ELECTRIC POWER RESEARCH INSTITUTE

Groundwater and Soil Remediation Guidelines for Nuclear Power Plants

Public Edition

2011 TECHNICAL REPORT

Groundwater and Soil Remediation Guidelines for Nuclear Power Plants

Public Edition

1023464

Final Report, July 2011

EPRI Project Manager
K. Kim

EPRI Staff Contributor
R. McGrath

This document does **NOT** meet the requirements of
10CFR50 Appendix B, 10CFR Part 21,
ANSI N45.2-1977 and/or the intent of ISO-9001 (1994)

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

THE FOLLOWING ORGANIZATION, UNDER CONTRACT TO EPRI, PREPARED THIS REPORT:

C.N. Associates, Inc.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

ACKNOWLEDGMENTS

The following organization, under contract to the Electric Power Research Institute (EPRI), prepared this report:

C.N. Associates, Inc.
PO Box 1446
Manchester, MA 01944

Principal Investigators
R. Cardarelli
G. Oliver

This report describes research sponsored by EPRI.

This publication is a corporate document that should be cited in the literature in the following manner:

Groundwater and Soil Remediation Guidelines for Nuclear Power Plants: Public Edition. EPRI, Palo Alto, CA: 2011. 1023464.

This report was prepared with support from the *EPRI Groundwater Guidelines Committee* composed of the following individuals:

Gail Gary, AmerenUE

Chris Graham, AmerenUE

Jim Hoffman, AmerenUE

Bill Wendland, ANI

John D'Souza, Constellation

Dean Desenza, Constellation

James Breeden, Dominion

Barry Muller, Detroit Edison

Larry Haynes, Duke Energy

Cyndi Martinec, Duke Energy

John Estridge, Duke Energy

Motley Hedges, Energy Northwest

Jay Scheffer, Entergy

Patrick Donahue, Entergy

Ken Sejkora, Entergy

Jay Adler, Entergy

Ronald Chrzanowski, Exelon

Zigmund Karpa, Exelon

Greg Gillespie, FENOC

Ernesto Castillo, INPO

Wook Sohn, KEPRI

Kathy Yhip, NEI & Southern California Edison

Bruce Vogel, NextEra Energy

Kevin O'Hare, NextEra Energy

Peter Harvey, NextEra Energy

Christine Neely, PSE&G

Helen Gregory, PSE&G

Soo Chae, OPG

Ronald Beck, OPPD

Louise England, Progress Energy

Michael Roberts, SCE&G

Michele Rosati, Sogin

Mary-Beth Lloyd, Southern Company

Greg Elmore, Southern Company

Dwight Hostetter, Southern Company

William Bullard, STP

Robert Richie, TVA

Gerald Malinowski, Xcel Energy

REPORT SUMMARY

The Electric Power Research Institute (EPRI) Groundwater and Soil Remediation Guidelines provides the nuclear power industry with technical guidance for evaluating the need for and timing of remediation of soil and/or groundwater contamination from onsite leaks, spills, or inadvertent releases to a) prevent migration of licensed material off-site and b) minimize decommissioning impacts.

Background

Experiences at decommissioning and operating nuclear power plants have shown that leaks and spills from systems, structures, and components (SSCs) and work practices can contaminate on-site soil and groundwater with radiological materials. While the levels of radioactivity caused by these leaks and spills do not pose a threat to public health and safety, stakeholders have expressed concerns related to the potential unmonitored off-site migration of licensed materials from nuclear power plant sites. In response to these concerns, the United States nuclear power industry committed to the Groundwater Protection Initiative in early 2006. The initiative commits each plant in the United States to implementing an on-site Groundwater Protection Program. The Nuclear Energy Institute (NEI) issued the *Industry Ground Water Protection Initiative – Final Guidance Document* (NEI 07-07) in August 2007. In parallel, the EPRI Groundwater Protection Technology Program issued the *Groundwater Protection Guidelines for Nuclear Power Plants: Public Edition* (EPRI Report 1016099) in January 2008 to provide technical guidance for implementing groundwater protection programs at nuclear power plant sites. These two guidance documents have been successful in guiding the implementation of the industry's groundwater protection programs.

As part of a nuclear plant's groundwater protection program, operators should have response procedures and policies in place for use if leaks or spills occur or if residual radioactivity is detected in soil or groundwater. NEI 07-07 and NEI 08-08 require these procedures at U.S. nuclear power plants. The decision-making protocol needs to evaluate the extent of the radiological impact on environmental media at the site, and the potential impact on decommissioning costs.

Objectives

To provide a process to determine whether a detailed evaluation of remediation options is necessary and, if so, provide guidance for a site-specific evaluation of the technical feasibility and cost of various remediation options.

Approach

This guidelines document was developed by EPRI and a committee of industry representatives. The project team incorporated experiences and lessons learned from soil and groundwater remediation at operating and decommissioned nuclear power plant and U.S. Department of Energy sites into the development of this guidance. They also incorporated results from past EPRI projects exploring innovative and advanced technologies for soil and groundwater remediation.

Results

This document provides the guidance necessary to establish a decision making protocol for soil or groundwater remediation at each nuclear power plant site. The remediation evaluation protocol includes remediation objectives, site investigation criteria, and draft site release limits to evaluate the need for remediation in the event of a leak or spill. Considerations that should be included in the decision-making protocol are:

1. Potential for off-site migration of contamination following an inadvertent release.
2. Potential impacts to decommissioning planning and costs, such as increases in contaminated materials requiring disposal at decommissioning.
3. Potential to exceed site release criteria at license termination.
4. Potential impacts to plant operation and business practices.

The document also provides the information necessary to evaluate remediation options with respect to technical feasibility, safety, and cost in order to determine if remediation is more effective and/or less costly during operation or decommissioning. Based on this evaluation, the user can make a site-specific and informed technical and business decision for each incident on undertaking remediation during operation or during decommissioning.

EPRI Perspective

EPRI developed these Guidelines in response to an industry-wide need for guidance in evaluating the need for soil and groundwater remediation and applicable and cost-effective technologies. The decision making process provided in this document was designed to ensure that each nuclear power plant could implement a remediation program that was appropriate for their site, thus allowing each plant to optimize their resources. This collaborative effort with NEI and a utility committee represents the industry's proactive management of groundwater protection issues. By developing and implementing these EPRI Guidelines in a timely manner, the industry can work with regulators and other stakeholders to develop groundwater-monitoring programs that address public concerns related to groundwater contamination.

Keywords

Groundwater protection
Groundwater remediation
Soil remediation
Decommissioning

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1
INTRODUCTION

The Electric Power Research Institute (EPRI) Groundwater and Soil Remediation Guidelines provides the nuclear power industry with technical guidance for evaluating the need for and timing of remediation of soil and/or groundwater contamination from onsite leaks, spills, or inadvertent releases to a) prevent migration of licensed material off-site and b) minimize decommissioning impacts. The objectives of these guidelines are to provide a process to determine whether a detailed evaluation of remediation options is needed and provide guidance for a site-specific evaluation of the technical feasibility and cost of various remediation options. The process in these Guidelines can be used to determine when soil and/or groundwater remediation would be most beneficial and effective (in terms of technical considerations, feasibility, and cost). The methodology in this guideline is intended to be used for new leaks or spills or newly discovered groundwater or soil contamination, but may be used for previously-identified contamination, at the licensee's discretion.

1.1 Background and History

Experiences at decommissioning and operating nuclear power plants have shown that leaks and spills from systems, structures, and components (SSCs) and work practices can contaminate on-site soil and groundwater with radiological materials. While the levels of radioactivity caused by these leaks and spills do not cause a threat to public health and safety, stakeholders have expressed concerns related to the potential unmonitored off-site migration of licensed materials from nuclear power plant sites. In response to these concerns, the Nuclear Strategic Issues Advisory Committee of the Nuclear Energy Institute (NEI) established the Groundwater Protection Initiative in early 2006 that commits each plant in the United States to implementing an on-site Groundwater Protection Program. NEI issued the Industry Ground Water Protection Initiative – Final Guidance Document (NEI 07-07, Reference 1) in August 2007. In parallel, the EPRI Groundwater Protection Technology Program issued the Groundwater Protection Guidelines for Nuclear Power Plants: Public Edition (EPRI Report 1016099, Reference 2) in January 2008 to provide technical guidance for implementing groundwater protection programs at nuclear power plant sites. These two guidance documents have been successful in guiding the implementation of the industry's groundwater protection programs.

The same instances of inadvertent releases of licensed material to soil and/or groundwater discussed above generated an internal review at the Nuclear Regulatory Commission (NRC.) The NRC issued the Liquid Radioactive Release Lessons Learned Task Force Final Report (Reference 3) on September 1, 2006. It is important to note that the NRC did not identify any instances where the health of the public or the environment was impacted due to the inadvertent releases of licensed materials. This report contained 26 recommendations on various issues.

Some of these recommendations addressed the adequacy of power reactor decommissioning funding (Recommendation #22) and development of regulations or guidance for remediation (Recommendation #7).

The decommissioning experiences of facilities other than nuclear generating stations have caused concern and led to the recommendations provided in the Task Force Report (Reference 3.) A number of these legacy sites are considered complex materials licensee sites. Further, from reviewing these, it appears that the sites with notable decommissioning issues are outliers, having unique site-specific issues (Reference 5). For example:

- A number of the complex decommissioning sites involved Manhattan Engineering District and defense-related activities which were not originally licensed by the U.S. Atomic Energy Commission (AEC)
- A number of the complex sites involve permitted burials made in accordance with the then applicable 10 CFR 20.304
- A number of listed examples related to no license termination process, or a less-than-adequate termination (closeout) survey, and the inappropriate termination of the license by the NRC
- A number of these complex sites utilized inadequate (non-synthetic) liners for process and evaporation ponds
- A number of the complex sites apparently processed uranium or thorium-containing ores without initially recognizing that a license from the AEC or NRC would be required

The conditions leading to the establishment of these legacy sites have a history unique to a period in history and specific situations that are not related to operation of nuclear generating stations. However, it is important to understand the context of these legacy sites and the reasons for public and regulatory concern.

All of the commercial nuclear power plants decommissioned in the United States to date have done so successfully following the existing decommissioning regulations (10 CFR Part 20, Subpart E.) The NRC licenses of these plants have been terminated and the sites are available for unrestricted use (Reference 4). Furthermore, the implementation of groundwater protection programs at all nuclear power plant sites (per NEI 07-07, the EPRI Groundwater Protection Guidelines for all plants and NEI 08-08 for plants to be licensed under 10 CFR 52) further reduces the potential for uncontrolled and undocumented contamination of nuclear power plant sites. However, the experiences at decommissioning plants such as Connecticut Yankee show that the remediation of soil, bedrock, and groundwater caused by such leaks and spills during operation can impact the cost and schedule of decommissioning.

Industry experience has shown that the cost of groundwater remediation during decommissioning, even under extreme conditions, has been a small fraction of the total cost of the decommissioning. At Connecticut Yankee, remediation costs related to reducing groundwater contamination was less than 9% of the total decommissioning costs. The cost of remediation and monitoring at Connecticut Yankee was $75 million. A portion of the cost for groundwater remediation was associated with meeting State as well as NRC requirements. Although the risk of a nuclear power plant site becoming a legacy site due to significant site contamination is low, there does exist opportunities for well-informed business decisions related to remediation and decommissioning.

The NRC regulations for decommissioning defined in 10 CFR 20 Subpart E contain requirements to learn from the lessons of the existing fleet of nuclear generating stations and to apply the lessons learned to the new plants to be licensed under 10 CFR Part 52. These requirements are defined in 10 CFR 20.1406 "Minimization of Contamination." NRC has published Regulatory Guide 4.21, "Minimization of Contamination and Radioactive Waste Generation: Life-Cycle Planning" (Reference 6). NEI and the NRC jointly developed NEI 08-08, "Generic FSAR Template Guidance for Life Cycle Minimization of Contamination" (Reference 7) to address the operational guidance of Regulatory Guide 4.21 and the requirements of 10 CFR 20.1406 for new plants to be licensed in the United States. There is design guidance in Regulatory Guide 4.21 beyond the scope of NEI 08-08. Much of NEI 08-08 is based on the industry groundwater protection guidance established in NEI 07-07. Section 5.1.2 of NEI 08-08 and Objective 1.4 of NEI 07-07 establish the requirement for a remediation protocol to prevent migration of licensed material off-site and to minimize decommissioning impacts. This requirement, established in NEI 08-08, is consistent with the guidance provided in NEI 07-07 (see below). Should a licensee commit to NEI 08-08, it becomes a part of the licensing basis for that plant and is a requirement subject to NRC inspection and enforcement. Refer to NEI 08-08 (Reference 7) for additional details.

Requirements for a remediation protocol are established in the Industry Groundwater Protection Initiative – Final Guidance Document (NEI 07-07) (Objective 1.4) for U.S. plants:

Establish a remediation protocol to prevent migration of licensed material off-site and to minimize decommissioning impacts.

<u>*Acceptance Criteria*</u>

a. *Establish written procedures outlining the decision making process for remediation of leaks and spills or other instances of inadvertent releases. This process is site specific and shall consider migration pathways.*

b. *Evaluate the potential for detectible levels of licensed material resulting from planned releases of liquids and/or airborne materials.*

c. *Evaluate and document, as appropriate, decommissioning impacts resulting from remediation activities or the absence thereof.*

The EPRI Groundwater Protection Guidelines for Nuclear Power Plants provides detailed guidance in Chapter 10 “Potential Mitigating Actions” and Chapter 11 “Decommissioning Considerations”.

Remediation is an effort to address the radiologically significant consequences of the leak or spill. Remediation in this context (and therefore, in the context of the U.S. Industry Groundwater Protection Initiative) is not defined by most existing site procedures designed to immediately address a leak or spill. NEI 08-08 has defined radiologically significant as:

Radiologically Significant: The “significance” threshold is the unexpected radiological conditions resulting from spills, leaks, unplanned releases or the identification of radioactive materials in unexpected locations that could have an adverse impact on license termination under Subpart E of 10 CFR Part 20

Nuclear plant operators need to have in place, as part of their plant’s groundwater protection program, response procedures and policies to be used if leaks or spills occur or if residual radioactivity is detected in soil or groundwater. At U.S. nuclear power plants, this is required by NEI 07-07 and NEI 08-08. The decision making protocol needs to evaluate the extent of the radiological impact on environmental media at the site and the potential impact on decommissioning costs. Note that the term “residual radioactivity” as defined in 10 CFR 20 applies to licensed material and other radiological material that originated from the licensee’s facility. For a more complete discussion of these distinctions see NRC Regulatory Issue Summary 2008-03 “Return/Re-use of Previously Discharged Radioactive Effluents” (Reference 8). Residual radioactivity levels of interest are those that will challenge the site in meeting 10 CFR 20.1402 Radiological Criteria for Unrestricted Use or 10 CFR 20.1403 Criteria for License Termination under Restricted Conditions of 25 millirem (mrem) per year (0.25 mSv/yr).

1.2 Scope of Guidelines Document

This guidelines document provides the guidance necessary to establish a decision making protocol for soil or groundwater remediation to satisfy NEI 07-07 Objective 1.4a at each nuclear power plant site. This remediation evaluation protocol should be established prior to a leak or spill event (i.e. as part of the site's groundwater protection program) and include the evaluation steps outlined in this guidelines document (depicted in Figure 1-1). The remediation evaluation protocol should include remediation objectives, site investigation criteria (developed per Guidance Statement 2.2), and draft site release limits (developed per Guidance Statement 2.3) that will be used to evaluate the need for remediation in the event of a leak or spill. The overarching considerations that should be included in the decision-making protocol are:

1. Potential for off-site migration of contamination following an inadvertent release
2. Potential impacts to decommissioning planning and costs, such as increases in contaminated materials requiring disposal at decommissioning
3. Potential to exceed site release criteria at license termination
4. Potential impacts to plant operation and business practices

The document also provides the information necessary to evaluate remediation options with respect to technical feasibility, safety, and cost in order to determine if remediation is less costly and/or more effective during operation or during decommissioning. Based on this evaluation, the user will then be able to make a site-specific and informed business decision for each incident on whether to remediate during operation or during decommissioning.

While the process in this guideline does not prescribe a particular remediation option, it does describe a number of options for consideration at a nuclear power plant site with soil and/or groundwater contamination. More importantly, the guideline provides an outline of a decision making process for the remediation of soil and groundwater that will support a well-defined business decision, meet regulatory requirements, and maintain the health and safety of the public and the environment.

This guideline contains guidance statements describing the actions to be performed at the critical steps in the process. A summary of these guidance statements is contained in Table 1-1. This process is also shown graphically in the flowchart in Figure 1-1.

Table 1-1
Summary of Guidance Statements

Guidance Number	Guidance Statement
2.1	Define remediation objectives.
2.2	Establish site-specific investigation criteria that will be used to evaluate the outcome of initial leak or spill response.
2.3	Determine draft site release limits for soil and groundwater. These draft site release limits define the allowable concentrations in soil and groundwater that meet the NRC site release criteria at license termination.
3.1	Once initial leak or spill response is complete, survey the area to determine if residual radioactivity exists. a: If residual radioactivity is below the investigation criteria determined in Guidance Statement 2.2, further remediation evaluations are not required. b: If residual radioactivity is below the draft site release limits defined per Guidance Statement 2.3, further remediation evaluations are not required.
3.2	Characterize the extent of soil and groundwater contamination.
3.3	Evaluate the potential for contamination to migrate off-site prior to the time of decommissioning.
3.4	Estimate the extent of soil and groundwater contamination at the time of decommissioning.
3.6	Compare the radionuclide concentrations that are projected to remain in the soil and groundwater at the time of decommissioning (determined per Guidance Statement 3.4) to the draft site release limits (determined per Guidance Statement 2.2). If the projected radionuclide concentrations are below the draft site release limits defined per Guidance Statement 2.2, further remediation evaluations are not required.
3.7	Define remediation criteria.
4.1	Evaluate and select viable remediation strategies for meeting remediation objectives. Both remediation during operation and remediation during decommissioning should be considered in order to make informed decisions about when to implement remediation.
5.1	Determine the costs to implement the technically viable remediation options chosen per Guidance Statement 4.1.
6.1	Implement and monitor the selected remediation option.

Note 1: Guidance statements are numbered to be consistent with the chapter and section containing these guidance statements.

NOTE TO USER:

A remediation evaluation protocol should be in place as part of the site's groundwater protection program per the site's implementation of Objective 1.4a of NEI 07-07.

This remediation evaluation protocol should include the steps outlined in this flowchart and include the site's remediation objectives (G.S. 2.1), site investigation criteria (G.S. 2.2), and draft site release limits (G.S. 2.3). The remediation evaluation will be conducted if a leak or spill occurs.

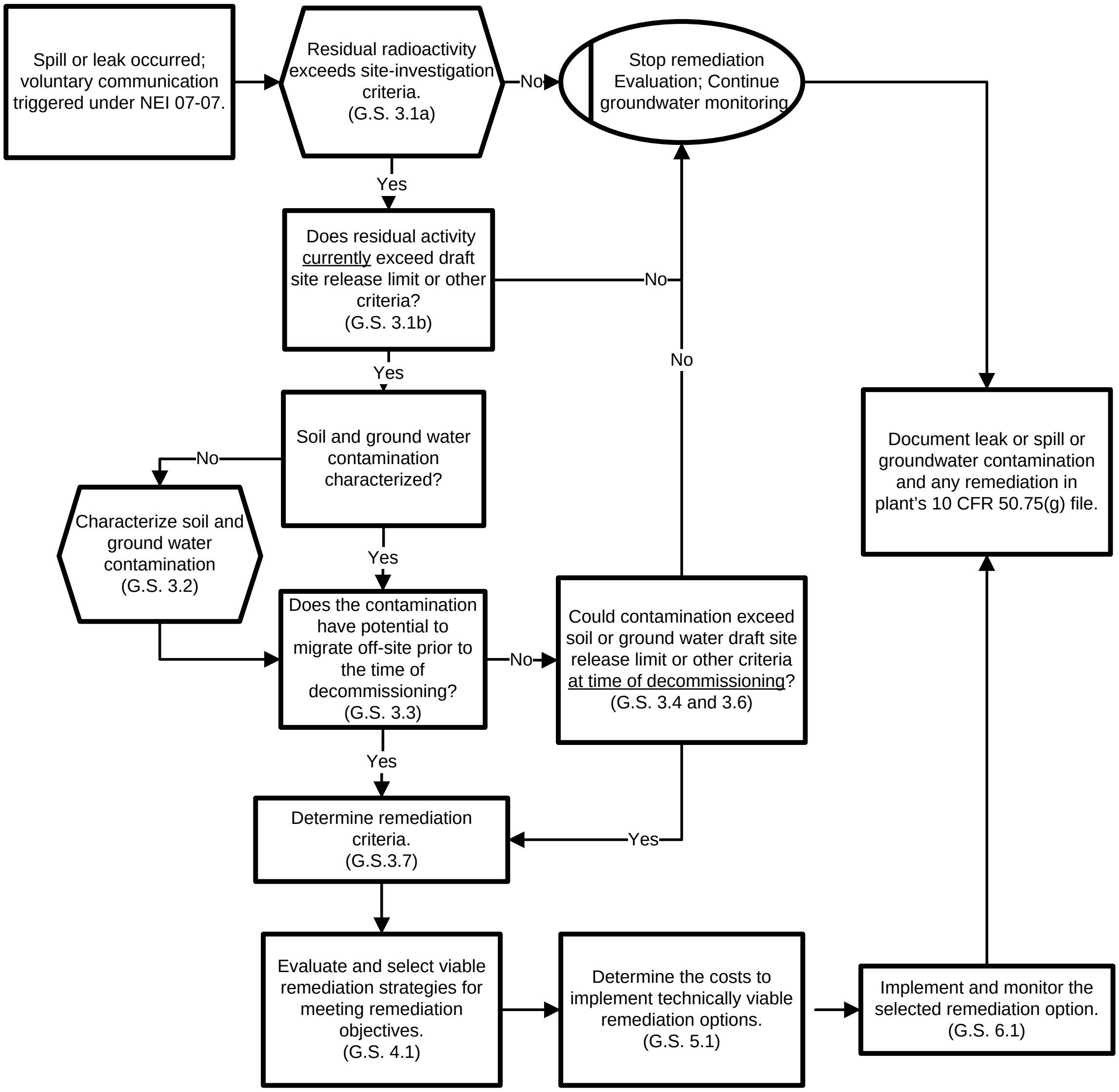

Figure 1-1
EPRI Groundwater & Soil Remediation Flow Chart

Note 1: Steps may be skipped in this flowchart, as applicable to given conditions at the facility under review.

Note 2: Remediation options may be implemented during operation or decommissioning based on the technical and business evaluation of the licensee. If the decision is made to delay remediation until decommissioning, a more accurate evaluation of remediation criteria and technologies may be possible at that time due to the availability of information about the future use of the site and site release/license termination strategy. Remediation options may include passive technologies (such as monitored natural attenuation) or aggressive technologies (such as removal of soil or bedrock.)

2
DETERMINING REMEDIATION OBJECTIVES AND CRITERIA

Projecting the amount of remediation that may be required is an important factor in remediation decision making. Before soil and groundwater characterization data can be used to determine what amount of remediation (if any) is needed and how effective a remediation option is expected to be, qualitative and numerical objectives and criteria for the remediation need to be defined. These objectives and criteria should be determined prior to any leak or spill event as part of the site's groundwater and soil remediation protocol (i.e. per NEI 07-07, Objective 1.4a).

2.1 Defining Remediation Objectives

***Guidance Statement 2.1*: Define remediation objectives.**

Remediation objectives, or the ultimate goals of any remediation, should be defined in the site's groundwater and soil remediation protocol. Remediation objectives may be dose based, qualitative, or radionuclide concentration based. For example, qualitative remediation objectives may include considerations such as re-establishing integrity of groundwater and soil resources or preventing off-site migration of contamination during operation. Acceptable time-frame for remediation to be completed should also be included in the remediation objectives. Remediation objectives should consider input from NRC and other interested stakeholders. The overarching considerations that should be included in the decision-making objectives are:

1. Potential for off-site migration of contamination following an inadvertent release
2. Potential impacts to decommissioning planning and costs, such as increases in contaminated materials requiring disposal at decommissioning
3. Potential to exceed site release criteria at license termination
4. Potential impacts to plant operation and business practices

2.2 Defining Site-Specific Investigation Criteria

***Guidance Statement 2.2*: Establish site-specific investigation criteria that will be used to evaluate the outcome of initial leak or spill response.**

The site-specific investigation criteria will be used to assess any residual radioactivity remaining in soil or groundwater after the initial cleanup or other response to a leak or spill event. The investigation criteria should be defined so that any residual radioactivity that does not exceed the investigation criteria will not impact decommissioning or groundwater and thus will not require further remediation evaluations. If the investigation criteria are exceeded, then the plant should continue on to further remediation evaluations.

The investigation criteria will bound situations where initial clean-up of a leak or spill may be adequate to ensure residual radioactivity will not impact decommissioning or groundwater. For example, if accessible, the initial response to a contamination event from a leak or spill may result in the removal of most, if not all, of the contamination. If this is the case, the residual radioactivity at the location of the leak or spill may be a small fraction of the site release criteria applicable at decommissioning. In this case, there is no need for immediate remediation in the affected area and therefore there is no need to perform a remediation evaluation.

The following radioactivity levels or programmatic standards provide examples of criteria that can be considered by each site in the development of their site-specific investigation criteria:

- Environmental Lower Limit of Detections (LLDs) defined in the site's Radiological Environmental Monitoring Program (REMP)
- Small fraction of the draft or actual site release limits developed per Guidance Statement 2.3 [See the Multi-Agency Radiation Survey & Site Investigation Manual (MARSSIM, Reference 14 for additional information) decommissioning survey guidance.]
- "Free Release" Limits defined by the site Radiation Protection Program
- Small fraction of the effluent concentration limits per site specific ODCM/ODAM
- Analysis sensitivities indentified through the implementation of NEI 07-07 Objective 1.3c.

2.3 Defining Draft Site Release Limits

***Guidance Statement 2.3*: Determine draft site release limits for soil and groundwater. These draft site release limits define the allowable concentrations in soil and groundwater that meet the NRC site release criteria at license termination.**

Draft site release limits will be used to determine whether remediation evaluations are needed, and if so, the criteria to be used in the evaluation of potential remediation scenarios and technologies.

An operating plant site has a number of options in determining the draft site release limits to be used in remediation evaluations. Draft site release limits that correspond to the NRC Site Release Criteria of 25 mrem/year (0.25 mSv/yr) needs to be developed for both soil and groundwater. If contamination in both soil and groundwater exist, the sum of fractions method can be used to determine appropriate allotment of dose to each contaminated media. Some of the options for determining the draft site release limits for soil and groundwater include:

Soil:

- Option 1 (Soil): Utilize NRC published generic Screening Values for Soil. Although conservative, these may be usable in remediation evaluations to provide a bounding estimate of any required remediation. This option avoids the effort to develop site specific DCGLs.
  - Option 1A (Soil): If a site anticipates groundwater contamination at time of decommissioning, the soil may need to be remediated to lower site release limits. The site can account for this potential contamination in groundwater at decommissioning and determine more conservative draft site release limits for soil by adjusting the NRC screening values.
- Option 2 (Soil): Use site specific DCGLs developed by another power plant that has been decommissioned such as Big Rock Point, Connecticut Yankee, Maine Yankee, Rancho Seco and Yankee Rowe. DCGLs determined by another power plant site being decommissioned could provide values that are applicable to the conditions and expected future use of the site being evaluated. This option, although saving the expense of actually calculating the DCGLs may involve effort to justify that the site specific parameters of the decommissioned plant reasonably represent the conditions at the operating plant site.

Groundwater

- Use site specific DCGLs developed by another power plant that has been decommissioned. Alternatively, site specific DCGLs can be determined as described below.

Soil and Groundwater

- Calculate site specific DCGLs for soil and groundwater using numerical models such as RESRAD. This option can provide less conservative DCGLs which reflect the specific conditions at a site and/or more realistic site future use scenarios than the Resident Farmer Scenario assumed by the NRC screening values. The disadvantage of this option for an operating plant is that it likely will require the collection of a great deal of computer model input information and technical labor resource to understand and run the computer model.

In all cases, the basis of the draft site release limits that are to be used by the plant performing a remediation evaluation needs to be compared to the plant's actual situation so that any limitations and/or conditions on the results of the remediation evaluation are understood.

The process described in Section 3.6 that follows evaluates current and future concentrations and the extents of groundwater contamination to determine if groundwater and/or soil remediation will be required. If remediation will be required, the process is continued with the evaluation of remediation technologies and costs for remediation during operation and decommissioning. Guidance for the evaluation of remediation technologies and costs are provided in Chapter 4 and 5.

3
CHARACTERIZATION OF SOIL AND GROUNDWATER CONTAMINATION

If soil or groundwater contamination is discovered on a site, or if a leak or spill leads to soil or groundwater contamination, the source must be identified and managed. Once the source is managed and initial clean up actions have been completed, it must be determined whether residual radioactivity exists and if further remedial actions should be evaluated. This chapter provides guidance for characterizing a site's soil and groundwater contamination.

3.1 Responding to Unintentional Groundwater and Soil Contamination Events

***Guidance Statement 3.1*: Once initial leak or spill response is complete, survey the area to determine if residual radioactivity exists.**

***Guidance Statement 3.1a*: If residual radioactivity is below the investigation criteria determined in Guidance Statement 2.2, further remediation evaluations are not required.**

***Guidance Statement 3.1b*: If residual radioactivity is below the draft site release limits defined per Guidance Statement 2.3, further remediation evaluations are not required.**

When evaluating the extent of clean-up activities required, affected media left in place should be sampled and compared to concentrations corresponding to the investigation criteria defined per Guidance Statement 2.2 and 2.3. If the residual radioactivity is less than these values, additional clean up or remediation evaluations need not be considered. Should the plant still wish to evaluate remediation options, the guidance in Chapter 4 and 5 can be consulted. If the residual radioactivity exceeds the investigation criteria, characterize the current and future extent of the contamination to determine if site release limits will be exceeded at the time of decommissioning.

3.2 Understanding the Current Extent of Contamination

If radioactivity in excess of the draft site release criteria is present in soil or groundwater after the spill response is complete, or when residual radioactivity not previously assessed is detected, the current extent of contamination in soil and groundwater must be known in order to provide input to the remediation decision making process. The following sections provide guidance for the characterization of the soil and groundwater contamination.

<u>Guidance Statement 3.2</u>: Characterize the extent of soil and groundwater contamination.

Initial characterization of soil and groundwater for the presence of radiological contamination will most likely focus on the water table (shallow) aquifer, which will generally be closest to the contaminant sources. If contamination is detected, further characterization will likely be required. This effort may include additional wells drilled in the shallow aquifer to delineate the extent of the contamination. If further contamination is confirmed, additional wells may be drilled in underlying strata to characterize the vertical distribution and movement of the contaminants. Care must be taken when drilling and constructing the wells to prevent hydraulic communication and potential contaminant transport between aquifers.

If characterization surveys are to collect the information needed to support remediation assessments, a carefully designed survey plan is needed. One of the key parts of designing the measurements and sampling of an effective survey plan is to establish and document Data Quality Objectives (DQOs), or an equivalent strategy to be used to directly determine the extent of soil/bedrock contamination. This process is described in detail in Chapter 6 of the EPRI Groundwater Protection Guidelines (Reference 2). The survey may include sampling to determine the horizontal and vertical extent of the contamination. The collection of relevant hydrogeological information may also be necessary to allow modeling of the transport of the radionuclides through groundwater and subsurface soil.

3.2.1 Site Conceptual Model

The Site Conceptual Model (SCM) is discussed in the EPRI Groundwater Protection Guidelines (Reference 2), Guidance Statements 4.1 and 7.5b. It is also addressed, in concept, in NEI 07-07 (Reference 1). This model is a useful tool for the documentation and understanding of the potential for movement of contamination in the groundwater under a site and the impact of any remediation on nearby systems, structures, and components.

3.2.2 Information Available from the Groundwater Monitoring Program

A significant amount of information may be available from the site's ongoing groundwater monitoring program concerning a site area being evaluated for remediation. Relevant information collected as part of the site’s groundwater monitoring program could include:

- Information collected in the site’s 10 CFR 50.75(g) file related to the response to prior spills or other contamination incidents.
- Groundwater sample analysis results from the site’s groundwater monitoring program
- Evaluations of the effects of site effluents may have been performed per NEI 07-07 Objective 1.4(c.).

3.2.3 Information from Direct Measurements

Depending on the amount of information that has been collected as part of groundwater monitoring program, additional information may be needed to allow an estimation of the contaminated area being evaluated for remediation. For example, information about soil and bedrock contamination is important to understanding current and future groundwater radionuclide concentration trends. The type of information needed depends on the method to be used to prepare the estimate. The first types of method to be discussed are those using direct measurements to determine the horizontal and vertical extent of the contamination.

Determining the extent of soil and bedrock contamination with direct measurements may be relatively expensive due to the large number of samples needed and the equipment and labor required. Additionally, access to the contamination areas for sampling or measurement may be precluded by the presence of buildings or equipment. The indirect determination methods described in Section 3.2.4 may be a more cost effective method of estimating the size of the contaminated area.

3.2.4 Indirect Estimation of the Current Extent of Contamination

As discussed above, the projected location of subsurface contamination may make sampling a risk to the safe operation of the plant and/or cost prohibitive. Also, the characterization effort needed for remediation evaluations during the operation of the plant are not site release surveys and therefore do not need to be performed to the same accuracy required during decommissioning. This means that the sampling required during decommissioning is not necessarily required for operating plant remediation evaluations. Indirect estimates of the extent of contamination may be sufficient to support remediation decision making.

3.2.4.1 Use of Modeling to Estimate the Extent of the Soil Contaminated Area

There is a number of modeling tools (the RESRAD dose modeling computer code being an example) that have the ability to calculate groundwater radionuclide concentrations for given soil concentrations and a known or estimated size of the contaminated area. For a site where the groundwater concentrations have been determined by the groundwater monitoring program, a modeling tool may be usable in determining an estimate of the extent of the source area for the groundwater contamination by varying the size of the contaminated area (horizontal and vertical or "volumetric" extent) assumed by the modeling tool until the actual groundwater concentrations are obtained by the code calculation.

As an alternative, if a fate and transport model has been prepared for a site (Per Guidance Statement 4.9 [ELEVATED] in Groundwater Protection Guidelines [Reference 2], it can be used to estimate radionuclide concentrations and the volumetric extent of the contaminated area. This information can help target potential source areas where additional characterization efforts may help to identify the volumetric extent of soil contamination. Similar information may be available from a site conceptual model that may have been prepared for the site. The site conceptual model is based on a less detailed analysis of the site hydrology and may not provide as much information as would a fate and transport model. The EPRI Groundwater Monitoring Guidance Report (Reference 9) and the EPRI Groundwater Protection Guidelines (Reference 2) contain additional information on site conceptual models and fate and transport models.

Some amount of soil sampling or other measurements of soil radionuclide concentrations may be needed to improve the accuracy of the models' calculation result.

3.2.4.2 Effect of Multiple Source Areas

Some of the techniques discussed in the previous section may be limited to modeling the level of groundwater contamination from a single source area. If a number of separate source areas could be contributing to the groundwater contamination measured in a particular well, additional information may be required to allow the estimation of each source area using a modeling tool and monitoring well sample results. This additional information could be in the form of soil sample results for each area and/or an estimate of the volumetric extent of the area contaminated.

3.3 Evaluating the Potential for Off-site Migration

***Guidance Statement 3.3*: Evaluate the potential for contamination to migrate off-site prior to the time of decommissioning.**

The process of characterizing the extent of contamination and determining the mechanisms for groundwater transport at a site will allow the plant to determine if the groundwater contamination may migrate off-site at any time before decommissioning. If it is likely that contamination will migrate beyond utility property, maintaining community relations may well contribute to decisions on remediation that are not the subject of regulatory requirements. Off-site migration should be prevented. If it is likely that contamination will migrate off-site before decommissioning, then remediation should be evaluated during operation to prevent such migration.

3.4 Understanding the Future Extent of Contamination

In order to determine whether remediation may be required at the time of decommissioning, the future extent of the soil and groundwater contamination at the time of decommissioning must be determined. By comparing the future concentrations of radionuclides in soil and groundwater to the draft site release limits (determined per the guidance in Chapter 2), the utility can determine if remediation will be required. This estimation also provides the plant with information needed to evaluate remediation options based on types and volume of media to be remediated and the location of the contamination.

***Guidance Statement 3.4*: Estimate the extent of soil and groundwater contamination at the time of decommissioning**

In order to model the future extent of contamination and determine if the contamination will meet site release criteria at the time of decommissioning, the time to decommissioning must be defined. If the plant does not currently have a defined time to decommissioning, define a time based on the current project date of shutdown (based on current operating license) plus 10 years for decommissioning. This estimation will provide a reasonable basis for the evaluation of remediation options in the case that the operating license of the site is extended and decommissioning of the site occurs further in the future.

To determine the future extent of contamination, the following should be considered:

- Modeling the migration of radionuclides over time
- The effect of radioactive decay on the concentrations of the radionuclides
- The effect of any remediation actions that are taken during the operation of the plant

The following sections provide information on the determination of the future extent of soil and groundwater contamination.

3.4.1 Determining the Transport of Contamination

There are a number of potential sources of information and methods to model the transport of contamination over time, from the remediation evaluation performed during plant operation until the decommissioning of the plant. Some of those sources and models are discussed below.

Reports of previous hydrogeologic investigations of the site should be examined. These reports may provide site-specific information regarding the direction of groundwater flow. The reports may also describe the geologic materials that underlie the site and provide estimates of the rate at which they transmit groundwater. These parameters are important to the understanding of the direction and rate of contaminant transport. Assumptions and conclusions of the hydrogeologic investigations should be verified following the completion of site construction for validity. (See Guidance Statement 4.3a [BASELINE] in the EPRI Groundwater Protection Guidelines [Reference 2].)

Once the current extent and radionuclide concentrations of a contaminated area has been estimated, consider using a modeling tool such as RESRAD, MODFLOW, or BIOSCREEN to predict the future soil and groundwater concentrations.

Modeling tools such as those listed above can calculate the groundwater concentrations over time for a given volumetric amount of contaminated soil and initial soil radionuclide concentrations. These concentrations may have been determined by actual measurements or estimated as discussed in Section 3.2.4.1. Once a groundwater concentration trend over time is determined, the model can be run again using the groundwater concentrations obtained to determine the corresponding soil concentrations over time.

3.5 General Considerations for the Assessment of Contamination

Listed below are several additional factors that may be considered during the assessment of radionuclide contamination in soil and groundwater:

- The presence and involvement of multiple aquifers
- The expected behavior, over time, of an unstable contaminated area (i.e. groundwater plume is not moving in a consistent pathway). This may be a simple projection or involve the need for advanced modeling depending on the contamination levels involved.
- Nuclear safety considerations, e.g., the impact to safety-related equipment, and the potential for unplanned limiting conditions for operation as defined in the NRC standard technical specifications (References 25 thru 29).
- The impact of operating plant on adjacent new plants, in terms of migration of contamination

3.6 Comparing Characterization Data to Site Release Limits

***Guidance Statement 3.6*: Compare the radionuclide concentrations that are projected to remain in the soil and groundwater at the time of decommissioning (determined per Guidance Statement 3.4) to the draft site release limits (determined per Guidance Statement 2.2). If the projected radionuclide concentrations are below the draft site release limits defined per Guidance Statement 2.2, further remediation evaluations are not required.**

If the future radionuclide concentrations do not exceed the draft site release limits and the contamination will not migrate off-site before decommissioning, neither remediation nor further remediation evaluation is required. However, the plant may wish to consider remediation based on other criteria (i.e. stakeholder or regulatory concern). If the future radionuclide concentrations do exceed the draft site release limits or if the groundwater contamination may migrate off-site before decommissioning, remediation evaluations should be conducted. This evaluation will be discussed in Chapters 4 and 5. Alternatively, a site has the option to perform a remediation evaluation as described in Chapters 4 and 5 in all cases, if they so desire.

3.7 Define Remediation Criteria

***Guidance Statement 3.7*: Define remediation criteria.**

For remediation that will be conducted at the time of decommissioning, the remediation objective is to reduce contamination levels to be less than or equal to the draft site release limits defined per Guidance Statement 2.2. As such, the draft site release limit serves as the remediation criteria.

For remediation that will be conducted at any time before decommissioning, the projected time to decommissioning and site release should be used to calculate a remediation criteria. By using the changes to the soil and groundwater concentrations over time determined by the process discussed in Section 3.4.1, the soil and ground water remediation criteria at the time of the remediation evaluation can be determined. The calculations discussed in Section 3.4.1 take into account:

- The redistribution of contamination driven by precipitation through the soil and into the groundwater during the remaining time that the plant is operating

- Other effects such as natural attenuation reducing radionuclide concentrations through migration via groundwater aquifers
- Radioactive decay of the radionuclides in soil and groundwater over time

Due to such natural attenuation, remediation conducted during operations may be performed to higher limits than remediation conducted during decommissioning.

Remediation criteria should be defined for soil and/or groundwater as appropriate. These remediation criteria will be used to assess the potential effectiveness of remediation strategies. Once a remediation strategy has been developed and implemented, the remediation limits can be used to assess the success of the remediation.

3.7.1 Defining the Area that Requires Remediation

In order to evaluate the technical and cost effectiveness of remediation during operation and at the time of decommissioning, the relative amounts of remediation required at both times needs to be determined. Determine how much groundwater and/or soil exceed the remediation criteria defined in Section 3.7 or other applicable criteria (driven by remediation objectives defined in Section 2.1). For groundwater, the vertical and horizontal contamination plumes should be evaluated. For soil or other geological media, the vertical and horizontal contaminated volume should be evaluated.

For a contaminated area where more than one medium exceeds the applicable limit, the media which results in the highest volume of remediation will need to be determined. This bounding volume would then be used in the remediation evaluation.

An example of this is for an area of contamination where both the soil in the source area and the groundwater in the aquifer below and/or down-gradient of the source area exceed the remediation criteria or draft site release limits. Removal of only the soil that exceeds limits above the water table may not result in groundwater concentrations that meet the site release limits due to the radionuclides being retained by the soil in the saturated zone. In this case, remediation of the soil in the saturated zone or a passive technique such as natural attenuation may be needed to meet the groundwater limits at the time of decommissioning.

4
SELECTION AND EVALUATION OF VIABLE REMEDIATION TECHNOLOGIES AND OPTIONS

Once the need for remediation has been established, remediation strategies will need to be evaluated and implemented. The remediation strategies may include passive remediation (i.e. monitored natural attenuation) or aggressive remediation (i.e. removal of soils, pumping of groundwater, etc.) during operation or decommissioning. Factors such as operational safety, effectiveness of remediation, and cost of remediation should be included in the evaluation of each remediation strategy. Viable remediation options that could be used to achieve the site release limits for a contaminated area will likely vary depending on the hydrogeological conditions and radionuclide concentrations present in that area. This chapter will discuss the various remediation options and how they may apply to various site specific situations.

***Guidance Statement 4.1*: Evaluate and select viable remediation strategies for meeting remediation objectives. Both remediation during operation and remediation during decommissioning should be considered in order to make informed decisions about when to implement remediation.**

4.1 Evaluation of Viable Remediation Options

There are many factors that affect the ability to remediate an area during the operation of the plant so that the site release limits are achieved at decommissioning. In order to determine viable remediation options for the situation being evaluated each technology that may be viable during operation and at the time of decommissioning is evaluated based on the following factors:

4.1.1 Impact on operations, reactor safety, and occupational safety

The location of the contaminated area will impact the types of remediation strategies that are viable and the timing of the remediation. Assess the contamination location with respect to systems, structures, and components that may impact remediation. For example, if a contaminated area is located under an SSC (e.g., including subsurface utilities), media removal options may not be possible during operation without impacting operations and reactor safety. Natural attenuation or pump and discharge options would be included with those evaluated in this situation. Conversely, if removal of the contaminated area is unobstructed by structures or equipment, removal can be included with the options evaluated. The availability of adequate space to conduct remediation without impacting operability and reactor safety should be considered.

Evaluate remediation options for their potential impact on operations, reactor safety, and occupational safety. Select options that will not adversely impact these factors outside of acceptable risks. The ability to conduct the remediation during scheduled outages or at the time of decommissioning to minimize impact on operations and reactor safety should be considered.

4.1.2 Effectiveness and ability to meet remediation limits

Evaluate and select remediation options that will meet remediation objectives (Guidance Statement 2.1) and remediation criteria (Guidance Statement 3.7). Acceptable time-frame for remediation should also be considered.

Whether the contamination exists in the soil and/or groundwater, the kinds of radionuclides, and radionuclide concentrations will impact which remediation technologies are applicable.

The extent of contamination (vertical and horizontal) in soil and/or groundwater and whether this contamination may migrate off-site will also impact the applicability of remediation options.

4.1.3 Radwaste generated

The types and amount of radioactive waste that will be generated during the remediation should be considered. There should be an acceptable storage strategy or disposal strategy for the waste forms generated. For example, if liquid radwaste is to be generated, a plan for permitting and releasing this liquid radwaste may be needed. If solid radwaste is to be generated the available pathways for the solid radwaste needs to be considered. For example, in the U.S. most plants do not have a disposal pathway for Class B/C waste. If the radwaste generated falls into the category of Class B/C waste the appropriate storage or disposal strategy needs to be developed. Also, any cost associated with radwaste storage or disposal needs to be factored into the cost evaluation for each remediation option.

At least one best case scenario for remediation during operation (if possible) and at least one best case scenario for remediation during decommissioning should be developed.

4.2 Example Remediation Options to Consider

The following sections provide examples of remediation technologies and additional guidance for evaluating each for their technical viability to various contamination situations. For each of the following remediation options, three qualitative factors will be given as follows:

- *Potentially Affects the Operation of the Plant:* Yes/No

  This factor will generally be "Yes" when the remediation option is invasive or involves some removal of media or other physical activity. This factor will generally be "No" if the option is passive.

- *Radionuclides for which Remediation Option could be Effective*:

  The rate that radionuclides travel through soil and bedrock is highly affected by the type of media present and the distribution coefficient (K_d) of the radionuclides present in that media.

  An example is an area where only Co-60 contamination is detected in clay-like soil. The movement of this contamination through the soil to the groundwater would be projected to be very slow in this situation. An option such as pump and discharge of groundwater will likely have little effect on the levels of Co-60 contamination over time since the radionuclide will be held tightly in the soil. Although removal would be an option evaluated, due to the lack of mobility of the Co-60 contamination, delaying the remediation until decommissioning will likely result in no increase in the volume of material requiring remediation nor off-site migration of contamination.

  A very different situation would be for an area where only tritium (H-3) contamination is present in sandy soil. As the H-3 moves through soil in the same manner as water (i.e., H-3 has little or no affinity for the granular media), the contamination would be expected to move very quickly through the vadose and saturated zones. Off-site migration may be a greater concern for such mobile radionuclides. An option like pump and discharge would likely be very effective and would be included in the options considered.

  The radionuclides that will be identified under this factor will generally fit into one of the two groups given below. It should be noted that the type of soil present in the contaminated area will affect the mobility of radionuclides. Table 2-3 of the EPRI Groundwater Monitoring Guidance Report (Reference 9) provides "Transport Factors" in the form of K_ds for a number of elements and different type of soil. As the chemical element for a radionuclide determines its' affinity for soil, all radionuclides that have the same chemical element are expected to exhibit the same degree of mobility in soil:

  - Group 1: Radionuclides that are relatively mobile through soil present in the contaminated area and with high solubility in groundwater. Radionuclides in this category generally have K_d values that are below 50. Most of the radionuclides in this group (except H-3) can be removed by processes such as ion exchange. The characteristics of H-3 are different than the rest of the radionuclides in this group as it is not removable from water by any process that is practical to a power plant. Radionuclides in this category are more likely to be entrained in groundwater.
  - Group 2: Radionuclides that are relatively immobile. Radionuclides in this category generally have K_d values that are 50 or higher. Radionuclides in this category would not be expected to migrate through soil to groundwater making delayed remediation a viable if not optimal option. Radionuclides in this category are more likely to be bound in the soil and manifest less in groundwater.

- *Types of Radioactive Waste that could be Generated by this Option:*

  Some of the remediation options would be expected to create solid radioactive waste that would require disposal and/or a liquid radioactive waste that would need to be treated/ monitored prior to discharge. For each remediation technique the potential types of radioactive waste will be listed.

Table 4-1 list a number of remediation technologies and which group(s) of radionuclides each would be expected to provide effective remediation.

4.2.1 Monitored Natural Attenuation

(Unless specified otherwise, the following information was taken from EPRI Report No. 1016764, "Technical Guidance for Monitored Natural Attenuation at Nuclear Power Plants" [Reference 19].)

Potentially Affects the Operation of the Plant: No

Radionuclides for which Remediation Option could be Effective: Group 1 and Group 2

Types of Radioactive Waste that could be Generated by this Option: None expected

Monitored Natural Attenuation (MNA) is a non-intervention remediation approach that relies on natural processes such as dispersion and radioactive decay to reduce or attenuate contamination in soil and groundwater. MNA achieves cleanup goals through the natural reduction of contaminant concentrations. MNA is a suitable alternative when the contamination source is under control and cleanup goals will be achieved within a reasonable timeframe.

For a site to be suitable for an MNA project, a number of factors must be considered. A list provided by EPA (Reference 20) includes the following:

- Can the contaminants be effectively remediated through natural attenuation processes?
- Is the contaminant plume stable (i.e. moving in a consistent pathway), and is it expected to remain stable over the remediation period?
- Has the source of contamination been eliminated or can it be controlled over the duration of remediation?
- What is the nature of the demand for the affected resource (soil and groundwater) over the time period that the MNA project is in effect?
- Are reliable institutional controls available for the site, and is the institution identified as being responsible for the site economically sustainable over the duration of the project?

For a site to be evaluated for the suitability of MNA, it must be accurately modeled in terms of contaminant migration, with a clear and full understanding of near-site receptors and near-site land and water use. This information is an important input to decisions on remediation alternatives and to the evaluation of the effectiveness of an ongoing MNA project. A site being recommended for MNA must have historical data that shows declining levels of radioactive contaminants in soils and groundwater. Characterization data that demonstrate a stable or diminishing groundwater plume will also likely be required for a site to be considered suitable.

A key objective of an MNA program is compliance with current and anticipated future regulatory criteria. Changes in regulations and allowed environmental contaminant levels should trigger the re-appraisal of an MNA project. Another important objective of an MNA project is that natural attenuation proceeds according to expectations, i.e., that the contaminant plume is not migrating off-site, or if it is, that contaminant levels are within anticipated and acceptable limits. A related objective is that there is no current or future unacceptable risk to receptors of interest.

One of the key considerations is the expected timeframe for the MNA project because institutional controls will need to be maintained throughout that period. Future land use on the site (i.e., residential, recreational, or industrial) must also be considered as part of the remedial objectives due to the impact on the local community.

Many active soil and groundwater remediation options are available that may be used: a) as an alternative to MNA, b) in conjunction with MNA to make the MNA option feasible, or c) as a contingency measure in the event that natural attenuation is not proceeding as planned.

Monitoring is continually used to evaluate the effectiveness of MNA during the implementation phase of the project, and to determine when the endpoint or goal has been achieved. The magnitude of the effort for the monitoring program should not be underestimated, since the program must measure the extent of a dynamic, contaminated plume in three dimensions. The degree of effort will depend on many factors, including the quality and quantity of monitoring done prior to the MNA feasibility study, the size and chemical/radiological nature of the plume, the complexity of the site and the affected aquifer(s), and the extent of engineered remedies.

Due to the affinity of the soil in the saturated zone for the radionuclide of interest, monitored natural attenuation may not reduce the concentrations in groundwater to the site release limits when the final status survey is scheduled to be conducted during decommissioning. In this case, although MNA has resulted in benefit, additional remediation, possibly in the form of soil removal would be required at decommissioning to achieve the site release limits. The volume of soil to be removed at decommissioning could be the same or more than that required if immediate removal had been performed. This could result in an overall increase in cost if remediation were delayed until decommissioning.

A contingency plan is needed in the event that the objectives of the MNA program are not being met. Caution should be taken to set the triggers for the contingencies such that seasonal fluctuations or sampling variability do not trigger a contingency when one is not warranted.

4.2.2 Augmented Monitored Natural Attenuation

Potentially Affects the Operation of the Plant: No

Radionuclides for which Remediation Option could be Effective: Group 1 and Group 2

Types of Radioactive Waste that could be Generated by this Option: None expected

With Augmented Monitored Natural Attenuation, one or more of the natural attenuation mechanisms would be augmented (i.e. enhanced) with treatment. For example, adsorption of radionuclides to the aquifer matrix could be decreased and dispersion increased by injecting surfactants or chelating agents in areas of high contaminant concentration. Pump and discharge could then be used to remove the mobilized radionuclides and reduce the volume of contaminants to be remediated by MNA. Conversely, soil or contaminant chemistries can be adjusted so that radionuclides can be held in place by the soil and decay away with decreased risk of off-site migration. This form of augmented MNA would require that the soil and contaminant chemistries and contaminant flow path are well understood.

4.2.3 Pump and Discharge

Potentially Affects the Operation of the Plant: No

Radionuclides for which Remediation Option could be Effective: Group 1

Types of Radioactive Waste that could be Generated by this Option: Liquid Radwaste (Extraction Water) to be monitored and discharged

Pump and discharge as a method of groundwater remediation generally involves the following approach. Wells designed as extraction points are constructed so as to be screened in the saturated zone in the area of contaminated groundwater. Submersible pumps are placed in the wells and used to pump contaminated groundwater to monitoring tank where samples can be taken for the purposes of quantifying the amount of radioactivity discharged. The extracted water is then discharged through the normal plant liquid effluent discharge pathway.

A properly designed pump and discharge system can redirect groundwater flow from the source area to the extraction wells rather than allowing it to flow to down-gradient areas. This keeps the contamination from spreading and contaminating or increasing the contamination levels in down-gradient areas. As pumping continues, contamination levels in the source area and in groundwater can be reduced as the overall source term of the contamination is reduced.

4.2.3.1 Discharge Point for Extraction Pumping Options

For areas of groundwater contamination where the radionuclide concentrations are well known and/or consistent, discharge through an approved discharge point without the use of a monitoring tank may be allowed. An alternate approach which has been used for the discharge of contaminated groundwater from a containment mat sump is to pump directly to the plant discharge point through an in-line composite sampler that determines the long term average radionuclide concentration of the effluent for use in effluent reporting.

In another case study at Connecticut Yankee, continuous discharge of contaminated extraction water up to a flow rate of 400 gpm was allowed during the decommissioning of the plant. The quantity of radioactivity discharged was based on periodic samples of the extraction water. A weir separator and bag filters were used to insure that the suspended solids level of the extraction water was below the NPDES permit limits.

If an approved discharge pathway for groundwater does not exist, changes to a plant's discharge permit may be needed.

4.2.4 Pump and Treat

Potentially Affects the Operation of the Plant: No

Radionuclides for which Remediation Option could be Effective: Group 1

Types of Radioactive Waste that could be Generated by this Option: Filter Cartridges and Ion Exchange/Carbon Media plus Liquid Radwaste (Extraction Water) to be monitored and discharged

Pump and treat is similar to pump and discharge as a method of groundwater remediation except that the level of treatment is generally more extensive. Wells designed as extraction points are constructed so as to be screened in the saturated zone in the area of contaminated groundwater. Submersible pumps are placed in the wells and used to pump contaminated groundwater to feed tank or directly through the processing equipment to monitoring tanks where samples can be taken for the purposes of quantifying the amount of radioactivity discharged. The treated water is then discharged through the normal plant liquid effluent discharge pathway.

A properly designed pump and treatment system can redirect groundwater flow from the source area to the extraction wells rather than allowing it to flow to down-gradient areas. This keeps the contamination from spreading and contaminating or increasing the contamination levels in down-gradient areas. As pumping continues, contamination levels in the source area and in groundwater can be reduced as the overall source term of the contamination is reduced.

Pump and treat technology is effective when the contaminant can be removed from the extracted groundwater (i.e., Sr-90 removed by ion exchange beds). For H-3 contamination in groundwater, this method would not be effective as no cost effective methods currently exist to remove H-3 from water.

4.2.5 Engineered Confinement

Potentially Affects the Operation of the Plant: Yes, if confinement installation affects plant systems, structures, or operator access

Radionuclides for which Remediation Option could be Effective: Group 1

Types of Radioactive Waste that could be Generated by this Option: Filter Cartridges and Ion Exchange/Carbon Media plus Liquid Radwaste (Extraction Water) to be monitored and discharged if Pump and Treat or Pump and Discharge are needed to make the Engineered Confinement effective.

Engineered confinements are structures or processes used to block the movement of groundwater and are typically used in unconsolidated sediments.

A contaminated area being evaluated for remediation may be under a structures or plant systems such that removal without impacting the safe operation of the plant is not practical. In this case, in order to keep the area of contamination from spreading, an engineered confinement structure may be a viable option. The engineered confinement would be used to keep the contaminated groundwater confined to a certain area so as to halt its spread to down-gradient areas or to allow other remediation techniques such as pump and discharge such that the total radioactivity source term can be reduced, potentially to the point of the remediation limits required at the time of decommissioning. Another potential benefit of the use of physical barriers is that they can slow or stop the movement of contaminants and therefore allow for longer time for decay and/or the reduction of down-gradient radionuclide concentrations through MNA.

It may be necessary to pump groundwater out of the confined area to insure that hydraulic pressures and leakage through the confinements is not moving contamination through the engineered barrier. To increase the effectiveness of some types of confinements, pumping of upgradient water with extraction wells may be useful.

Examples of engineered confinement structures are:

- Sheet pile walls: Thick metal sheets are driven or vibrated into the soil often down to another restriction of groundwater flow by an impermeable barrier, such a structure, a clay zone or bedrock to effectively impede groundwater flow.
- Grout Curtains: Grout curtains are thin, vertical, grout walls constructed by pressure-injecting grout directly into the soil at closely spaced intervals, thus forming a continuous wall or curtain. Typical grouting materials include hydraulic cements, clays, bentonite, and silicates. Polymer grouts are often used for barrier applications as they are impermeable liquids. These types of barriers must reach down to an impermeable barrier to effectively impede groundwater flow.
- Slurry Walls: Slurry walls are subsurface barriers that are poured into trenches cut into the subsurface. A mixture of materials such as soil, bentonite, clay, and water is poured in the trenches as a "slurry." The trenches form a filter cake that serves as a barrier. Slurry walls are used to contain contaminated groundwater, divert uncontaminated groundwater flow, and/or provide barriers for groundwater treatment systems. Slurry walls can be placed at depths up to 200 feet and vary in thickness from 2 to 4 feet. As with barriers discussed above, slurry walls must reach down to another impermeable barrier to effectively impede groundwater flow.
- Freeze Walls: The use of freeze walls involves inserting a row of pipes into the ground. A cooling medium is circulated through the pipes freezing the free and pore water outside the pipe. The frozen area outside the pipes forms columns which grow in diameter until the columns merge to form a frozen wall to prevent flow into or out of the contaminated area. This technique can be used in concert with other confinements such as structures or bedrock and may be the only practical means of confining a contaminated area when the depth to bedrock or other impermeable barrier is great at a site. Due to the operating cost of maintaining a freeze wall for extended periods of time, this technique may be limited to short term application to allow the contamination in the confined area to be removed.

Sheet pile walls and grout curtains were used along with others in order to control groundwater during the Saxton power plant decommissioning.

The Big Rock Point Plant used a slurry wall as a confinement for groundwater during its decommissioning.

Additional information on the use of engineered confinements is contained in Reference 31

4.2.6 Permeable Reactive Barriers

Potentially Affects the Operation of the Plant: No, (assumes barrier is away from plant systems and structures)

Radionuclides for which Remediation Option could be Effective: Group 1

Types of Radioactive Waste that could be Generated by this Option: Ion exchange media used in the barrier

Permeable Reactive Barrier (PRB) technology in the context of address groundwater contaminated with radionuclides involves the engineering of a subsurface zone (chiefly by trenching, mixing, or injection) that can immobilize target radionuclides *in-situ* while allowing groundwater to continue to flow down-gradient through the treatment area. Treatment can be provided by physical, chemical, and biological processes promoted by the type of material (granular or liquid) that is placed, mixed, or injected into the subsurface treatment zone. An effective permeable reactive barrier treatment technology for H-3 not does currently exist.

Permeable reactive barriers may be a viable confinement and remediation option when the source of the groundwater contamination is not accessible (i.e., blocked by plant structures or equipment) and migration of the contamination off-site needs to be precluded or reduced. This method does not in itself remove the source of the groundwater contamination. If the source area is not attenuated to the site release criteria by the time of decommissioning, additional remediation such as soil or bedrock removal may be necessary.

The EPRI Report on "Advanced Technologies for Groundwater Monitoring and Remediation at Nuclear Power Plants" (Reference 21) contains additional information of the use of PRBs for the control of contaminated groundwater.

4.2.7 Soil and Bedrock Removal

Potentially Affects the Operation of the Plant: Yes

Radionuclides for which Remediation Option could be Effective: Groups 1 and 2

Types of Radioactive Waste that could be Generated by this Option: Excavation soil and/or fractured bedrock. Filter Cartridges and Ion Exchange/Carbon Media plus Liquid Radwaste

(Extraction Water) to be monitored and discharged if the excavation area needs to be dewatered to allow for the removal of the soil in a relative dry state.

One method of meeting site release criteria is the removal of the media that exceeds the concentration limits and/or removing the source of the contamination in groundwater when this activity does not affect the safe operation of the plant. This technique can involve the excavation of contaminated soil which is subsequently disposed of as radioactive waste. For bedrock removal, the bedrock would need to be broken up by hydraulic rams or low impact blasting if this could be performed without affecting the safe operation of the plant.

After the removal of soil or bedrock estimated to exceed the applicable remediation criteria (defined in Section 3.7), samples of the perimeter and base of the excavation should be taken to confirm that all media that exceeds the criteria has been removed. Soil that has detectable activity below the applicable remediation criteria can remain, as the radionuclide concentrations in the soil and groundwater will decrease to the site release limits by the time of decommissioning.

Shipping of radioactive waste in granular form (such as soil) requires that the waste being shipped have a minimum of free liquid. Soil located below the water table will need to be dewatered prior to loading into waste boxes for shipment. One method is to dewater the area being excavated prior to beginning the soil excavation. This would allow the soil to be loaded directly into waste boxes for shipment.

If the soil drying is done after the soil has been excavated, any water drained or otherwise removed from the soil needs to be collected and treated appropriately as this water is likely contaminated. Allowing this water to drain back into the ground needs to be carefully evaluated as it may result in the contamination of new areas of the site.

It is preferable to perform remediation during the periods of the year that have lower amounts of precipitation. During these periods, the water table is likely lower and intrusion into the open excavations will be less. This can reduce the total amount of groundwater that needs to be handled during the excavation.

Experience with excavations conducted below the water table has shown problems with excavation sidewall collapse in certain situations. When the side wall of the excavation under the groundwater level consists of unconsolidated sediments, hydraulic forces will push the sidewall material into the open space of the excavation. This may result in an unsafe condition as the surface soil near to the excavation is undercut. It also may result in the removal of additional soil that would otherwise not need to be removed from the excavation. In these situations dewatering of the area to be excavated may be a preferable option.

4.2.8 Soil Mixing

Potentially Affects the Operation of the Plant: Yes

Radionuclides for which Remediation Option could be Effective: Groups 1 and 2

Types of Radioactive Waste that could be Generated by this Option: Excavation soil plus filter cartridges and ion exchange/carbon media plus liquid radwaste (extraction water) to be monitored and discharged if the excavation area needs to be dewatered to allow for the removal of the soil in a relative dry state.

There may be areas of the site where contamination is located below an area of non-contaminated soil due to conveyance by groundwater from an upgradient source or leakage of a buried fluid containing component or piping. In these cases, using soil mixing may be a viable remediation technique.

The NRC has issued guidance concerning compliance with site release limits through the intentional mixing of soil in Regulatory Issue Summary: RIS 2004-08 (Reference 22). The following provides a summary of the content of the RIS concerning the intentional mixing of soil:

Appropriateness of Allowing Intentional Mixing: Although some mixing of uncontaminated and contaminated soils inevitably occurs during the course of a remediation, the NRC had not until 2004 permitted intentional mixing of contaminated soil with non-contaminated soil. In this RIS, the Commission approved the staff recommended options allowing the evaluation for approval of intentional mixing of soil given that the following conditions are met:

- The resultant footprint of the area containing the contaminated soil after license termination should be equal to or smaller that the footprint of the zones of contamination before the decommissioning work begins, and
- Normally only soil from the zones of plant that contained contaminated soil before the start of decommissioning work can be used in the mixing process. That is, clean soil, from outside the footprint of the original zones of contaminated soil, should not be mixed with contaminated soil to lower concentrations. However, in rare cases such as when decommissioning funds are very limited, the use of soil from outside the footprint will be considered by the NRC.

A situation that this approval would save costs is where a large amount of soil is contaminated below the surface by conveyance via groundwater or due to a leaking buried pipe. The soil above the water table or the leaking pipe in this case would contain little or no contamination. The intentional mixing of the soils in a defined footprint where this situation existed could result in an average concentration below the soil DCGLs. Due to the relatively high costs of transportation and disposal of soil, this approach could result in significant savings.

4.2.9 Biological Remediation Options

Potentially Affects the Operation of the Plant: No (assumes biological material being used is located away from plant systems and structures)

Radionuclides for which Remediation Option could be Effective: Groups 1 and 2

Types of Radioactive Waste that could be Generated by this Option: The plants used to extract the radionuclides are typically harvested and incinerated with the residue sent for traditional radwaste disposal

There are other remediation techniques, including bioremediation and phytoremediation, which could be viable for use at a site for a particular contamination situation. Information on these and other potentially useful techniques is included in EPRI Report #1016763 (Reference 21). (All information in this section can be referenced to EPRI Report #1016763, Reference 21.)

Bioremediation can be defined as "the use of naturally-occurring microorganisms or genetically engineered microbes to sequester toxic and radioactive compounds or transform them into less harmful chemical forms." This technology uses microbes to change the mobility (increase or decrease) of contaminants or to transform them into a less-toxic state in soil, water, or sediment. While most of the success with bioremediation has been with uranium, plutonium, technetium, and to a limited degree with strontium, ongoing research is expected to make inroads in the remediation of other radionuclide contaminants. It should be noted that bioremediation has shown the most success with immobilization of radionuclides in soil. At a commercial nuclear power plant site, this might not be a suitable endpoint, and might have to be followed up with additional remediation techniques, such as MNA or pump and treat.

Phytoremediation is an emerging remediation technology that uses plants to contain, degrade, immobilize, or remove hazardous materials present in the soil or groundwater. It has been receiving attention as an innovative, cost-effective alternative to the more traditional treatment methods often used at sites with contaminated soil and groundwater. While phytoremediation is most often used for non-radiological chemical contaminants, it is finding an increasingly greater application to the remediation of radiological contaminants, including tritium. It works by either:

- Storing contaminants in the plant tissues (roots, leaves, and/or stems).
- Converting contaminants into gases that are transpired into the air.
- Sorbing the contaminants onto plant roots.

Two of the more successful variants of phytoremediation are phytoextraction and phytoevaporation. Phytoextraction has proven successful in extracting contaminants such as Cs-137 and Sr-90 onto plant roots at shallow soil depths. Following extraction, the plants are typically harvested and incinerated, thereby removing and extracting the contaminants for traditional disposal. Phytoevaporation has also proven effective for the extraction and evaporation, through plant tissues, of tritium. Phytoremediation processes are best suited to sites that have low to moderate amounts of contamination, which is generally the case with nuclear power plant sites.

All bioremediation technologies are heavily dependent on factors such as the climate, soil type, soil biochemistry, and depth to groundwater at the remediation site, as well as on the chemical form of the contaminant. Significant characterization efforts are needed before choosing and implementing a biological remediation option.

4.2.10 Combinations of the Above Options

Although the remediation options discussed above are generally described as standalone methods, in practice the remediation option chosen to address soil and/or groundwater contamination may be a combination of options. Examples of some potential combination are the following:

- If removal of the contaminated material is not practical without affecting the safe operation of the plant, engineered confinement may be used to stop the spread of the contamination during the operation to the plant. The contaminated material could then be safely removed during the decommissioning of the plant.
- Another method of reducing the spread of contamination during plant operation would be the pump and discharge or pump and treat options discussed above. The difference in this option compared to the first bullet above is that radioactivity is being removed from the contaminated area. If this process does not remove enough contamination from the soil and/or groundwater to meet the site release limits at the time of decommissioning, source removal would be required during decommissioning.
- Another combination of remediation options is to first remove contaminated media during the operation of the plant but not to the levels required at decommissioning. This combination would count on the natural attenuation process that would occur from the time of the remediation to the time of decommissioning to reduce the levels of radionuclides in soil and groundwater to the site release limits at decommissioning. Groundwater monitoring would likely be needed to monitor the progress of natural attenuation and soil and/or groundwater sampling would be needed at decommissioning.

4.3 Summary of Remediation Options

Table 4-1 shows a summary of the remediation options described in this chapter with their potential applicability and the potential impact of their use on the operation of a power plant.

Table 4-1
Summary of Remediation Options

Remediation Option	Potentially Effects the Operation of the Plant	Potentially Effective for Radionuclide Group (See Section 4.2 for Group Definitions.)
Monitored Natural Attenuation	No	Groups 1 and 2
Augmented Monitored Natural Attenuation	No	Group 1 and 2 (Excluding H-3)
Pump and Discharge	No	Group 1
Pump and Treat	No	Group 1 (Excluding H-3)
Engineered Confinement	Yes	Group 1
Permeable Reactive Barriers	No (assumes barrier is away from plant systems/ structures)	Group 1 (Excluding H-3)
Soil and Bedrock Removal	Yes	Groups 1 and 2
Soil Mixing	Yes	Groups 1 and 2
Biological Remediation	No	Group 1

Table 4-2
Options That Could Be Effective for Typical Scenarios

General Description of Contaminated Area	Remediation Options That Could Be Effective (Site Specific Evaluation of Option is Needed)
Area of Soil with Only H-3 from the Group 1 Category of Radionuclides	Monitored Natural Attenuation Pump and Discharge Engineered Confinement Biological Remediation Soil Mixing Soil Removal
Area of Soil with Other Group 1 Radionuclides in Addition to H-3	Monitored Natural Attenuation Augmented Monitored Natural Attenuation Pump and Treat Permeable Reactive Barriers Engineered Confinement Biological Remediation Soil Mixing Soil Removal
Area of Soil with Only Group 2 Radionuclides	Soil Mixing Soil Removal
Area of Bedrock with Only H-3 from the Group 1 Category of Radionuclides	Monitored Natural Attenuation Pump and Discharge Engineered Confinement Bedrock Removal
Area of Bedrock with Other Group 1 Radionuclides in Addition to H-3	Monitored Natural Attenuation Augmented Monitored Natural Attenuation Pump and Treat Permeable Reactive Barriers Engineered Confinement Bedrock Removal
Area of Bedrock with Only Group 2 Radionuclides	Bedrock Removal

5
ESTIMATION OF REMEDIATION COSTS AND COMPARISON OF REMEDIATION COST BENEFITS

5.1 Overview

Guidance Statement 5.1**: *Determine the costs to implement the technically viable remediation options chosen per Guidance Statement 4.1.***

Once the technically viable remediation options are determined, the cost effectiveness of these remediation options needs to be evaluated. The plant should develop cost estimates of each of the technically viable remediation options to determine a) whether it is most cost beneficial to remediate during operation or during decommissioning and b) how the remediation costs will impact decommissioning costs if conducted at the time of decommissioning. This cost estimate should take into account the capital costs of the remediation technology, operating costs, labor costs, and any long term groundwater monitoring costs.

Presentation of the detailed financial analysis that may be needed to support corporate decisions regarding the cost benefit of potential groundwater and soil remediation are beyond the scope of this EPRI guideline. Each corporation will have established methodologies for such financial analysis. The expertise that may be needed for these analyses will likely be present in the corporate finance and treasury organizations. Additional valuable support may be provided by the corporate organizations responsible for nuclear facility decommissioning planning and funds management.

Remediation may require years of activity to be successful and the financial analysis will likely require a detailed cash flow, identifying the cost incurred by year for each of the options considered. For those options involving remediation now or later the establishment of the cash flow will likely be more important to the financial analysis.

The financial analysis that may require additional information, such as:

- Escalation rates for the different types of cost such as labor, equipment, services, transportation, and disposal cost.
- Also the anticipated return on the investments in the decommissioning fund may an important consideration if considering an option of remediation at the time of decommissioning.
- The source of the funds used to support the remediation and the implications to the corporation.

The business decision regarding remediation options will likely require the participation of a number of parties including technical, financial, and regulatory expertise.

The following provide some examples of remediation technologies and their associated cost factors. Table 5-1 shows which costs may apply for the various remediation options. This chapter also provides selected generic unit costs for a number of remediation options.

5.2 Cost of Monitored Natural Attenuation

Long-term monitoring of groundwater quality presents the base case condition and foundation of a MNA closure outcome. The costs associated with MNA can be divided into the following four categories:

- Well Installation – Includes the labor and expenses to advance soil borings and install a permanent monitoring well system. The cost for a monitoring well is highly dependent on the target depth, diameter of well, and type of geologic conditions. In addition, drilling in known contaminated areas require additional technologies to prevent cross-contamination and impact from shallow to deeper intervals.
- Sampling – Includes the labor and expenses associated with the field collection and laboratory analysis required to monitor the nature and extent of the groundwater impacts. Total sampling costs for MNA are derived by multiplying the number of wells included in the MNA program by the unit sampling costs and then by the number of monitoring years that are required before concentrations of radionuclides in groundwater have naturally attenuated to levels that satisfy remedial criteria specified in the LTP.
- Data Management/Modeling – Includes labor costs to compile and analyze groundwater data to evaluate the performance of MNA over the remedial timeframe. Groundwater data are evaluated to ensure site conditions are consistent with initial conditions identified in the conceptual site model. Data is also used to evaluate concentration trends over time in order to verify the additional amount of time necessary to achieve remedial criteria specified in the LTP. Data analysis can be supporting using a combination of analytical and numerical models.
- Reporting – Includes labor costs for preparing routine reports for regulatory agencies and other stakeholders, documenting the results of MNA sampling activities, and presentation of data and results relative to the remedial criteria and timeframe.

It should be noted in Table 5-1 that all of the above listed items are potential cost components for all the remediation options.

Table 5-1
Potential Cost Components of Groundwater and Soil Remediation Options

Potential Cost Components		**Remediation Option**									
	Monitor Ground-water	Natural Attenuation		Bio-Remed-iation	Pump & Discharge	Pump and Treat	Engineered Confinement		PRBs	Media Removal	Soil Mixing
		Monitored	Augmented Monitored				Other Than Freeze Walls	Freeze Wall			
Data Management/Modeling	X	X	X	X	X	X	X	X	X	X	X
Install Monitoring Wells	X	X	X	X	X	X	X	X	X	X	X
GW Sampling & Analysis	X	X	X	X	X	X	X	X	X	X	X
GW Transport Modeling	X	X	X	X	X	X	X	X	X	X	X
Soil Sampling & Analysis	X	X	X	X	X	X	X	X	X	X	X
Extraction Wells (EW)					X	X	X	X		X	X
Extraction Well Operation					X	X	X	X		X	X
Sampling of Discharges					X	X	X	X		X	X
Treatment System (TS) Purchase & Installation				X		X					
Treatment System Operation				X		X					
Package, Ship & Disposal of Waste from TS				X		X					
Confinement Installation							X	X			
Package/Ship/Dispose Waste from Confinement Removal							X	X			X
Operation of Freeze Wall								X			
Installation of PRB									X		
Package, Ship & Disposal of Waste from PRB Removal									X		
Waste: Removal									X	X	X
Waste: Transportation									X	X	
Waste: Disposal									X	X	
Excavate/Mix & Replace Soil											X
Sample Excavation after Removal									X	X	X

5.3 Cost of Pump and Discharge

The main costs associated with the pump and discharge remediation options are:

- Installation of extraction wells
- Any system modifications or additions needed for the collection, sampling and discharge of the extraction water
- Operational labor costs
- Groundwater Modeling and Monitoring

5.4 Cost of Pump and Treat

The use of pump and treat technology can have significant cost in the form of:

- Installation of extraction wells
- Treatment system procurement and installation costs
- Any system modifications or additions needed for the collection, sampling and discharge of the treated extraction water
- Operational labor costs
- Costs associated with the relatively large quantities of low level radioactive waste generated
- Groundwater modeling and monitoring

These costs need to be carefully evaluated when considering the use of this technology.

5.5 Cost of Engineered Confinements

The following types of engineered confinements are available for groundwater remediation:

- Grout Curtains
- Sheet Pile Walls
- Slurry Curtains
- Freeze Walls

Other costs likely associated with this remediation option are:

- Installation of Extraction Wells
- Any system modifications or additions needed for the collection, sampling and discharge of the extraction water
- Operational labor costs associated with extraction, collection, sampling and discharge of extraction water
- Groundwater Modeling and Monitoring
- Operation Labor for Freeze Walls
- Electricity for Freeze Wall Refrigerant Unit

5.6 Cost of Permeable Reactive Barriers (PRBs)

A permeable reactive barrier for use in the remove of a radionuclide (i.e., Sr-90) involves the placement of an ion exchange media wall into the path of the groundwater plume. This wall will capture radionuclides and likely need to be excavated and disposed of as radioactive waste at the time of decommissioning.

In addition to the cost of installing a PRB, other costs likely associated with this remediation option are:

- Installation of Extraction Wells
- Any system modifications or additions needed for the collection, sampling and discharge of the extraction water
- Operational labor costs associated with extraction, collection, sampling and discharge of extraction water
- Groundwater Modeling and Monitoring
- Removal of PRB media when expended or no longer required
- Packaging, shipment and disposal of PRB media
- Sample excavation after PRB media removal to confirm that remediation is complete

5.7 Cost Soil and Bedrock Removal

There are three primary components of the costs of this option:

- The removal of contaminated material from the subsurface can involve a range of techniques from simple excavation of soil to blasting of bedrock to reduced its' size for subsequent loading. Based on the removal of approximately 1.2 million ft^3 of soil during the decommissioning of the Connecticut Yankee plant, cost for the removal and packaging of soil were in the range of $17/$ft^3$ (Reference 23).
- The cost of transportation of remediated material is highly dependent on the distance and mode of transportation to the disposal site. Some sites being decommissioned have found it less costly to ship large volumes of soil and bedrock by train either directly from the site or by transporting the material to a local transloading facility for loading into gondola cars.

  The radionuclide concentrations in soil and bedrock remediation waste have generally been relatively low at plants sites that have been decommissioned. Much of the waste has been below the level that requires DOT packaging. Should this be the case, shipment in soft covered dump trucks or trailer dumps could result in lower transportation costs.
- Waste disposal costs are site specific. Some plants being decommissioned have been able to obtain lower unit costs through volume discounts depending on the volume to be remediated. Each site should use its site-specific cost in the remediation evaluation.

The NRC has granted exempt status for certain very low level waste from decommissioning projects under a 10 CFR 20.2002, "Alternate Waste Disposal Procedure" based on the use of a identified construction debris or hazardous waste disposal site defined in the application. The Big Rock Point site disposed of a very large quantity of very slightly contaminated concrete demolition debris in a Michigan construction debris disposal site in this manner. This type of disposal could greatly reduce disposal costs and transportation costs if the disposal site is closer to the plant than the NRC licensed disposal site.

Soil remediation cost estimates need to consider the method used to perform the excavation. Depending on the type of granular material being excavated, the excavation side wall may need to be angled to provide safe working conditions. This may result in cross contamination of the material in the side wall that would not otherwise need to be disposed of as radioactive waste.

Careful segregation of the excavated materials can minimize this cross contamination. Depending on the level of contamination in the soil being remediated, survey or sampling of the side wall material to be returned to the excavation may be needed.

The use of trench boxes or other barriers on the sides of the excavation can reduce the amount of layback required for the excavation. This approach may also facilitate the excavation by allowing the removal equipment to be placed closer to the excavation.

5.7.1 Restoration Costs

After removal of media under this remediation option, there may be a significant expense required in restoring the excavated area to the required final state. Suitable backfill will be needed that may need to meet some if not all of the following criteria:

- Free of plant related radioactivity or hazardous chemicals (Needs to be verified thru survey and sampling of potential backfill source)
- For remediation while the plant is operating, backfill may need to meet standards defined during plant construction
- If backfill is to be "engineered" to provide a level of radionuclide retention capability, these characteristics will need to be verified thru sampling and testing of prospective backfill materials.

5.7.2 Other Costs

Other costs likely associated with this remediation option are:

- Installation of extraction wells so that soil located below the groundwater table may be excavated in a shippable state
- Any system modifications or additions needed for the collection, sampling and discharge of the extraction water
- Operational labor costs associated with extraction, collection, sampling and discharge of extraction water
- Groundwater modeling and monitoring
- Post-remediation soil sampling to determine that remediation is complete.

5.8 Cost of Soil Mixing

Some of the cost components of the Soil Mixing remediation option are the same as those for Soil Removal except that little or no radioactive waste is created. The following are likely cost components for the Soil Mixing option:

- Soil Removal, mixing and replacement costs
- Installation of Extraction Wells so that soil located below the groundwater table may be excavated in a shippable state
- Any system modifications or additions needed for the collection, sampling and discharge of the extraction water
- Operational labor costs associated with extraction, collection, sampling and discharge of extraction water
- Groundwater Modeling and Monitoring
- Post remediation soil sampling to determine that remediation is complete

5.9 Delayed Remediation

The cost implications for delaying soil and groundwater remediation until facility decommissioning activities are underway are dependent upon the level of certainty in future conditions versus current conditions. Changes in remedial technologies, regulatory environments, and economic conditions over time can result in either both positive or negative cost benefit to delaying remediation. Delaying remediation due to access limitations (e.g., contamination near deep foundations or safety-related features) is largely unavoidable and cost beneficial. However, for areas without access limitations, the decision to delay remediation should consider the following criteria:

- Technology – Changes in technology over time, specifically remedial treatment options and/or disposal costs for radioactive materials, will alter the future cost of remediation versus current costs.
- Regulatory – Changes in land use scenarios that are more or less restrictive than those projected at the time of closure can result in lower or higher remediation costs. For example, delaying remediation and a change from unrestricted to restricted land use (e.g. change from resident farmer to industrial) would result in a cost savings relative to not delaying the remediation. The cost savings would be recognized by lower volumes of soil and groundwater that require remediation, as well as shorter timeframes for cleanup. A potential change in dose pathways and understanding of specific radionuclide dose impacts on receptors over time may be another consideration. Additional dose pathways and/or lowering of remedial criteria concentrations due to revised dose implications would result in higher remedial costs in the future.
- Economic – Considerations for delaying remediation include changes in the cost of money due to inflation and setting financial reserves in order to satisfy future remedial costs. Rising inflation rates reduce the ability of future dollars; therefore, delaying remediation will increase the overall costs due to inflationary pressures. Delaying remediation, however, offers the ability to raise the necessary money in order cover remedial costs through investing and compounding interest. As such, less money for remediation can be reserved against now, with interest payments applied to cover the future costs of remediation.
- Environmental – Tied with the above are decisions defined by the stability of the radionuclide and its ability to migrate both on- and off-site and the potential present and future dose implications. Managing a release condition at the time of detection may prevent significant future costs as a result of contaminant migration.
- Stakeholder Confidence – A management decision due to political and business reputational risks may factor into decisions whether to commence remediation now or at a later date

6
IMPLEMENTING REMEDIATION AND MONITORING EFFECTIVENESS

Based on the evaluations conducted per the Guidance provided in Chapters 4 and 5, each plant should implement the most technically effective and cost effective remediation option to meet decommissioning site release criteria at the time of decommissioning. Based on many considerations, including prevention of off-site migration of contamination and decommissioning cost, the remediation may be implemented during operation or during decommissioning. Once implemented, processes should be in place to monitor and verify that the remediation is progressing as anticipated and meet or will meet the remediation objectives defined in Chapter 3. If the remediation is not progressing as planned to meet the remediation objectives, a contingency plan for alternative remediation strategies should be in place.

Guidance Statement 6.1**: Implement and monitor the selected remediation option**

Procedures and processes should be developed based on the remediation objectives and limits defined per Guidance Statements 3.6 and should include chronological trigger criteria (expected concentrations at various times after the remediation option has been implemented) that allows the success of the remediation to be evaluated throughout its implementation. It is also important that the benefits expected are achieved and the cost monitored to ensure that the selected option remains cost effective.

Exceeding the chronological trigger criteria during the monitoring of the remediation may also indicate that additional areas or higher levels of contamination are present than those estimated for a remediation area. In the process of performing a remediation evaluation, it is likely that a projection of any expected changes to soil and groundwater radionuclide concentrations will be made. These projections in some cases form an important basis for the cost/benefit evaluation that is performed as part of the remediation evaluation.

Also, if a remediation option is implemented during the operation of the plant, there may be expected changes to soil and/or groundwater concentrations that are projected to occur.

In order to confirm the accuracy of the remediation evaluation, monitoring to confirm that the projections of effect of the option(s) chosen should be performed. Although it is not expected that additional soil or bedrock sampling after the initial characterization of a contaminated area will be cost justified, monitoring well sampling as part of the site's groundwater monitoring program should be performed. The expected changes to the radionuclide concentrations in at least some of the site's monitoring wells over time may have been determined as discussed in Section 3.4.1. As new well sample data is collected, it could be compared to the values determined per Section 3.4. If the actual values differ significantly from those that have been projected, the remediation evaluation for the contaminated area(s) contributing to the contamination in the applicable well should be revaluated.

The contingency plans should be in place prior to the implementation of the primary remediation strategy to ensure quick and effective transition and successful remediation. Contingency plans for other failure scenarios that could prevent the completion of the remediation (i.e. mechanical failure, weather delays, unanticipated cost, etc) should also be developed.

7 REFERENCES

1. Nuclear Energy Institute, Industry Ground Water Protection Initiative – Finial Guidance Document NEI 07-07, August 2007
2. EPRI Report # 1016099, Groundwater Protection Guidelines for Nuclear Power Plants, January 2008
3. U.S. Nuclear Regulatory Commission, Liquid Radioactive Release Lessons Learned Task Force Final Report, September 1, 2006 (ML062440497)
4. EPRI, Power Reactor Decommissioning Experience, September 2008
5. U.S. Nuclear Regulatory Commission Web Site at URL: http://www.nrc.gov/info-finder/decommissioning/complex/
6. U.S. Nuclear Regulatory Commission Regulatory Guide 4.21 Minimization of Contamination and Radioactive Waste Generation: Life-Cycle Planning, NRC, June 2008 (ML080500187)
7. Nuclear Energy Institute, Generic FSAR Template Guidance for Life Cycle Minimization of Contamination, NEI 08-08A Revision 0, October 29, 2009
8. U.S. Nuclear Regulatory Commission Regulatory Issue Summary 2008-03 Return/Re-use of Previously Discharged Radioactive Effluents, February 2008 (ML072120368)
9. EPRI Report # 1011730, Groundwater Monitoring Guidance Report for Nuclear Power Plants, September 2005
10. EPRI Report # 1019224, Radioactive Materials Monitoring and Control Guideline, December 2009
11. EPA, EPA QA/G-4; EPA/600/R-96/005, "Guidance for the Data Quality Objectives Process," September 1994. Available at http://www.epa.gov/QUALITY/qs-docs/g4-final.pdf.
12. Code of Federal Regulations, Title 10, Part 20.1402, "Radiological Criteria for Unrestricted Use."
13. U.S. Nuclear Regulatory Commission, Memorandum of Understanding between the Environmental Protection Agency and the Nuclear Regulatory Commission, "Consultation and Finality on Decommissioning and Decontamination of Contaminated Sites", October 9, 2002. (ML073250093, ML022830208)
14. U.S. Nuclear Regulatory Commission, NUREG-1575 Revision 1/EPA 402-R-97-016, "Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), NRC. (ML003761445)

15. U.S. Nuclear Regulatory Commission, NUREG-1757, NRC Consolidated Decommissioning Guidance, Volume 2, September 2006.
16. Oak Ridge Associated Universities Website address, www.orau.gov/ddsc/dose/compcode.htm
17. U.S. Nuclear Regulatory Commission, Policy Issue, SECY-03-0069, Results of the License Termination Rule Analysis, May 2, 2003.
18. Argonne National Laboratory Website address, www.ead.anl.gov/project
19. EPRI Report No. 1016764, "Technical Guidance for Monitored Natural Attenuation at Nuclear Power Plants"
20. EPA Directive 9200.4-17P, "Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites," U.S. Environmental Protection Agency, April 1999
21. EPRI Report # 1016763, Advanced Technologies for Groundwater Monitoring and Remediation at Nuclear Power Plants, December 2008.
22. U.S. Nuclear Regulatory Commission, Regulatory Issue Summary 2004-08, "Results of the License Termination Rule Analysis", May 28, 2004. (ML041460385)
23. EPRI Report # 1013511, Connecticut Yankee Decommissioning Experience Report, 2006.
24. EPA Document # 816-D-00-002, Implementation Guidance for Radionuclides, January 2002 Appendix I has MCLs
25. U.S. Nuclear Regulatory Commission Standard Technical Specifications — Babcock and Wilcox Plants, (NUREG-1430, Revision 3) (ML041830589, ML041800598)
26. U.S. Nuclear Regulatory Commission, Standard Technical Specifications — Westinghouse Plants, (NUREG-1431, Revision 3) (ML041830612,ML041830209
27. U.S. Nuclear Regulatory Commission, Standard Technical Specifications — Combustion Engineering Plants, (NUREG-1432, Revision 3) (ML041830597, ML041830101)
28. U.S. Nuclear Regulatory Commission, Standard Technical Specifications — General Electric Plants (BWR/4), (NUREG-1433, Revision 3) (ML032720559, ML041910212)
29. U.S. Nuclear Regulatory Commission, Standard Technical Specifications — General Electric Plants (BWR/6), (NUREG-1434, Revision 3) (ML041910204, ML041910224)
30. EPRI Report #1019115, Buried Pipe Guided Wave Examination Reference Document, October 2009.
31. "Optimized Hydraulic Conductivity to Limit Contaminant Flux Through Cut-off Walls" (Devlin, J.F. and Parker , B.L.) – University of Waterloo, Ontario, Canada published in GROUNDWATER. Volume 34 No. 4 July-August 1996.

8
DEFINITIONS

Derived Concentration Guideline Levels (DCGLs): DCGLs are defined in the Multi Agency Radiation Survey and Site Investigation Manual (MARSSIM) (Reference 14), developed jointly by the Department of Energy (DOE), the EPA, the Department of Defense (DOD), and the NRC, as the radionuclide concentrations in media or building surface activity levels against which actual measurements will be compared in order to determine if the Survey Area/Unit (the land area or room in a building over which the Final Status Survey is being conducted) meets the dose limits of the License Termination Rule (i.e., 25 mrem/yr per the Code of Federal Regulations, Title 10, Part 20.1402, "Radiological Criteria for Unrestricted Use") or other applicable standards.

Decontamination: The removal of undesired residual radioactivity from facilities, soils, or equipment prior to the release of a site or facility and termination of a license. This is also known as remediation, remedial action, and cleanup.

Graded Approach: This is a defined process for evaluating the significance of potential or actual groundwater contamination. The specific actions recommended for implementation in all groundwater protection programs are identified in this Guideline under the "Baseline Program." At sites with a higher risk contamination situation (e.g., more complex hydrogeology, closer proximity of leak/spill to site boundary, greater amount of contamination), a licensee might use characterization methodologies identified in the "Elevated Program" in this Guideline.

Groundwater: Any subsurface water, whether in the unsaturated or vadose zone, or in the saturated zone of the earth.

Leak or Spill: An inadvertent event or perturbation in a system or component's performance that results in contamination escaping from its intended confinement or container.

Legacy Site: A site for which adequate resources do not exist to support required decommissioning at the time of decommissioning.

Licensed material: Source material, special nuclear material, or byproduct material received, possessed, used, transferred, or disposed of under a general or specific license issued by the Commission.

Radiologically Significant: The "significance" threshold is the unexpected radiological conditions resulting from spills, leaks, unplanned releases or the identification of radioactive materials in unexpected locations that could have an adverse impact on license termination under Subpart E of 10 CFR Part 20

<u>Remediation:</u> See "Decontamination."

<u>Residual radioactivity</u>: Radioactivity in structures, materials, soils, groundwater, and other media at a site resulting from activities under the licensee's control. This includes radioactivity from all licensed and unlicensed sources used by the licensee, but excludes background radiation. It also includes radioactive materials remaining at the site as a result of routine or accidental releases of radioactive material at the site and previous burials at the site, even if those burials were made in accordance with the provisions of 10 CFR Part 20.

<u>Site conceptual model</u>: A unifying hypothesis to describe how a contaminant release may be observed and measured currently in the site environment, and to identify the ultimate fate of the contaminant in the future. The model incorporates what is known about a site’s hydrogeology, existing and past site activities that may have resulted in contaminant releases to the environment, the locations of those releases, the contaminants of interest, and their fate and transport.

The Electric Power Research Institute Inc., (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

Together...Shaping the Future of Electricity

Program:

Nuclear Power

1023464

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com