate for the small number of animals that are used. Carcinogenicity data on short-term or single exposures are virtually nonexistent for most chemicals. For most chemicals, the current scientific view is that any exposure, no matter how short in duration, can result in a carcinogenic risk. Characterizing this risk is complicated, however, because of factors such as age at first exposure and mechanism of the carcinogen's action. Consistent with RAGS/HHEM Part A and the Guidelines for Carcinogen Risk Assessment (EPA 1986a), the preferred approach would be to consider cumulative dose, averaged over a lifetime. This met hod is discussed in Section C.2.2.1.

Several investigators have reported additional methods to characterize the effects from short-term exposure to carcinogens. Some of these methods are currently being investigated by EPA but are not recommended for short-term carcinogenic assessments at this time. However, brief summaries of these methods are provided below with documentation for the interested reader to pursue.

C.2.2.1 RAGS/HHEM Part A Method

RAGS/HHEM Part A currently recommends that lifetime average exposures always be used to estimate carcinogenic risks. That is, because the cancer toxicity values (i.e., SFs) are based on lifetime average exposures, Part A recommends that less-than-lifetime exposures be converted to equivalent lifetime values for the assessment of risk. (This is also the recommended approach in EPA's Guidelines for Carcinogenic Risk Assessment [EPA 1986].) In this manner, risks from short-term exposures would be averaged over a 70-year lifetime, with modifications for specific chemicals if appropriate, and, therefore, may appear to be relatively minor in comparison to risks from longer-term exposures. While adjusting less-than-lifetime exposure to an equivalent lifetime exposure may be valid for relatively long exposure durations, this adjustment for short-term exposures may underestimate the risk for "early-stage" carcinogens (i.e., DNA-damaging agents).

C.2.2.2 Office of Research and Development (ORD) Interim Method for Vinyl Chloride

EPA's ORD (EPA 1989a) used a study by Drew *et al.* (1983) to determine that the lifetime carcinogenic risk from vinyl chloride inhalation increases when exposure occurs early in life. Drew *et al.* showed that the effects from exposure to vinyl chloride depend on both age at initial exposure and duration of exposure. His data showed that children face higher risks than adults for exposures of a given duration. Cogliano stated that if risk for partial lifetime exposures is estimated by ignoring the age at initial exposure and considering only the duration, the risk will be underestimated for children and overestimated for adults over 30. He proposed that risk for partial

lifetime exposure to vinyl chloride be: (1) estimated as being proportional to the remaining lifetime of the exposed individual, and (2) adjusted depending on the length of exposure. The author also stated that, at this time, this analytical technique is applicable onlv to vinyl chloride and should not be applied to any other substances. The TSC should be contacted for further guidance on assessing risks from vinyl chloride.

C.2.2.3 EEGLs for Carcinogens

The NRC (1986) has developed a method for deriving EEGLs (1 to 24-hour exposure guidelines) for inhaled carcinogens when the computed cancer risk associated with the toxicity-based EEGL (see Section C.2. 1.6) is more than one in 10,000. In these cases, the EEGL is lowercd so that the risk is not more than one in 10,000 ($1x10^{-4}$). The NRC method draws on the analysis of Crump and Howe (1984) and appears to employ a higher level of acceptable lifetime risk (i.e., $1x10^{-4}$) than the RAGS/HHEM Part A method. This method is discussed in further detail in *Criteria and Methods for Deputing Emergency Guidance Level (EEGL), Short-term Public Emergency Guidance Level (SPEGL), and Continuous Exposure Guidance Level (CEGL) Documents* (NRC 1986). The 24-hour EEGL for a carcinogen is estimated as follows:

$$EEGL = d \times \frac{25{,}600}{2.8} \times \frac{R}{\text{level of risk at d}}$$

where:

d = lifetime exposure level (air concentration), as computed by a regulatory agency or by the NRC Committee on Toxicology in accordance with procedures used by regulatory agencies (multistage model) associated with "acceptable" level of cancer risk, e.g., $1x10^{-6}$ level of risk,

25,600 = number of days in a lifetime (25,600 days = 70 years); application of this duration factor assumes that carcinogenic effects are a linear function of the total (cumulative) dose,

2.8 = a factor to account for uncertainties regarding which stage of carcinogenesis is affected by the substance and for the likely youth of military personnel; the NRC (1986) states that "the maximal additional risk that these considerations contribute is a factor of 2.8," based on the "data of Crump and Howe (1984)," and

R = target acceptable risk level (e.g., $lx10^{-4}$) for one day of exposure.

The reservations with this method concern the choice of a higher target risk level ($1x1^{-4}$) in combination with other assumptions of this method, and the origin of the above uncertainty factor of 2.8. The origin of this uncertainty factor is not explained adequately by NRC (1986), nor is it apparent in the cited paper (Howe and Crump 1986).

REFERENCES FOR APPENDIX C

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APPENDIX D

RADIATION REMEDIATION TECHNOLOGIES

This appendix presents two exhibits designed to assist the RPM with the process of using risk information to evaluate and select remediation technologies for sites contaminated with radioactive substances. The first exhibit, Exhibit D-1, summarizes the potential routes by which radioactivity may be released to the air, ground water, surface water, or other media when remedial technologies are implemented. Similar to Exhibit A-2 in Appendix A, Exhibit D-1 groups process variations with similar potential release mechanisms under the technology categories. Exhibit D-1 includes ground and surface water releases under the "water" column, and includes other unique release mechanisms under the "other" column. The reader is referred to EPA's report, *Assessment of Technologies for the Remediation of Radioactively Contaminated Superfund Sites (EPA/540/2-90/001),* for descriptions of each technology listed in Exhibits D-1 and D-2.

The second exhibit, Exhibit D-2, presents a qualitative estimate of the potential short-term risks posed by each technology during its implementation phase, and its potential long-term risks anticipated after cleanup. Potential short-term risks and potential long-term risks are classified as being low, moderate, or high, or some combination of these levels. This classification scheme is based on the potential for releases of radioactivity arising from the use of these technologies to lead to potential short- and long-term risks. Under this scheme, "low" means a low potential for releases of radioactivity assuming a reasonable worst-case scenario and therefore, a low potential for human health or environmental risk. "Moderate" means a moderate potential for release and risk, and "high" refers to a high potentiaI for release and risk.

Although the determinations of low, moderate, and high potential risks presented in Exhibit D-2 are based on the professional judgment of experienced risk assessors, they are provided only to the RPMs for making preliminary technology screening decisions. The actual risks associated with a remedial alternative at a specific site must be evaluated on a case-by-case basis. That is, technologies rated as high potential risk should not necessarily be eliminated from consideration, nor should technologies rated as low potential risk be considered safe, without evaluation of site-specific factors.

The Agency recognizes that other determinations of degree of potential risks are possible and may be acceptable. (In fact, if remediation technologies are properly designed and excuted, few, if any, of the potential releases and risks may be expected.) Therefore, the RPM is encouraged to consider all qualified source-s of technical information when selecting a radiation remedial technology based on site-specific conditions.

Potential releases of mixed radioactive and nonradioactive hazardous substances are not covered in this appendix due to the limited number of technologies currently available, and the complexities involved in identifying release pathways and mechanisms. Because releases of mixed waste contaminants will warrant additional risk evaluation and considerations, RPMs should consult with a radiation protection specialist prior to selecting a remedial design for these types of sites.

EXHIBIT D-1

POTENTIAL RELEASES OF RADIOACTIVITY ASSOCIATED WITH RADIATION REMEDIATION TECHNOLOGIES

Technologies	Air	Water[a]	Other[b]
SOIL AND SLUDGE TECHNOLOGIES			
Natural Attenuation (Non-treatment Action)	Potential emissions of radioactive particulate and volatiles	Continued migration of radionuclides to ground water and possible transport to surface water	External radiation exposure due to gamma-emitting radionuclides in soil
Soil Handling			
Soil Excavation, Transport, and Offsite Disposal	Resuspension of radioactive particulate Enhanced emissions of volatile radionuclides	Enhanced runoff or leaching of radionuclides to surface water or ground water	Seepage/runoff to soil Enhanced external radiation exposure of workers during excavation, handling, shipping, and disposal Offsite migration of radioactivity due to transport by contaminated vehicles or equipment
Soil Washing, Extraction, & Bioremediation			
Soil Washing with Water	Resuspension of radioactive soil particles and enhanced emissions of volatile radionuclides during handling and treatment	Spills? leaching, and/or runoff of residual radionuclides in washed soil or in process water Accumulation of dissolved or suspended radionuclides in recycled water/solvents	Enhanced external radiation exposure from gamma-emitting radionuclides in soil

(Continued)

EXHIBIT D-1 (Continued)

POTENTIAL RELEASES OF RADIOACTIVITY ASSOCIATED WITH RADIATION REMEDIATION TECHNOLOGIES

Technologies*	Air	Water[a]	Other[b]
Soil Washing, Extraction, & Bioremediation (Continued)			
Chemical Extraction	• Potential emissions of volatile chemicals and radioactive particulate and volatiles during handling and treatment	• Spills, leaching, and/or runoff of residual radionuclides in process water • Accumulation of dissolved or suspended radionuclides in recycled water/solvents	• Spills or leakage of extract with high concentrations of radioactive contaminants and solvents from storage tanks
Bioremediation	• Areal or fugitive emissions of radioactive particulate and volatiles • Exhaust stack emissions of incinerated biosorbants containing residual radioactivity	• Discharge of process water containing residual radioactivity • Inadvertent spills or leaching of radionuclides	• External radiation exposure from biomass containing residual gamma-emitting radionuclides
Immobilization			
Capping	• Continued emissions of some volatile radionuclides after capping	• Leaching and horizontal migration of radionuclides to ground water with rain water infiltration	• Partial reduction of external radiation exposure

(Continued)

EXHIBIT D-1 (Continued)

POTENTIAL RELEASES OF RADIOACTIVITY ASSOCIATED WITH RADIATION REMEDIATION TECHNOLOGIES

Technologies*	Air	Water[a]	Other[b]
In-situ Vitrification	• Volatilization of certain radionuclides during treatment • Cracks or fissures in vitrified mass may act as conduits for the release of volatile radionuclides	• Possible leaching and migration of radionuclides to ground water due to soil matrix destabilization	• External radiation exposure in radium contaminated soils due to the buildup of radon decay products
GROUND WATER AND SURFACE WATER TECHNOLOGIES			
Natural Attenuation (Non-treatment Action)	• Potential buildup of volatile radionuclides (eg, radon) in ground-water and municipal water distribution systems	• Continued transport of radionuclides to the aquifer and possible discharge to surface water	• Potential deposition of radioactive sediments in surface water over large areas (eg, river basins)
Filtration	• Fugitive emissions of volatile radionuclides	• Discharge of effluent water containing dissolved radioactive solids	• Potential leaching of radionuclidc.s from filter cakes or sludge • External radiation exposure from radioactive cakes or sludge
Granular Activated Carbon Adsorption	• Potential stack emissions of volatile radionuclides upon saturation or breakthrough	• Discharge of treated water containing residual radioactive contamination • Possible release of radionuclidcs due to backflushing and/or regeneration	• Potential external radiation exposure due to the sorption and buildup of gamma-emitting radionuclides
Ion Exchange	• Potential for off-gassing of volatile radioactive decay products from parent nuclides on resin columns	• Discharge of treated water containing residual radioactive contamination • Possible release of radionuclides due to backflushing or regeneration	• Potential external radiation exposure due to the buildup of gamma-emitting radionuclides

(Continued)

EXHIBIT D-1 (Continued)

POTENTIAL RELEASES OF RADIOACTIVITY ASSOCIATED WITH RADIATION REMEDIATION TECHNOLOGIES

NOTES

* Source for radiation remediation technologies US Environmental Protection Agency (EPA). 1990. *Assessment of Technologies for the Remediation of Radioactively Contaminated Superfund Sites. EPA/540/2-90/OOl.*

[a] In general, seepage and leaching are more likely to affect ground water, but could also lead to surface water contamination. Runoff and discharge are releases that will most likely contaminate surface water, but may also lead to ground-water contamination.

[b] Other releases include treatment residuals requiring further remediation and/or special handling and disposal considerations. External radiation exposure due to the presence of gamma-emitting radionuclides in treatment residues should also be considered as a potential human health exposure pathway, even though this pathway does not involve the physical release of radionuclides into the environment. The risk assessor should also consider other common technologies used to remediate ground water and surface water contaminated with radioactive substances, such as aeration, evaporation, distillation and solvent extration, not included in Exhibits D-1 or D-2.

EXHIBIT D-2

DEGREE OF POTENTIAL SHORT- AND LONG-TERM RISKS ASSOCIATED WITH RADIATION REMEDIATION TECHNOLOGIES

Technologies*	Potential for Short-term Risks	Potential for Long-term Risks	Comments
SOIL AND SLUDGE TECHNOLOGIES			
Natural Attenuation (Non-treatment Action)	High	High	• The No Action alternative will not meet the two NCP threshold criteria: (1) protection of human health and environment, and (2) compliance with ARARs • Migration and release of radioactive contaminants would be expected to continue unless abated or mitigated
Soil Handling			
Soil Excavation, Transport, and Offsite Disposal	Moderate/High	None/Low	• During excavation, the potential for short-term radiation risks to remedial workers onsite and to the general public offsite may be moderate to high • Once the source or sources of radioactivity has or have been removed, the potential for long-term risks should be minimal or non-existent, depending on the level of residual radioactivity remaining onsite
Soil Washing, Extraction, & Bioremediation			
Soil Washing with Water	Moderate	Low	• During excavation and soil washing, the potential for short-term radiation risks to remedial workers onsite and to the general public offsite may be moderate • Depending on the level of residual radioactivity remaining, the potential for long-term risks may be low to moderate
Chemical Extraction	Moderate/High	Low/Moderate	• During excavation and chemical extraction, the potential for short-term radiation risks to workers onsite and to the general public offsite may be moderate to high • The potential for long-term risks depend upon the chemical and radiological characteristics of the treated soil recycled back into native soil

(Continued)

EXHIBIT D-2 (Continued)

DEGREE OF POTENTIAL SHORT- AND LONG-TERM RISKS ASSOCIATED WITH RADIATION REMEDIATION TECHNOLOGIES

Technologies*	Potential for Short-term Risks	Potential for Long-term Risks	Comments
Soil Washing, Extraction, & Bioremediation (Continued)			
Bioremediation	Moderate	Moderate	• Accidental spillage of radioactivity from biotreatment solutions, off-gassing of volatile radionuclides, and elevated external radiation exposures may contribute to the potential for moderate short-term radiation risks • Long-term risks depend upon the chemical and radiological characteristics of the treated soil recycled back into native soil In general, these risks should be low to moderate
Immobilization			
Capping	Low/Moderate	Moderate/High	• Short-term radiation risks to workers and offsite populations should be low to moderate, provided that the source or sources of radioactivity are not excavated before capping • Since the sources of radioactivity will be left in place, long-term risks to human health and the environment may be moderate to high depending on the extent to which the cap is capable of preventing the migration of radionuclides in the future
In-situ Vitrification	Moderate/High	Moderate	• Initially, both radiation and physical hazards contribute to the moderate to high potential for short-term radiation risks posed by the use of this technology, primarily to onsite workers • Since the stability and long-term integrity of vitrified soils containing radioactive materials remain unverified in the field at the present time, and since the buildup of radon decay products in vitrified soils may increase external exposure rates with time, potential long-term radiation risks to the general public may be moderate to high

(Continued)

EXHIBIT D-2 (Continued)

DEGREE OF POTENTIAL SHORT- AND LONG-TERM RISKS ASSOCIATED WITH RADIATION REMEDIATION TECHNOLOGIES

Technologies*	Potential for Short-term Risks	Potential for Long-term Risks	Comments
GROUND WATER AND SURFACE WATER TECHNOLOGIES			
Granular Activated Carbon Adsorption	Low/Moderate	Low	• The buildup of radon and radon progeny on activated charcoal may increase both potential short- and long-term risks of external radiation exposures to workers Regeneration of GAC may release radionuclides that are not well sorbed Disposal of spent GAC containing elevated concentrations of lead-210 (and chemical contaminants) may pose handling problems Buildup of radon and other radionuclides on GAC also depends on: (1) the concentrations of radionuclides in the ground or surface waters; (2) collection efficiencies; (3) GAC breakthrough time, and; (4) the change-out or regeneration cycle time
Ion Exchange	Low/Moderate	Low	• Similar to the potential risks posed by the treatment of radionuclides in ground water and surface water using filtration or carbon absorption techniques, the potential for short- and long-term risks posed by the collection of radionuclides on ion exchange resins depends primarily on the radionuclide-specific collection efficiency and water concentrations In general, these potential risks may be low to moderate

* Source for radiation remediation technologies: U.S. Environmental Protection Agency (EPA). 1990. ***Assessment of Technologies*** *for the Remediation of Radioactively Contaminated Superfund Sites.* Office of Solid Waste and Emergency Response. EPA/540/2-90/001.

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