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A Risk Analysis of Remediation Technologies for a DOE Facility

Helene A. Wilson

A RISK ANALYSIS OF REMEDIATION TECHNOLOGIES FOR A DOE FACILITY

THESIS

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AFIT/GOR/ENS/98M-28

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Abstract

The Department of Energy is responsible for selecting a remediation technology to cleanup the Waste Area Group (WAG) 6 site at the Paducah Gaseous Diffusion Plant (PGDP) in Kentucky. WAG 6 is contaminated with an uncertain amount of trichloroethylene (TCE) and technetium-99 (Tc-99). Selecting a remediation technology involves a certain degree of risk because many of these technologies are new or proven only for a specific type of contaminant or a particular set of site conditions. Differences between contaminant type and site conditions are enough to make the performance of a remediation technology uncertain. This research identifies the technological risks of two remediation technologies: Dynamic Underground Stripping (DUS) and In Situ Chemical Oxidation (ISCO). Risk is defined as the likelihood of undesirable events occurring during the implementation of a technology at WAG 6. These risks were divided up into two categories: acceptable risks and unacceptable risks. For unacceptable risks, technological "fixes" were developed to reduce the probability of occurrence. Further investigations into DUS's technological risks determine the effects these risks have on CERCLA's five balancing criteria. Incorporating the technological risks and their effects into a decision analysis model produces a risk profile for DUS. The results of this research provided the decision makers at WAG 6 with insights into the performance risks for Dynamic Underground Stripping and In-Situ Chemical Oxidation.

A Risk Analysis of Remediation Technologies for a DOE Facility

1 Introduction

1.1 General Issue

At one time contamination of land and water was believed to be an unavoidable consequence of industrial and technological progress. Due to perceived national needs, a lack of knowledge, and changing national priorities less attention was placed on environmental controls for facilities associated with nuclear generation. By 1970, stronger environmental rules started to take effect, but not until 1989 did environmental cleanup became a high priority [Office of Environmental Restoration Home Page, 1998: www.em.doe.gov/er/]. Due to this lack of environmental regulations and awareness many nuclear facilities and their surrounding areas were contaminated with radioactive and/or hazardous materials. The National Priority List (NPL), managed by the Environmental Protection Agency (EPA), identifies over 1,300 of this nation's most hazardous waste sites [O'Brien and Gere, 1995: xvii]. The Paducah Gaseous Diffusion Plant (PGDP) was listed on the NPL on 31 May 1994 and is the subject of this research.

1.2 Background

The PGDP is located approximately 10 miles west of the city of Paducah, Kentucky and encompasses 750 acres inside a 3,422 acre reservation owned by the

Department of Energy (DOE). The PGDP has been in full operation since 1955, with startup operations beginning in 1952. The mission of the plant is the separation of uranium isotopes by gaseous diffusion. Commercial nuclear power plants use the enriched uranium produced. The United States Enrichment Corporation took control of the production portion of the plant in 1993. However, DOE retains responsibility for the environmental remediation of the PGDP site.

Currently there are two hundred potential source sites identified in the PGDP area from which contamination could and has migrated. For the purposes of remediation these sites are arranged into 24 Waste Area Groups (WAGs). This research focuses on WAG 6.

At WAG 6, the two principal contaminants of concern (PCOC) are trichloroethylene (TCE) and technetium-99 (Tc-99). TCE is a Dense Non-Aqueous Phase Liquid (DNAPL). DNAPLs are heavier than water and readily sink into the subsurface. Before 1993, TCE was used as a cleaning solvent for decontaminating equipment and waste material before disposal. Tc-99, a radioactive material, reputedly came from the reactor tails stored at the site after 1975. Plutonium production reactors sent these reactor tails to PGDP for uranium re-enrichment [DOE/OR/07-1243&D4, 1997: 4-4].

1.3 CERCLA

In response to the growing concern about hazardous waste sites, Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) in 1980 [EPA/540/G-89/004, 1989]. CERCLA, also known as the

Superfund Act, established the hazardous substance release reporting and cleanup program and gave the EPA legal enforcement authority. CERCLA was later amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA). The Superfund Act established nine evaluation criteria divided into three groups (Figure 1-1) as a basis for analyzing alternative remediation technologies. Technologies that fail to meet the *threshold criteria* are rejected. Evaluation by the *modifying criteria* occurs only after selecting a remediation technology. The *balancing criteria* are the primary parameters used in the detailed analysis of remediation alternatives and are the focus of this research.

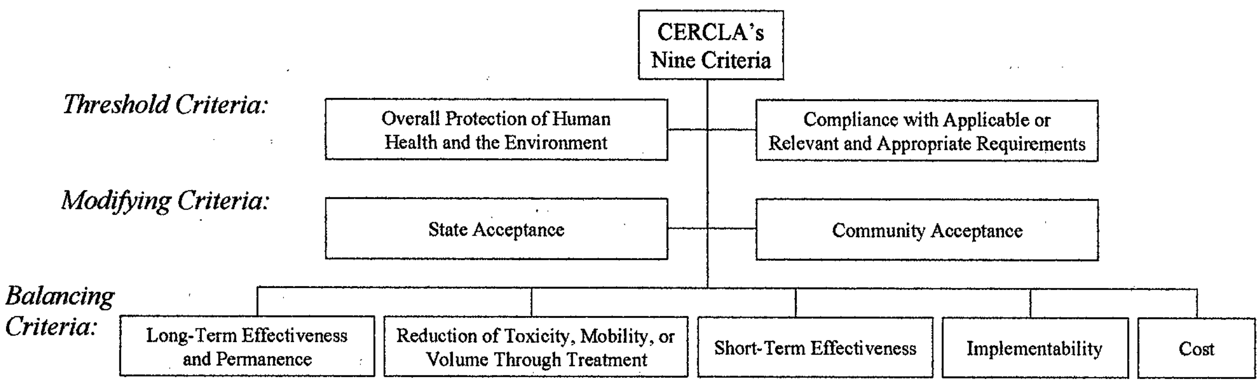


Figure 1-1 CERCLA Criteria Hierarchy

1.3.1 Remediation Investigation/Feasibility Study

Within six months of placement on the NPL, PGDP was required to start a Remediation Investigation/Feasibility Study (RI/FS). The purpose of the remediation investigation is to assess site conditions, while the purpose of the feasibility study is to evaluate available alternatives concerned with eliminating, reducing, or controlling risks to the human health and the environment [40 CFR S300.430(a)(2)]. Implementation of the RI and FS is concurrent. This research focuses primarily on supporting the FS.

The FS involves (1) development and screening of alternatives, and (2) detailed analysis of alternatives [EPA/540/G-89/004, 1989: 1-7]. The first step is concerned with assembling combinations of technologies into alternatives. The alternative, normally called a technology train, is a technology or a group of technologies, which will remediate a site. The second step is the detailed analysis of these technology trains with respect to the CERCLA criteria.

1.4 Problem Statement

Placement on the NPL requires the DOE to carry out long-term remedial actions which will permanently and significantly reduce the dangers associated with hazardous materials released at the PGDP site [EPA/540/G-89/004, 1989: 1-4]. The specific challenge that the decision makers face at PGDP is to remediate an uncertain volume of TCE and Tc-99 located below an operational plant and its associated utilities.

These characteristics make it a significant challenge to select the best technology train available for the WAG 6 area. CERCLA mandates the detailed analysis of these remediation technologies, including the "degree of certainty that the alternative will prove successful" [40 CFR S300.430 (e)(9)(iii)(C)]. In other words, what is the degree of risk associated with a particular remediation technology.

1.4.1 Risk Analysis

In cleaning up any contaminated site, one of the most difficult and risky decisions is the selection of a remediation technology train. The intent of these technology trains is to cleanup and/or control contaminated areas to a point where the protection of human health and the environment will not be compromised. Selecting the best technology train for a given site can minimize the negative consequences to time, money, effort, environment, and human health. There are two reasons selection of a technology train is risky. First, remediation of contaminated sites is a relatively new field, filled with many innovative and unproven technologies. Second, a technology train that proves effective at one contaminated site has no guarantee of success at another. Thus, a detailed risk analysis for a technology train is a critical step in the decision process.

1.4.2 Technology Risks and Uncertainty

In the remediation arena, "risk" refers to both human health hazards and the uncertainty surrounding a successful use of a technology train. Human health risk is the likelihood people associated with or living near a contaminated area are exposed to hazardous material from that site. Technological risk is the likelihood of undesirable events and the magnitude of their consequences due to technological decisions. This research focuses on the technological risks and associated uncertainties.

There are two types of uncertainty: unforeseeable future and ignorance [Chechile, 1991: 9]. The unforeseeable future is an uncertainty where the process is known but the outcome is not known until it happens. For unforeseeable future, the best a decision maker can do is to consider carefully the probability of possible outcomes. Ignorance is the lack of information. Ignorance changes to enlightenment by acquiring more information. While obtaining more information can reduce this type of uncertainty, it is often cost and time prohibitive to try to remove all uncertainty. A more reasonable objective would be to gather enough information to make an informed decision.

1.5 Research Objective

The primary objective of this research is to provide the DOE with detailed insight into the technological risks of two remediation technologies: Dynamic Underground Stripping (DUS) and In-Situ Chemical Oxidation (ISCO). This research will focus on the undesirable events that can adversely affect the technologies' CERCLA performance, including both acceptable and unacceptable risks.

Decision and risk analysis techniques can provide valuable insight for the trains containing these two technologies. This research begins by identifying the technological risks associated with DUS and ISCO. Current published information, the WAG 6 team, and technology experts allowed for identification of the undesirable events and quantification of the associated probabilities. Investigation of the unacceptable risks helps determine if engineering fixes can be developed to reduce the probability of occurrence. Incorporation of the acceptable risks into a probabilistic model allows for evaluation based on CERCLA's five balancing criteria.

The results from the probabilistic model are risk profiles that show the possible CERCLA value ranges and their associated probabilities.

1.6 Overview

Chapter 2 reviews the current literature on the DUS and ISCO technologies and risk analysis applications. Chapter 3 outlines the methodology including the development of influence diagrams, event probabilities, evaluation measure scores, and risk profiles. Chapter 4 covers the results and Chapter 5 concludes with final observations and future research possibilities.

2 Literature Review

2.1 Introduction

This research involves a detailed risk analysis of two technologies, Dynamic Underground Stripping (DUS) and In-Situ Chemical Oxidation (ISCO). The chapter reviews risk analysis concepts and the decision methods used to perform a risk analysis. This review also presents a general description of the process for each technology.

2.2 Risk Analysis

The word risk means different things to different people. There are even different types of risks, such as investment risk, health risk, environmental risk, and technological risk. Kaplan identifies three questions associated with the inquiry "What is the risk?"(Figure 2-1).

	Notation	Example
❖ What can happen? (What can go wrong?)	(S_i)	Fire/explosion
❖ How likely is it? (What is its frequency/probability?)	(L_i)	0.01%
❖ What are the consequences? (What is the damage?)	(X_i)	$100,000 Two injuries. Environmental problems. Embarrassment, reputation.

Figure 2-1 The three risk questions [Kaplan, 1997: 408].

His answer, the set (S_i, L_i, X_i) can be applied to the different types of risks described above [Kaplan, 1997]. Obtaining the set (S_i, L_i, X_i) can be done by the use of various methods, such as event trees and subjective probability assessment. Beim and Hobbs use these risk-defining methods to attack a problem at Sault Ste. Marie [1997].

Given the limited amount of literature on technological risk in relation to contaminated site remediation, this section covers a risk analysis of another type, cargo carrier accidents and other nonstructural failures. The study pertains to the reliability of a waterway transport system. While not about remediation technologies, the article provides a well-rounded picture of what is required for a good risk analysis.

2.2.1 Poe Lock Closure Risk

Beim and Hobbs illustrate the use of event trees and subjective probability assessment on a risk analysis of the Poe Lock, which is the largest of four parallel locks that make up the waterway transport system on the St. Mary's River (Sault Ste. Marie, Michigan) [1997]. The study estimated the probability of extended closures resulting from vessel or railroad accidents. This study was one of two research efforts investigating the benefits of building a second Poe-class lock.

In order to find (S_i), Beim and Hobbs used an event tree -- a chronological sequence of events that could lead to an undesirable event. Asking, "What could happen next?" builds an event tree. The five elements that make up an event tree are: antecedent conditions, initiating events, intermediate events, recovery actions, and terminal events. Definitions of these terms are in Figure 2-2. The size of an event tree depends upon the nature of the problem and the level of detail desired. While it is desirable to have a manageable event tree, the authors caution against constructing too small of a tree. Eliminating branches can unintentionally remove disastrous consequences from consideration.

- ❖ Antecedent conditions describe states of the system (e.g., weather, type of vessel entering the lock) that affect the probability of various events. These conditions could instead be treated as initiating events. However, the logic of event trees is easier to explain if antecedent conditions, which are associated with a period of time and precede an accident sequence, are separated from events that occur at points in time.
- ❖ Initiating events (such as an equipment failure) begin a sequence of events that could lead to system failure.
- ❖ Intermediate events logically follow the initiating event but by themselves do not represent system failures.
- ❖ Recovery actions represent responses that attempt to prevent or mitigate the damage from a failure.
- ❖ Terminal events represent various modes and severities of system failure.

Figure 2-2 Event Types [Beim et al., 1997: 170]

Once the event tree is established, the next step is to assess probabilities (L_i) for all branches of the event tree. Although historical frequency is the best way to generate probabilities, it is often non-existent, in which case subjective probabilities, obtained from experts are used. Subjective probability, "a measure of an individual's degree of belief concerning the likelihood of an event," is usually present in various degrees in any risk analysis study [Beim et al, 1997: 170]. Since these probabilities are subjective, care was taken to avoid bias. Beim and Hobbs provide a good summary of ways to avoid bias when eliciting subjective probabilities. Obtaining probabilities (L_i) for the tree, Beim et al used historical frequency, subjective probabilities and a combination of both of these types.

An extended closure of the Poe Lock would have severe economic consequences. Thus, the definition of consequence (X_i) for Beim and Hobbs' study was the time it takes to repair the lock after an accident occurs. It was defined this way to answer the question; "Is the probability of an extended closure high enough to warrant the expense of building another Poe Lock to reduce the possibility of a major economic crisis?"

The conclusion of their study indicated that most of the influencing variables did not greatly affect the probability of an extended lock closure. Their application showed the importance of correctly eliciting subjective probabilities and the importance of historical data, when available. It also showed that sensitivity analysis is essential when using subjective probabilities and limiting assumptions. Sensitivity analysis will indicate which assumptions have the most influence and therefore require more research.

2.3 Decision Analysis

Decision Analysis (DA) provides decision makers with a systematic way of approaching difficult decisions. Most complex decisions are permeated with conflicting objectives, various uncertainties, and diverse opinions. By using DA methods, these problems are handled in an organized, systematic manner to gain insight into the various aspects of the decision [Clemen, 1996: 4].

DA methods include value-focused thinking, value hierarchies, multiattribute preference theory, decision trees, and influence diagrams. Two excellent reviews of these methods were produced in previous work for the PGDP site [Kerschus, 1997; Papatyi, 1997; Grelk, 1997].

Decision analysis is well suited for remediation of contaminated sites because environmental remediation by its very nature involves complexity, inherent uncertainties, and conflicting objectives. DA methods have been applied to a number of environmental areas: budget estimates, prediction of an uncertain variable(s) and risks to human health and the environment [Jennings et al., 1994: 1133 - 1135]. In addition to those areas, DA is increasingly applied to the RI/FS process [Kerschus, 1997; Papatyi, 1997].

In reference to the PGDP, Papatyi used decision analysis methods on WAG 6's environmental remediation problem. Papatyi performed an initial screening of all the remediation technologies available and then evaluated the remaining technology trains. In the initial screening, by way of strategy generation tables, influence diagrams and dominance theory, approximately 16.8 million possibilities were trimmed to 58 technology trains. In evaluating the remaining trains he used three evaluation measures: cost, time, and performance. Using these evaluation measures and their single objective value function, the 58 technology trains were screened down to seven. Further in-depth analysis trimmed this list to the top three: Dynamic Underground Stripping (DUS), 2 Phase and Oxidation, and LASAGNA and Oxidation [Papatyi, 1997].

Kerschus developed a method for selecting remediation technologies based on the CERCLA criteria instead of limiting the process to cost, time and performance evaluation measures. Her analysis also addressed some of the uncertainty surrounding the amount of DNAPL in the subsurface. In the process of building her model, the initial set of technology trains was cut from 58 to 22, with a baseline train of monitoring only added to yield a total of 23. Her detailed analysis concluded with a set of five promising technology trains at the expected spill volume: DUS, 2 Phase & Oxidation, 2 Phase & Surfactants, LASAGNA & Oxidation, and 2 Phase & CoSolvents. In addition, there were three trains that performed well at higher spill volumes: DUS, 2 Phase and Permeable Treatment Zone (PTZ) and LASAGNA and PTZ [Kerschus, 1997].

These two previous research efforts showed that decision analysis is an iterative process which provided the decision maker valuable insight into the WAG 6 problem. The first study laid the groundwork and the initial analysis for the WAG 6 team. It also indicated which areas needed further investigation. The second research project incorporated these results and provided additional insight into the selection process. As a result of Kerschus' work, two potential technologies were chosen for further analysis. It is the intent of this research to provide the WAG 6 team with a decision analysis approach to technological risk on DUS and ISCO.

2.4 Dynamic Underground Stripping (DUS) Process

Dynamic Underground Stripping is a remediation technology, which is itself a combination of three other technologies: steam injection, electrical heating, and underground imaging [DOE/EM/0271, 1995: 1]. DUS is considered a "silver bullet" technology train because of its ability to achieve high levels of contaminant removal above and below the water table. Figure 2-3 is a simplistic diagram of the DUS system.

The primary advantage of the DUS technology is the substantial decrease in remediation time and the robustness of the process [Falta et al, 1996: 13]. Another advantage is the monitoring technology applied during DUS, Electrical Resistance Tomography (ERT). ERT generates two-dimensional images of the subsurface, thus providing the ability to monitor the cleanup with a minimum number of monitoring wells.

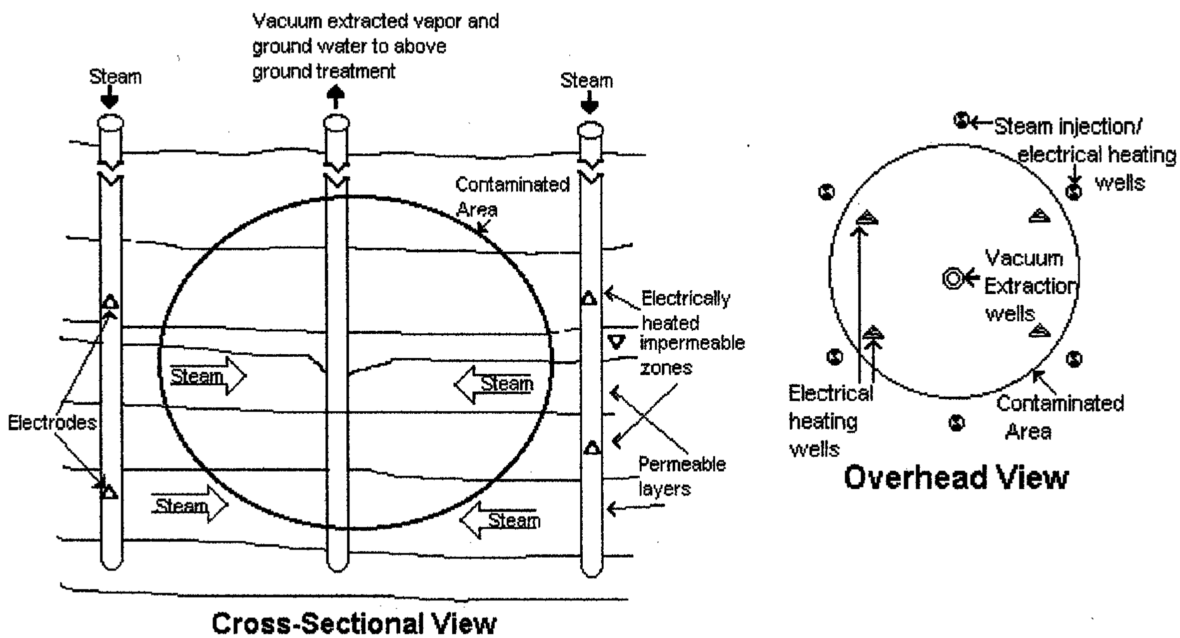


Figure 2-3 Dynamic Underground Stripping [DOE/EM/0271, 1995: 1]

2.4.1 Steam Injection and Vacuum Extraction

Steam heats the subsurface to the boiling point of water. The heat of the steam vaporizes Volatile Organic Compounds (VOC) with boiling points below that of water. (TCE has the boiling point of 87°C.) These VOCs move with the steam front through the soil to the extraction wells. In DUS, the steam injection wells are drilled around a contaminated area with the extraction wells in the center of the area [DOE/EM/0271, 1995: 1].

2.4.2 Electrical Resistance Heating

Steam works well in permeable soils, but electrical heating may be required to vaporize VOCs located in impermeable soils. Electrical resistance heating uses the injection wells to place the electrical current close to the impermeable areas [DOE/EM/0271, 1995: 1]. It should be noted that electrical heating may not be necessary for WAG 6 because of its high permeability.

2.4.3 Underground Imaging

Temperature measurements, Electrical Resistance Tomography (ERT), and tiltmeters monitor steam migration. Each indirectly monitors the TCE movement since the vaporized DNAPL will flow with the steam. Temperature measurements are taken from monitoring wells placed throughout the contaminant area. ERT monitors the progress of the steam front by electrical conductivity measurements. Tiltmeters are use to detect pressure changes in the subsurface caused by steam front movement [DOE/EM/0271, 1995: 1]. Electrical Resistance Tomography is essential in controlling the steam migration. This control translates into increased performance efficiency.

2.4.4 Dynamic Underground Stripping (DUS) Technological Risks

The DUS technology was chosen for further detailed evaluation due to its perceived high value in initial studies (Kerschus, 1997) and because considerable amount of uncertainty surrounds this innovative technology. There have been only two field demonstrations to date. The first full-scale demonstration of DUS was successfully completed in December 1993 for a gasoline spill at Lawrence Livermore National Laboratory (LLNL). DUS is also currently being applied to Southern California Edison's Visalia Pole Yard, which is contaminated with Dense Non-Aqueous Phase Liquid (DNAPL) [Aines et al, 1996: 1].

2.5 In-Situ Chemical Oxidation (ISCO) Process

In-Situ Chemical Oxidation is an in-place remediation technology, which uses an oxidizing agent to convert organic contaminants into harmless compounds. The two most commonly used oxidizing agents are hydrogen peroxide (H_2O_2) and potassium permanganate ($KMnO_4$). There are three ways to delivery the oxidant solution into the ground: high pressure injection, soil fracturing, or soil mixing. The only option for WAG 6 is injection. Soil fracturing and soil mixing are not practical for WAG 6 due to the depth of contamination and the existence of a buildings and structures over the contaminated area.

The main advantage of ISCO is the in-place destruction of the contaminant, which virtually eliminates contaminated waste. Another benefit is the enormous potential to decrease the remediation time for contaminated sites.

2.5.1 Hydrogen Peroxide (H_2O_2)

There are two ways to use hydrogen peroxide (H_2O_2) in the ISCO process, with iron or by itself. Hydrogen peroxide catalyzed by iron refers to a process called Fenton's reagents. Iron occurs naturally in the soil or it is added as a supplement with the hydrogen peroxide. Although both hydrogen peroxide and Fenton's reagents oxidize organic compounds like TCE (C_2HCl_3), and produce water, carbon dioxide and chloride (Equation 2.1), hydrogen peroxide by itself is not as efficient as Fenton's

$$C_2HCl_3 + 3H_2O_2 \rightarrow 2CO_2 + 2H_2O + Cl^- \qquad \textbf{(2.1)}$$

reagents. The limiting factor for Fenton's reagents is the pH of the soil. For a reliable reaction the soil needs to be acidic (pH < 6) with the best reaction at pH equal to three [Gates et al, 1995: 2-3]. A catalyst, usually sulfuric acid, can be added to the soil if it is not acidic enough. The soil at WAG 6 will require a catalyst, since the soil's pH is seven [Morti, 1997]. In addition to not wanting to add another chemical into the ground unnecessarily, the WAG 6 team is concerned about the amount of sulfuric acid that would be required to change the soil's pH. The aquifer for this area contains high amounts of carbonate. The carbonate would neutralize the sulfuric acid; therefore, large amounts of acid would be required to offset this reaction in order to change the soil's pH. This could be cost prohibitive since the cost of sulfuric acid is almost as expensive as Fenton's reagents. For these reasons Fenton's reagents will not be used at WAG 6 [Richards, 1997].

2.5.2 Potassium Permanganate ($KMnO_4$)

Potassium Permanganate is another strong oxidizing agent. When it encounters organic compounds such as TCE (C_2HCl_3), carbon dioxide, manganese dioxide, and chloride are produced (Equation 2.2). Potassium Permanganate is

$$2MnO_4^- + C_2HCl_3 \longleftrightarrow 2CO_2 + 2MnO_2 + 3Cl^- + H^+ \qquad \textbf{(2.2)}$$

inherently more stable then H_2O_2, which rapidly decomposes when it comes in contact with soil [West et al, 1997: 1]. This is favorable if the oxidizing agent has to travel any distance to reach the DNAPL. A drawback to this stability is a slower reaction time for $KMnO_4$. ISCO will also require twice as much potassium permanganate as hydrogen peroxide to oxidize the same amount of DNAPL. Unlike hydrogen peroxide, soil pH is less of a concern when using potassium permanganate. $KMnO_4$ is deep red in solution and therefore easily detected but could present an aesthetic problem because of its color.

2.5.3 In Situ Chemical Oxidation Technological Risks

ISCO requires further investigation because of the uncertainty surrounding its application at PGDP. The size of the contaminated area at WAG 6 is substantial. The investigating team is concerned with how well chemical oxidation will perform on such a large scale. A related issue to performance is the enormous amount of oxidant that this remediation area will require. Since there is no historical data to show how efficient ISCO is on such a large scale and because the oxidants are very expensive, a failure of this technology will be quite costly in both time and money.

3 Methodology

3.1 Introduction

This analysis must first identify the technological risks inherent in the technologies under consideration. The next step is to determine how these undesirable events influence the decision criteria, the CERCLA values. A basic approach to such an assessment is to determine which evaluation measures are sensitive to these events and how they are affected. After the technological risks were determined for DUS and ISCO, DUS is used to demonstrate this risk analysis methodology.

The focus of Kerschus' research was to build a decision analysis model for remediation technology selection at WAG 6 [1997]. With the exception of volume uncertainty, that model was deterministic. However, some of the scores for the evaluation measures were educated estimates. A better reflection of the uncertainty inherent in these scores is to find a distribution of possible scores instead of a single score for each evaluation measure. This chapter presents the methodology behind a probabilistic model for WAG 6.

Given the importance of site characteristics in selecting remediation technology, this chapter begins with a brief overview of WAG 6's site characteristics.

3.2 WAG 6 Site Characteristics

Successful remediation depends upon a technology train's performance. Subsurface characteristics and principal contaminants of concern (PCOC) can severely influence the performance of a technology train. One of the main purposes of a Remediation Investigation (RI) is to obtain data on the type, amount and source location of PCOCs in the subsurface and to determine the soil characteristics.

Although the PCOCs for WAG 6 have been identified as trichloroethylene (TCE) and technetium-99 (Tc-99), the exact quantity and location of these two contaminants are unknown. However, based upon current RI data, two contamination zones delineate the general location of the spills (Figure 3-1). According to the WAG 6 team, there are three TCE spills. Two of these TCE spills are in zone two and the other is in zone one. Only zone one has a significant concentration of Tc-99.

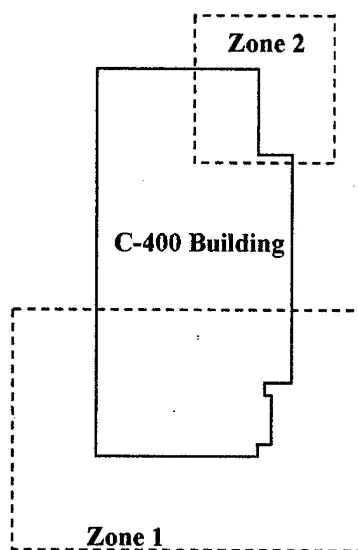


Figure 3-1 Contamination Zones

The total TCE spill is currently estimated to be between 10,000 and 500,000 gallons (as of 29 Jan '98). Based upon the latest finding from the RI, the cumulative probability distribution of the DNAPL volume first shown in Kerschus' research has been updated to yield Figure 3-2 [1997: Chapter 3]. According to the graph, the expected DNAPL volume is 115,250 gallons (Appendix B). The initial concentration estimate for Tc-99 remains unchanged at 43,922 piC/L (as of 29 Jan '98).

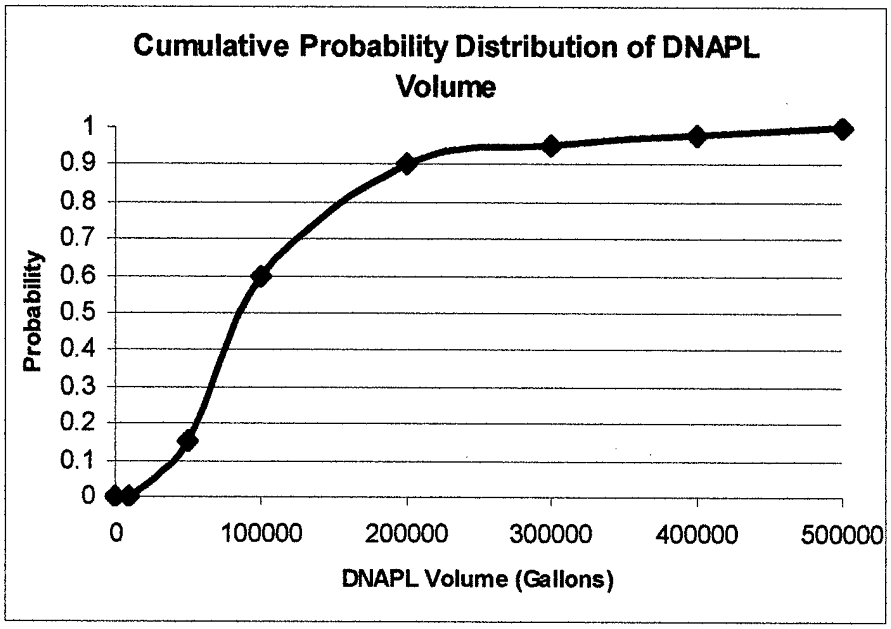


Figure 3-2 DNAPL Volume Uncertainty

The most current data on soil characteristics indicates two major geological zones, the Upper Continental Recharge System (UCRS), and the Regional Gravel Aquifer (RGA). There are two distinct areas in the UCRS: unsaturated and saturated. At the beginning of the RI/FS, the saturated zone was believed to be quite substantial but in the course of the investigation, the saturated zone was found to be almost non-existent. Figure 3-3 shows where these areas are in relation to each other.

The permeability of the soil affects the spread of the DNAPL. All of these zones are relatively permeable with two exceptions. There is an impermeable area underneath the C-400 building and a low permeable area between the RGA and the

McNairy Formation. Based upon the limited data available, Figure 3-3 presents a general idea of the subsurface spread of DNAPL.

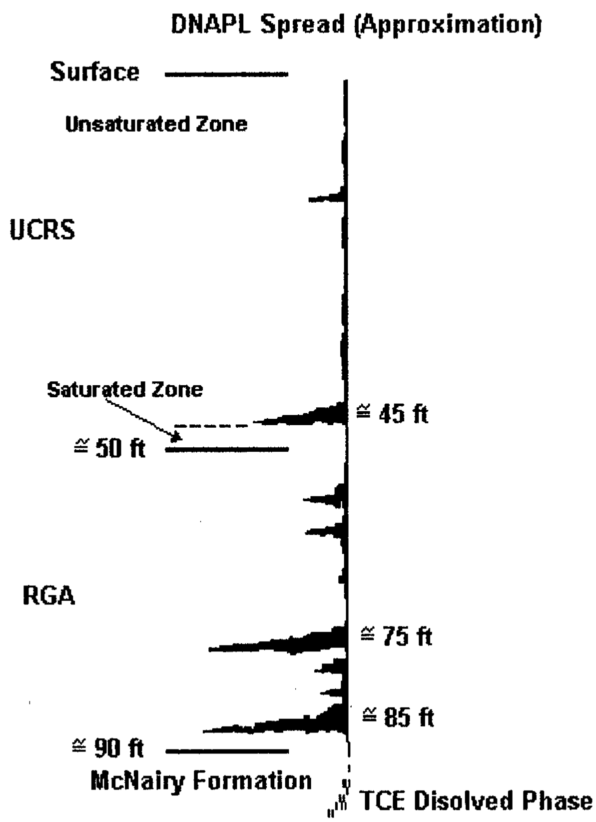


Figure 3-3 WAG 6 Subsurface and DNAPL spread [Morti, 1997]

Another important consideration for WAG 6 when selecting a technology train is the operational C-400 building. The design configuration for any technology train selected must consider the impact of the building. This research assumes that the configuration of DUS and ISCO is correctly engineered for the WAG 6 site. This assumption narrows the risk to technology application risks and not design risks. There is no current literature to discount this assumption.

3.3 Dynamic Underground Stripping's Technological Risks

Although the performance of DUS appears promising, there is concern about its technological risks. With the above site characteristics in mind, an investigation to determine these undesirable events began. Information was collected from a variety of sources: literature reviews, experts, previous studies on similar technologies, and the technology applications to date. The result from this initial investigation was a preliminary list of technological risks. A detailed examination of this list by the WAG 6 team generated an event tree for DUS.

In the process of determining the technological risks relevant to the WAG 6 area, the likelihood of occurrence for the events within the event tree were ascertained. The probability of these events happening depends upon the percentage of DNAPL affected by a particular event. Therefore, these probabilities are defined as the amount of affected DNAPL as well as the likelihood of occurrence.

Originally, the event probabilities elicited were single points. The decision was made to expand these point estimates to uniform distributions since the RI data was still being compiled and the analysis was not yet complete. Eric Morti, a hydrogeologist conducting the field studies at WAG 6 suggested a range of +/- 100% of the point estimates. For example, if the point estimate was 15%, then the uniform distribution would range from 0% to 30%. This estimation procedure provided a probability range for most of the events in the tree.

The event tree was transformed into four separate influence diagrams, which corresponds to the four terminal events: unrecovered DNAPL, DNAPL not removed, TCE plumes outside the remediation area, and steam breakouts. An explanation of influence diagrams is provided in Appendix C

3.3.1 Unrecovered DNAPL

The biggest concern when using steam as an extraction method is the possibility of the contaminants migrating downward [Falta et al, 1996:12]. DNAPL's downward movement is caused by three primary factors (Figure 3-4 and Table 3-1). First, the steam heating of the DNAPL reduces viscosity and interfacial tension allowing for freer movement in all directions. Second, if DNAPL cools and re-condenses into pools of four feet or greater depth at this site, the pool density may overcome the capillary forces which help prevent downward migration [Falta et al, 1996: 12]. Third, the presence of fissures and sand lenses at the bottom of the RGA provides preferential pathways for the DNAPL to migrate downwards. During the DUS process, there is a potential for the steam to push the DNAPL into a fissure or sand lens, which will allow the DNAPL to migrate downwards. The downward migration of DNAPL is a major concern at WAG 6 because of the possible penetration of the McNairy Formation.

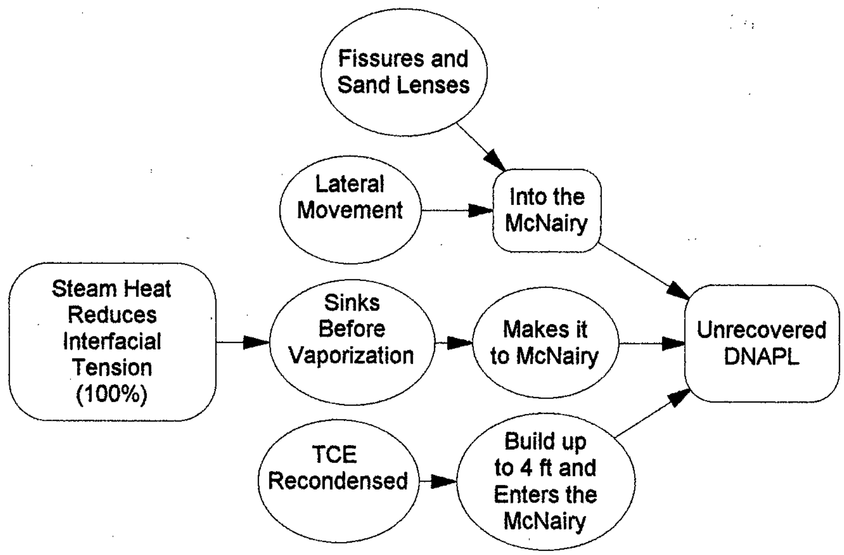


Figure 3-4 Unrecovered DNAPL Influence Diagram

Table 3-1 Unrecovered DNAPL Node Summary

	Node Designator	Equation/Probability	Description
1	Steam Heat Reduces Interfacial Tension	100% (Information Only)	Steam heat generated by DUS will reduces the interfacial tension
2	Sinks Before Vaporization	Uniform (0, 0.10)	Percentage of DNAPL that will sink before vaporizing.
3	Makes it to McNairy (Factor 1)	Uniform (0, Node 2*0.20)	Percentage of DNAPL, which makes it to the McNairy.
4	TCE Recondensed	Uniform (0, 0.40)	Percentage of TCE, which recondensed during DUS operations.
5	Build up to 4 ft and Enters the McNairy (Factor 2)	Uniform (0, Node 4*0.02)	The percentage of TCE that recondenses into four foot pools.
6	Fissures and Sand Lenses	Uniform (0, 0.30)	Fissure and sand lens present at the bottom of the RGA, which leads into the McNairy.
7	Lateral Movement	Uniform (0, 0.10)	Percentage of DNAPL at the bottom of the RGA, which moves laterally.
8	Into the McNairy (Factor 3)	Node 6 * Node 7	Percentage of DNAPL that moved laterally and finds a fissure or sand lens.
9	Unrecovered DNAPL	Node 3 + Node 5 + Node 8	Total percentage of DNAPL that makes it into the McNairy.

A primary reason it is undesirable to have DNAPL in the McNairy Formation is that the "McNairy may be an indirect source of water to the municipal supply wells of Metropolis, Illinois, located approximately 3 miles to the north" [Davis and Morti, 1998]. The McNairy is divided into upper, middle, and lower formations (Figure 3-5). Alternating fine sands, silts, and impermeable clays with occasional fine gravel make up the upper layer. The middle layer, known as the Levings formation, consists of silts and clays. The lower formation is composed of fine sand. "Ground water flow in the upper and middle McNairy formations has limited lateral extent. However, ground water flows in the lower layer from beneath the PGDP to the Ohio River" [Davis and Morti, 1998].

According to Davis and Morti, it is possible that the Metropolis municipal wells' area of influence extends to the Ohio River in the lower McNairy layer [1998]. "Although the Metropolis wells are completed in the Mississippian bedrock beneath the McNairy Formation, the bedrock aquifer is likely recharged from the McNairy in areas of ground water withdrawal" [Davis and Morti, 1998]. If there are dissolved contaminants from the PGDP present in the lower McNairy, the contaminants could be captured by the Metropolis wells.

Currently, only dissolved TCE concentrations have been found on top of the upper McNairy layer. None of the TCE detections in the McNairy were at concentrations indicative of DNAPL pools [Davis and Morti, 1998]. "From the perspective of the PGDP environmental restoration program, these TCE levels do not pose a threat to off-site receptors and can probably be addressed by natural attenuation" [Davis, 1998]. If DNAPL penetrates the McNairy Formation, the limited migration of fluids permitted by the hydrogeology of the McNairy significantly increases the difficulty of remediation [Davis and Morti, 1998].

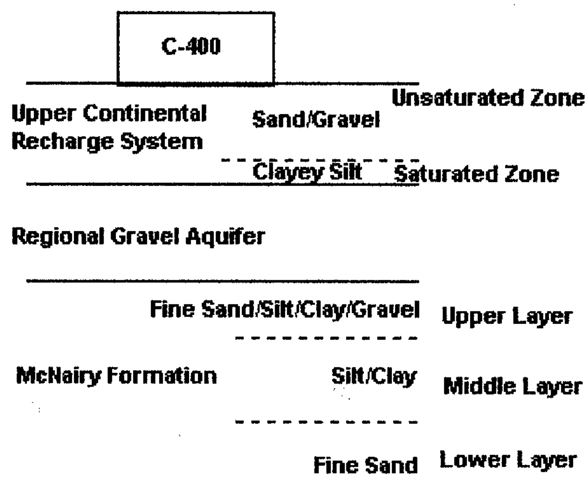


Figure 3-5 Subsurface Formations

3.3.2 DNAPL not Removed

With DUS, it is critical to place the injection wells in a pattern that completely surrounds the contaminated area with steam. Failing to do so increases the chance of DNAPL migrating outside the encircled area or remaining in the subsurface. In order to correctly place the injection wells, the distribution of DNAPL within the subsurface needs to be well defined. However, the detection of DNAPL can be difficult. With only a discrete number of soil samples taken it is easy to miss small DNAPL pockets [DOE/OR/07-1243&D4, 1997: 10-1]. Increasing the number of soil samples expands our knowledge of the distribution of the DNAPL, but does not eliminate the possibility of not detecting small pockets of DNAPL. In addition, the sampling process can be costly. Figure 3-6 and Table 3-2 present the influence diagram and data, respectively for this probability.

The DNAPL not removed event is different from the unrecovered DNAPL event since the unrecovered DNAPL event applies to the DNAPL within the circle of injection wells and the DNAPL not removed event applies to the DNAPL outside the circle of injection wells.

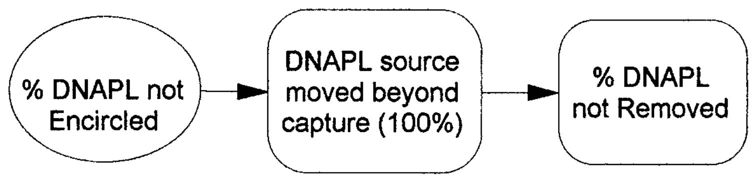


Figure 3-6 DNAPL not Removed Influence Diagram

Table 3-2 DNAPL not Removed Node Summary

	Node Designator	Equation/Probability	Description
1	% DNAPL not Encircled	Uniform (0, 0.10)	Amount of DNAPL, which is not captured by the DUS design.
2	DNAPL source moved beyond capture	100% (Information Only)	The percent of DNAPL not encircled will be pushed away from the injection wells.
3	% DNAPL not Removed	Node 1	Percent of DNAPL not removed from the subsurface that is outside the injection wells.

3.3.3 TCE Plumes outside the Remediation Area

The TCE plumes outside the remediation area event depends upon the occurrence of the DNAPL not removed event (Figure 3-7 and Table 3-3). If the injected steam pushes the TCE away from its original location in the WAG 6 area the migrated TCE will become a new source. Although the RI/FS for this project is limited to WAG 6, the total remediation area includes both WAG 6 and the TCE plumes, which extend beyond the WAG 6 area. The hydrogeology of the subsurface and ground water movement create these TCE plumes. A process called Pump and Treat contains the TCE plumes by pumping ground water to the surface for treatment. The pumping wells are placed according to the width and depth of the plumes. If the DNAPL migrates due to steam injection, the width of the TCE plumes may change, therefore the Pump and Treat system may no longer contain the TCE plumes.

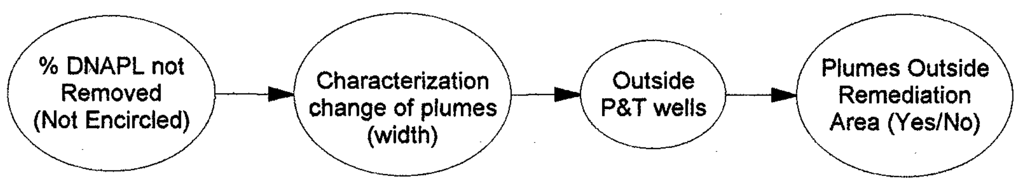


Figure 3-7 Plumes outside Remediation Area Influence Diagram

Table 3-3 Plumes outside Remediation Area Node Summary

	Node Designator	Equation/Probability	Description
1	DNAPL not Removed (Not Encircled) From Section 3.3.2	Uniform (0, 0.10)	The probability of the plumes being outside remediation area depends upon this effect happening.
2	Characterization change of plumes (width)	Uniform (0, Node 1*0.10)	Probability of the width of the plumes changing.
3	Outside P&T wells	Uniform (0, Node 2*0.16)	Probability that the new width is outside pump and treat wells containing the TCE plumes.
4	Plumes Outside Remediation Area (Yes/No)	Node 3	Probability that the TCE Plumes is outside remediation area.

3.3.4 Steam Breakouts

Steam naturally rises to the surface and its heating effect is normally a benefit to the remediation process. Nevertheless, a potential undesirable outcome of the process is a steam breakout. Instead of going to the extraction wells the steam finds another pathway to the surface, which results in an untreated release. Underground utility lines provide steam with several preferred pathways (Figure 3-8 and Table 3-4). These pathways can lead to either the surface, the C-400 building and/or above ground utility structures. Steam breakouts are dangerous because there is a possibility of exposing personnel to TCE and Tc-99 vapors.

One of these events happened at the Visalia Pole Yard where a steam breakout occurred inside an electrical panel bunker and duct bank resulting in damage to the utility structures [Richards, 1998]. To correct the problem the steam injection patterns were modified and cold water was placed over the breakout area [Richards, 1998]. In general, maintaining vacuum extraction 24 hours per day helps prevent a steam breakout.

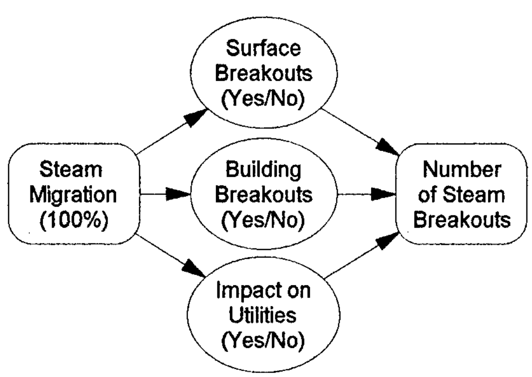


Figure 3-8 Steam Breakouts Influence Diagram

Table 3-4 Steam Breakouts Node Summary

	Node Designator	Equation/Probabilities	Description
1	Steam Migration	100%	This is the initializing event for steam breakouts.
2	Surface Breakout (Yes/No)	99%*	Probability of steam being released to the atmosphere.
3	Building Breakout (Yes/No)	99%*	Probability of steam being released within the building.
4	Impact on Utilities (Yes/No)	95%*	Probability of steam impacting utilities.
5	Number of Steam Breakouts	Node 2 + Node 3 + Node 4	Total number of steam breakouts

*See Section 3.5

3.3.5 Other Technological Risks

Other technological risks were investigated, but are not included in the tree because they are temporary problems and/or easily controlled by the DUS process itself. These risks include TCE degradation products and a failure to vaporize the TCE.

When enough heat is applied to TCE it will degrade to vinyl chloride; 1,1-dichloroethene; cis-1,2-dichloroethene; and trans-1,2-dichloroethene. Except for vinyl chloride, all of these chemicals are DNAPLs. Vinyl chloride is a carcinogenic and ranks fourth on the Environmental Protection Agency's Top 20 Hazardous Substances 1995 list [http://atsdr1.atsdr.cdc.gov:8080/cxcx3.html]. If TCE degrades, the degradation will occur along the steam front, where the temperature is too low for TCE to vaporize but hot enough to degrade. Although this is a technological risk, it was not included in the model. All of the degradation products, including vinyl chloride vaporize more readily than TCE. Therefore, when the steam front passes the degraded products, they will vaporize.

The purpose of DUS is to efficiently remediate a contaminated site by vaporizing TCE. Two effects hamper vaporization: (1) impermeable pockets; (2) and missed DNAPL pockets because of steam channeling, due to soil composition. The impermeable pockets and missed DNAPL pockets are considered temporary problems because the soil, by conduction, will eventually become hot enough to vaporize the TCE. This problem was not included in the model because the WAG 6 team believes that these pockets will be remediated during the DUS process.

3.4 Technological Risks Summary

A summary of the technological risks associated with DUS is in Table 3-5. This research focuses only on the critical events. A technological risk is unacceptable if the probability of occurrence is too high. The unacceptable risk of steam breakouts required further investigation to determine if there is an engineering application available to apply the suggested fix.

Table 3-5 Summary of DUS Technological Risks

	Risk Events	Critical?	Acceptable?	Suggested Fixes for Unacceptable
	Dynamic Underground Stripping			
1	Unrecovered DNAPL (RGA Only, McNairy)	YES	YES	
2	DNAPL, Tc-99 not Removed	YES	YES	
3	Plumes Outside Remediation Area (Depends upon Event 2)	YES	YES	
4	Steam Breakouts (UCRS Only)	YES	NO	Vacuum Pressure
5	TCE Degradation Products	NO	N/A	
6	TCE Fails to Vaporize	NO	N/A	

3.5 New Alternative: Dynamic Underground Stripping and 2 Phase

During the probability elicitation session, it was determined that one of the terminal events for DUS, steam breakouts, had an unacceptable likelihood of occurring. After some discussion, the WAG 6 team decided to add the 2 Phase technology to the DUS technology train. The addition of 2 Phase technology to DUS reduced the probability of steam breakouts from 99% to 2% (Table 3-6). The 2 Phase technology applicable to the UCRS zone would increase the control over the steam migration in this zone (see Appendix D). DUS would be limited to the RGA. However, the incorporation of 2 Phase with DUS added another terminal event to the event tree called *short circuit*.

Table 3-6 Steam Breakouts Node Summary (Updated)

	Node Designator	Equation/Probabilities	Description
1	Steam Migration	100%	This is the initializing event for steam breakouts.
2	Surface Breakouts (Yes/No)	Uniform (0, 0.04)	Probability of steam being released to the atmosphere.
3	Building Breakouts (Yes/No)	Uniform (0, 0.04)	Probability of steam being released within the building.
4	Impact on Utilities (Yes/No)	Uniform (0, 0.02)	Probability of steam impacting utilities.
5	Number of Steam Breakouts	Node 2 + Node 3 + Node 4	Total number of steam breakouts

3.5.1 Short Circuits

In the normal application of the 2 Phase system, the vacuum forms a relatively circular pattern around the well, depending upon the soil characteristics. As the vapor and ground water are extracted from the subsurface, the vacuum pressure extends further and further away from the well. A short circuit occurs when the vacuum pressure finds a preferred path and all the created suction is diverted to this avenue.

Such an event means a loss of vacuum in all other areas and a failure to remove the subsurface vapor and ground water. This problem is fixed by either drilling another well or blocking the preferred pathway. With the addition of this technological risk, the event tree for 2 Phase & DUS has five terminal events.

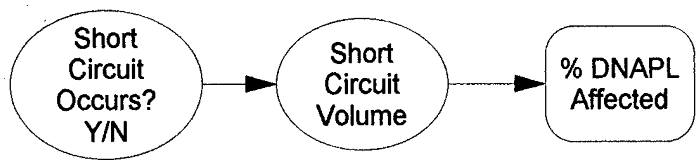


Figure 3-9 Short Circuit Influence Diagram

Table 3-7 Short Circuit Node Summary

	Node Designator	Equation/Probability	Description
1	Short Circuit Occurs Y/N	75%	There is a 75% chance that a short circuit will occur.
2	Short Circuit	Uniform (0, 0.10)	Percentage of Volume affected.
3	% DNAPL Affected	Node 1 * Node 2	Total percent of affected DNAPL.

3.5.2 Dynamic Underground Stripping & 2 Phase Evaluation Measure Scores

This new alternative needed to be scored against the CERCLA value hierarchy. Appendix E presents the WAG 6 CERCLA value hierarchy and evaluation measures from Kerschus in 1997.

Since a few of the scores for the evaluation measures contain uncertainty, the WAG 6 team provided a range of three scores (Appendix F). This range consists of the lowest, most likely, and highest outcomes. The uncertainty involved required changing the original deterministic model into a probabilistic model. The result from the probabilistic model is a range of possible CERCLA values for 2 Phase & DUS.

The next step was to obtain probabilities for this range of lowest, most likely, and highest outcomes. Use of probabilities will clear up any ambiguity in these expressions. Since most of the evaluation measures are continuous and the range of scores is limited, it was decided to use the extended Pearson-Tukey approximation method to convert the continuous probabilities to a discrete probability distribution [Kirkwood, 1996: 134]. The Pearson-Tukey method provides three discrete probability levels, set at 0.05, 0.50, and 0.95 fractiles, corresponding to the lowest, most likely, and highest outcomes and delivers a reasonably accurate approximation for a wide variety of distributions [Clemen, 1995: 278].

3.6 The Complete Model

The event models and the CERCLA probabilistic model were merged to determine the effect of the undesirable events on the overall CERCLA value of the 2 Phase & DUS alternative. Analyzing the effect of the technological risks on the overall CERCLA value was only performed for the most promising technology, 2 Phase & DUS. The influence diagram for the complete model is presented in Appendix G. In order to determine the overall effect, each event was assessed against the balancing criteria's evaluation measures.

3.6.1 Evaluation Measures Scores

The occurrence of an undesirable event affects some of the evaluation scores. This required an assessment of each evaluation measure to determine if the undesirable events influence the evaluation measure's score. To illustrate the evaluation measures in Table 3-8 are the only scores affected by the occurrence of the unrecovered DNAPL event. The rest of the events and their affected evaluation measures are in Appendix I.

Table 3-8 Evaluation Measures Affected

	Evaluation Measures
DNAPL Unrecovered	% TCE Left in the Subsurface
	%TCE Destroyed, Treated, or Recycled
	Volume Reduction of TCE
	%TCE Irreversible Treated/Removed
	Community Protection
	Risk of Exposure from Unmonitored Pathways

With a list of affected measures, the next concern centered on how the scores for these evaluation measures changed. The modification of a score depends upon the amount of DNAPL affected and the definition of the measure. In the case of unrecovered DNAPL, the change in the score for Percent TCE left in the Subsurface is additive. To be able to use the additive function, the original scores are required to be independent of the undesirable events. Unfortunately, some bias was unavoidable, since the alternative 2 Phase & DUS was scored after the undesirable events were discussed with WAG 6.

To show the effect the event unrecovered DNAPL has on the Percent TCE left in the Subsurface evaluation measure see Table 3-9. Using a computer program called Decision Programming Language (DPL) to obtain a cumulative distribution for this event furnished the 5%, 50%, and 95% fractiles needed for the Pearson-Tukey method. The amount of affected DNAPL at these fractiles is 0.343%, 1.32%, and 2.96% respectively. These percentages were added to the original scores.

Table 3-9 2 Phase & DUS Scores for Unrecovered DNAPL

% TCE left in subsurface		Lowest	Most Likely	Highest
	Original Score:	5%	10%	30%
	Probability:	0.185	0.63	0.185
Unrecovered DNAPL				
Probability	Percentage			
0.185	0.351%	5.351%	10.351%	30.351%
0.63	1.26%	6.26%	11.26%	31.26%
0.185	2.99%	7.99%	12.99%	32.99%

3.7 Modeling Assumptions and Limitations

Assumptions for this model were necessitated by the limited amount of data available. These are:

1. The additive value function used in the CERCLA probabilistic model requires the elements of the CERCLA value hierarchy to be mutually preferentially independent. According to Kerschus, this is a reasonable assumption since the value hierarchy was built with this in mind. For a further explanation of this assumption reference Section 3.7 of Kerschus' research.

2. Although the 2 Phase technology has been applied with other technologies, it has never been used with the DUS. Because there is no data available about the performance of the 2 Phase & DUS technology train the following assumptions were made:

A. The configuration design for 2 Phase & DUS is correctly engineered with respect to the C-400 building (Section 3-2).

B. According to the Life Cycle Cost model developed by MSE Technology Application, Inc (MSE) for WAG 6, the 2 Phase technology will require at least 2.54 years to remove 90% of the DNAPL from the UCRS. It is believed that the steam heat generated from the DUS technology will enhance 2 Phase's efficiency. The heat increases the mobility of the DNAPL, which makes it easier to remove by vacuum extraction. It is for this reason that 2 Phase is assumed to operate for only as long as the DUS technology operates [Luong, 1998].

C. Removal of Tc-99 will be accomplished by DUS, since the latest information has the Tc-99 located in the RGA. It is assumed that by removing the DNAPL from the RGA, the Tc-99 will also be removed. This is a reasonable assumption since Tc-99 is more soluble than TCE.

D. When 2 Phase & DUS were incorporated into the same technology train the capital cost was estimated by adding the capital cost of each technology together. Before adding these two together the capital cost for 2 Phase required some adjustments (Table 3-10). There are three significant changes to 2 Phase's capital cost [Luong, 1998]. (1) In a normal application of 2 Phase the pipes used are made of PVC. The heat generated by the DUS technology requires that the piping be made of steel. (2) There is no need for two surface treatments; therefore, the carbon vessels are not required. (3) There is additional construction cost when incorporating 2 Phase with DUS.

Table 3-10 2 Phase Capital Costs [Luong, 1998]

2 Phase Capital Cost: Item Description	Original Cost	New Cost
Design and Permitting	80,000	80,000
Regulatory Negotiation/Public Relations	54,000	54,000
Skid Mounted Vacuum system	80,000	80,000
Piping (1)	20,000	36,600
Electrical Service	20,000	20,000
Carbon Vessels (2)	80,000	N/A
Construction/Startup (3)	N/A	267,000
TOTAL	334,000	537,600

E. Initially, the application of DUS was for both the UCRS and the RGA zones. It is assumed that the discount received by decreasing the area that DUS is applied to equals the operating cost of the 2 Phase technology. There is no data to support or discount this assumption.

3. The undesirable events which affect the evaluation measures Time Until Protection and Cost are penalties and are not a reflection of the actual amount of time or dollars needed to recover from an event. These penalties are relative to the degree of belief the WAG 6 team has for the effect these events have on time and cost.

4. The following assumptions were made by MSE in developing the Life Cycle Cost model [Luong, 1998].

A. The DUS performance curve obtained from the vendor is an accurate reflection of the technology's performance.

B. The LCC model addresses the DNAPL volume uncertainty by varying the RGA length. The UCRS area does not change for different volumes.

3.8 Conclusion

In evaluating the technological risks for DUS a new alternative 2 Phase & DUS was created. The technology risks for this new alternative are unrecovered DNAPL, DNAPL not removed, plumes outside the remediation area, steam breakouts and short circuits. The influence diagrams built for these events were incorporated into the CERCLA probabilistic model to provide a risk profile for the 2 Phase & DUS technology. In addition to the risk profile, Chapter 4 will present the CERCLA value position of this new alternative compared to the other technology trains. Unlike the other technology trains, this ranking will be a range, which takes into account the uncertainty of the evaluation measures' scores.

4 Results and Analysis

4.1 Introduction

Results of the technological risk event models and the CERCLA probabilistic model for 2 Phase & DUS are presented here. To provide a common basis of comparison with the other technology trains, this chapter first displays the deterministic CERCLA value ranking of all technology trains, including the new alternative 2 Phase & DUS.

The chapter then discusses the results of the 2 Phase & DUS probabilistic model without technological risks to provide a baseline. The majority of the chapter presents the risk profiles for the technological risks and their effect on the overall CERCLA value for 2 Phase & DUS. An investigation of the impact of volume uncertainty is also included.

4.2 Deterministic Ranking of 2 Phase & DUS

The first step in this analysis was to determine where the new alternative ranks in comparison with the other technology trains (Table 4-1). This overall CERCLA value ranking is for 100,000 DNAPL gallons and uses the most likely score for 2 Phase & DUS, the conditions for the other technology trains given in Table 4-1. For a description of each of the technologies see Appendix D. To maintain continuity with Kerschus' research, the train numbers are the same, except that train 1 is now 2 Phase & DUS instead of simply DUS [1997]. It must be noted that LASAGNA & ISCO (Train 21) is not included in this analysis. Compared to the other two technologies that are grouped with ISCO, 2 Phase and 6 Phase, the LASAGNA technology does not provide the vapor control needed for the ISCO process [Richards, 1998].

In comparison to Kerschus' results for DNAPL volume at 100,000 gallons, these CERCLA value rankings differ slightly. These differences are attributed to a new version of MSE's Life Cycle Cost model used in this analysis. The most significant change is that the top two trains (9 & 7) swap positions. There were also some minor shifts among the lower ranked trains.

The 2 Phase & DUS technology train ranks 3rd against the other trains at the 100,000 gallon spill volume. As the volume of DNAPL increases, the 2 Phase & DUS train maintains this third ranking until the 400,000 and 500,000 DNAPL volume where it moves to the 2nd and 1st ranking, respectively. This is similar to the performance of the original DUS technology train. It indicates that the addition of the 2 Phase technology to the DUS alternative does not adversely affect the CERCLA value ranking.

Another important aspect to consider is the effectiveness of a particular train. According to CERCLA, effectiveness is defined by the following three balancing criteria: Short Term, Long Term, and TMV. Table 4-1 provides an effectiveness ranking for the technology trains at 100,000 DNAPL volume. Although the top train (2 Phase & Surfactants) and 2 Phase & DUS do not change positions between the overall CERCLA list and the effectiveness list, there are two significant changes that require comment. The first change is train 9; it moves from second position in overall CERCLA value to eighth position in effectiveness rankings. This ranking change is due to train 9's low ranking in the TMV criterion (Ranked 14th). Another significant detail is the location of the no action alternative. In effectiveness rankings, the no action alternative is ranked last, which is expected because it has by definition the lowest remedial effectiveness.

Table 4-1 Overall and Effectiveness Rankings for all Alternatives (100,000 Volume)

Overall Ranking			Effectiveness Ranking		
Rank	**Train**	**Value**	**Rank**	**Train**	**Value**
1	2 Phase & Surfactants. (Train 7)	7.66	1	2 Phase & Surfactants (Train 7)	7.60
2	2 Phase & ISCO (Train 9)	7.54	2	2 Phase & Cosolvents (Train 6)	7.57
3	**2 Phase & DUS (Train 1)**	7.42	3	**2 Phase & DUS (Train 1)**	7.54
4	2 Phase & Cosolvents (Train 6)	7.41	4	6 Phase & Surfactants (Train 13)	7.44
5	6 Phase & Surfactants (Train 13)	7.07	5	6 Phase & Cosolvents (Train 12)	7.40
6	6 Phase & Cosolvents (Train 12)	6.98	6	LASAGNA & Surf. (Train 19)	7.33
7	LASAGNA & Surf. (Train 19)	6.97	7	LASAGNA & Cosol. (Train 18)	7.29
8	2 Phase & PTZ (Train 5)	6.93	8	2 Phase & ISCO (Train 9)	7.22
9	LASAGNA & Cosol. (Train 18)	6.87	9	LASAGNA & PTZ (Train 17)	7.01
10	LASAGNA & PTZ (Train 17)	6.77	10	LASAGNA & Redox (Train 20)	6.60
11	RHF & ISCO(Train 22)	6.75	11	RHF & ISCO (Train 22)	6.51
12	6 Phase & ISCO (Train 15)	6.48	12	2 Phase & PTZ (Train 5)	6.47
13	6 Phase & PTZ (Train 11)	6.40	13	6 Phase & ISCO (Train 15)	6.46
14	No Action (Train 23)	6.26	14	6 Phase & PTZ (Train 11)	6.26
15	LASAGNA & Redox (Train 20)	6.07	15	2 Phase & Redox (Train 8)	5.89
16	2 Phase & Redox (Train 8)	5.99	16	6 Phase & Redox (Train 14)	5.68
17	Dual Phase (Train 3)	5.78	17	2 Phase & P & T (Train 4)	4.90
18	UVB (Train 2)	5.69	18	Dual Phase (Train 3)	4.86
19	6 Phase & Redox (Train 14)	5.55	19	UVB (Train 2)	4.82
20	2 Phase & P & T (Train 4)	5.24	20	6 Phase & P &T (Train 10)	4.69
21	6 Phase & P & T (Train 10)	4.38	21	LASAGNA & P & T (Train 16)	4.62
22	LASAGNA & P&T (Train 16)	4.31	22	No Action (Train 23)	4.49

CERCLA also requires a technology train to be cost effective. A good way to distinguish cost effective technology trains is a scatter plot (Figure 4-1). This plot compares the effectiveness of a technology train against its Net Present Value (NPV). The best position to be at on this graph is the upper left corner where the trains have the highest effectiveness and the lowest NPV. For instance train 17 does not have the highest effectiveness value, but it is less expensive than the other trains with higher effectiveness. In other words, train 17 is not dominated by the other trains.

A train is dominated when there is an alternative with an equal or higher value for all criterion. The two criteria for this graph are NPV and effectiveness value. As indicated by the scatter plot, 2 Phase & DUS (point 1) is not dominated by any other train. The other non-dominated trains are 23, 17, 9, and 7. There are three dominated trains (4, 10, 16) not shown on this plot. These three trains are low in effectiveness and cost over $25 million dollars. Their inclusion would have lowered the resolution of the plot without adding useful information.

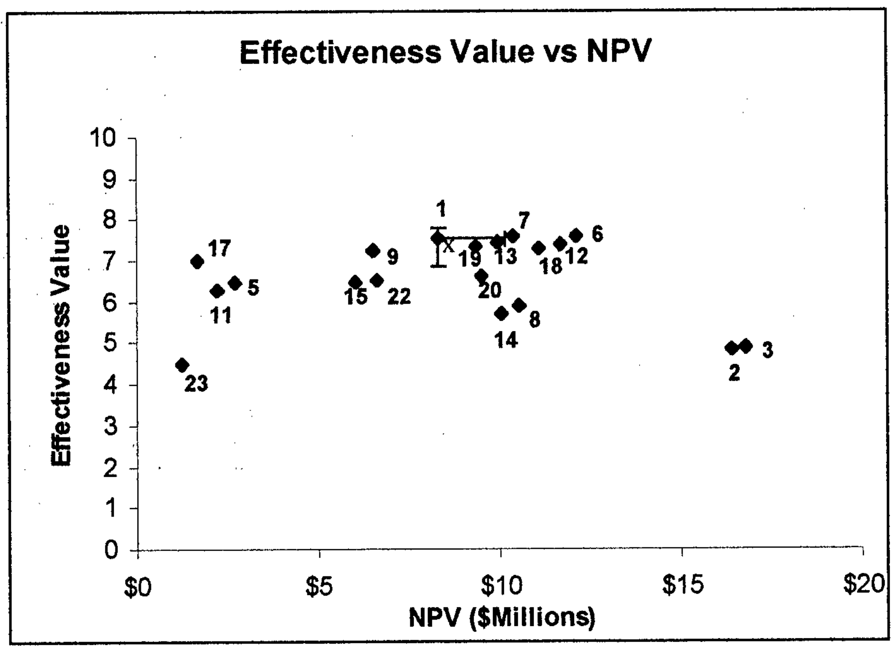


Figure 4-1 Effectiveness Value vs. NPV (100,000 Volume)

Obtaining a range of scores for 2 Phase & DUS provides a maximum and minimum effectiveness value for this alternative as indicated by the vertical bar in Figure 4-1. Total range of variations in effectiveness for 2 Phase & DUS is relatively small, less than 1/10 of the total effectiveness value available. This indicates that the effectiveness of 2 Phase & DUS technology train is fairly constant.

In Figure 4-1, the horizontal bar on train 1 is the possible NPV range. The NPV depends upon the length of time a technology train operates. The WAG 6 team indicates that 2.33, 2.33, and 5.33 years are the shortest, most likely, and longest lengths of time until protection for 2 Phase & DUS. This time includes the one year needed to design and set up the technology at PGDP. For the shortest and most likely case of 2.33 years, the NPV is $8.3 million. If the worse case occurs at 5.33 years, the NPV is $10.2 million.

Using the Pearson-Tukey assumption, as presented in Table 4-2, the expected values for effectiveness and NPV are 7.46 and $8.7 million respectively. Plotting the expected values on the above graph indicates that train 1 (point x) is not dominated at this point.

Table 4-2 Effectiveness and NPV Expected Values for 2 Phase & DUS (100,000 Volume)

Probability	NPV	Effectiveness
0.185	$8.3	7.7813
0.63	$8.3	7.5354
0.185	$10.2	6.882
Expected Value:	$8.7	7.46

4.3 Probabilistic Ranking of 2 Phase & DUS

A range of data for the evaluation measures allows for a probabilistic analysis of 2 Phase & DUS. This analysis indicates the possible CERCLA values with their associated probabilities for the 2 Phase & DUS alternative. The result of this analysis is portrayed by a risk profile generated from DPL (Figure 4-2).

A risk profile is a common method used to display results that include uncertainty. A risk profile is interpreted in the following fashion; the y-axis indicates the probability of the CERCLA value being less than or equal to the corresponding value on the x-axis. To illustrate, in Figure 4-2 there is a 100% probability that the CERCLA value for 2 Phase & DUS is less than or equal to 7.75 and a zero probability that the CERCLA value is 6.5 or less. An expected value can also be indicated on a risk profile. For 2 Phase & DUS the expected value is 7.33. However, some care is required when using expected values. The expected value calculation assumes a long run average with multiple trials. This implies that there are many chances to make the decision or in WAG 6's case remediate the site. However, there will only be one decision for WAG 6. The cleanup of the WAG 6 area is too costly in time, money and human health to do more than once. By using risk profiles, all possible values are presented with their associated probability, not just the expected value.

The DNAPL volume at WAG 6 is uncertain and a cumulative probability distribution was obtained to quantify this uncertainty (Figure 3-2). This spill volume distribution has been discretized to obtain probabilities for 50,000, 100,000, 200,000, 300,000, 400,000, and 500,000 DNAPL spill volumes (Table 4-3). The moment matching method used to obtain these probabilities is explained in Appendix B. The results presented in Figure 4-2 include the spill volume uncertainty.

Table 4-3 DNAPL Spill Volume Probabilities

DNAPL Volume	Probability
50,000	0.43
100,000	0.29
200,000	0.24
300,000	0
400,000	0.03
500,000	0.01

Figure 4-2 indicates that for 2 Phase & DUS the CERCLA value can range from 6.42 to 7.75. There is a probability of 44% that the value is 7.33 or less.

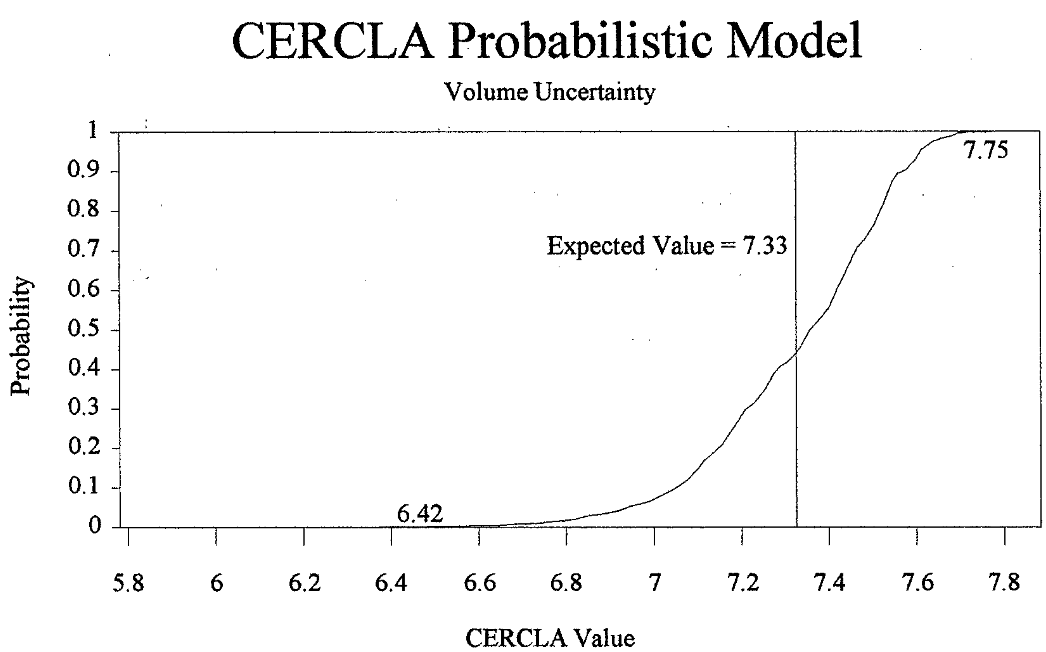


Figure 4-2 2 Phase & DUS CERCLA Probabilistic Risk Profile

Since the expected value is not located at the 50% fractile, the mode, there is more variance to the left of the mode. The CERCLA value range to the left of the mode is from 6.42 to 7.36 and to the right, it is 7.36 to 7.75. The left side has a larger possible range than the right side.

Given the uncertainty in volume, it is desirable to select a train that performs well over all volume possibilities. According to the risk profile in Figure 4-2, 2 Phase & DUS performance is relatively stable across the different volume possibilities since the range of possible CERCLA values is small.

There are no risk profiles for the other trains, but expected values with volume uncertainty exist. Figure 4-3 is the same risk profile as above but it includes the expected CERCLA values for the other trains with respect to volume uncertainty. If there are a group of trains with expected values close together, they are indicated by only one line. Figure 4-3 shows that 2 Phase & DUS can range from having a value worse than trains 22 and 17 to having the best CERCLA value. However, the probability of 2 Phase & DUS having a CERCLA value less than the expected values for trains 13, 19, 12 & 5 is only 7.4%.

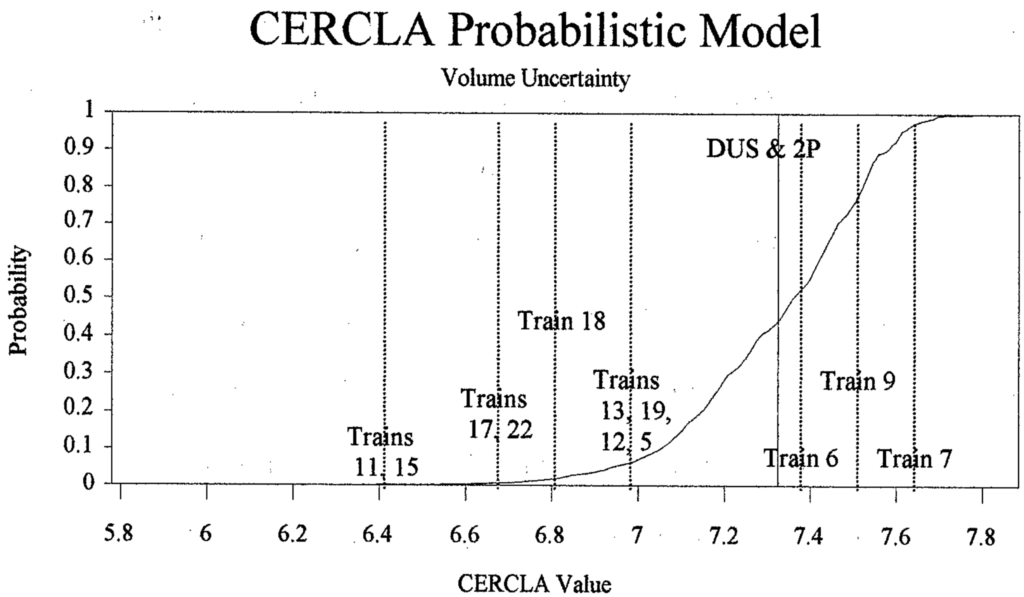


Figure 4-3 2 Phase & DUS Expected Value Comparison

4.4 Technological Events

Risk profiles are a good way to present the outcomes of the five technological risks for 2 Phase & DUS. For each event, there are four risk profiles. The first set of two risk profiles presents the results of running the event model with the probability of occurrence included. The second set of two risk profiles presents the worse case scenario, the technological risk definitely occurs. By including the worse case scenario, the most unfavorable outcome can be determined. The first risk profile of the two sets is the percent of affected DNAPL and the second includes volume uncertainty as discussed in Section 4.3.

4.4.1 Unrecovered DNAPL Risk Profile

The first technological risk identified was unrecovered DNAPL. The effect of this event was on the amount of DNAPL that may migrate into the McNairy

Formation. Figure 4-4 presents the risk profile generated, which includes the uncertainty of event occurrence. The percentage shown along the x-axis is the percent of DNAPL volume affected. A positive point about this profile is the small range; there is a 100% chance that the affected DNAPL will be 2.6% or less and a 98% probability of the event having no effect on the amount of DNAPL recovered. Figure 4-5 shows this same risk profile except the volume uncertainty is included. By including this uncertainty, the amount of affected DNAPL can be gauged. This risk profile indicates that there is a 99% probability of 207 gallons or less of affected DNAPL and a 100% probability of 2,975 gallons or less. These two risk profiles indicate that the consequences of the unrecovered DNAPL event are low.

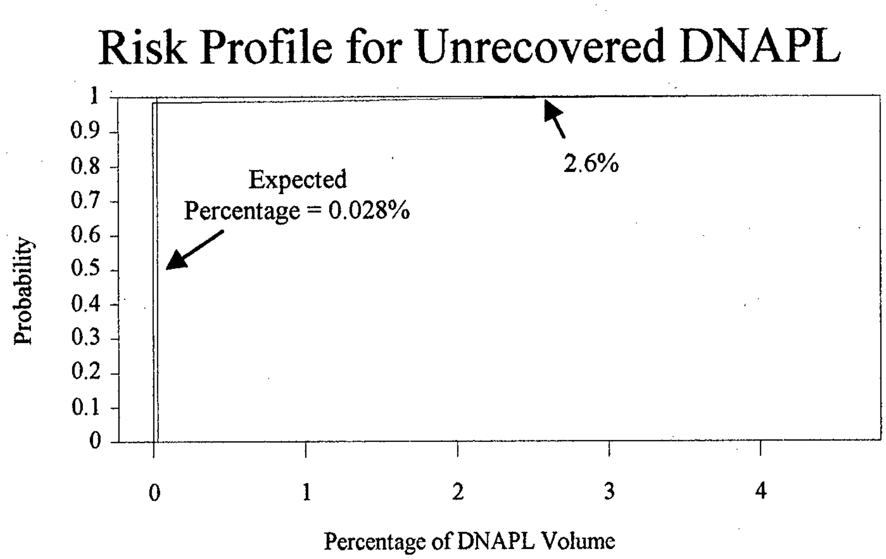


Figure 4-4 Unrecovered DNAPL Risk Profile

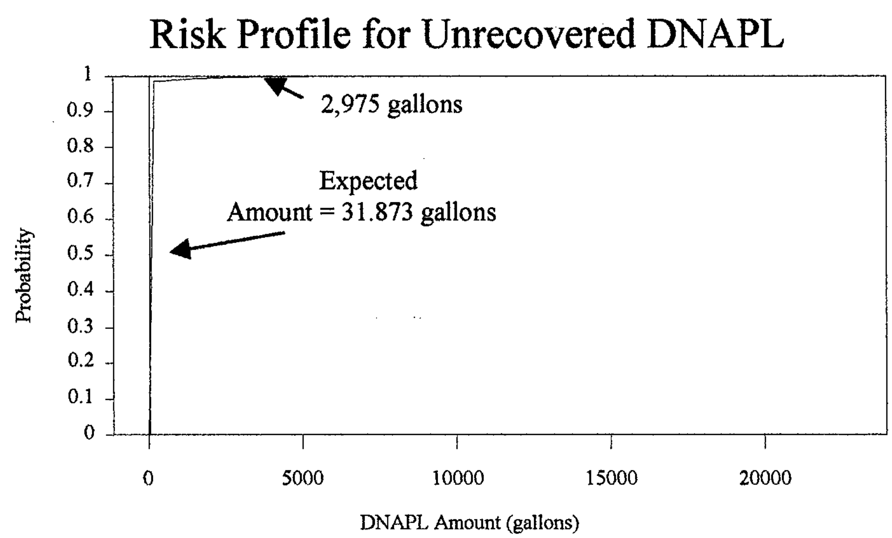


Figure 4-5 Unrecovered DNAPL Risk Profile with Volume Uncertainty

The above two graphs assume that the probability of occurrence for the unrecovered DNAPL event is correct, but the worse case would be for the event to occur. The next two risk profiles assume that the unrecovered DNAPL event occurs.

Figure 4-6 indicates that there is a 100% chance of 4.2% or less of DNAPL that is unrecovered even if the event occurs and there is a 54% probability of 1.45% or less of DNAPL volume. The beginning of the risk profile is relatively straight (AB) which indicates that the probability is constant for that area of the graph. The upper portion of the graph tapers off, this indicates a decreasing probability for the higher percentages.

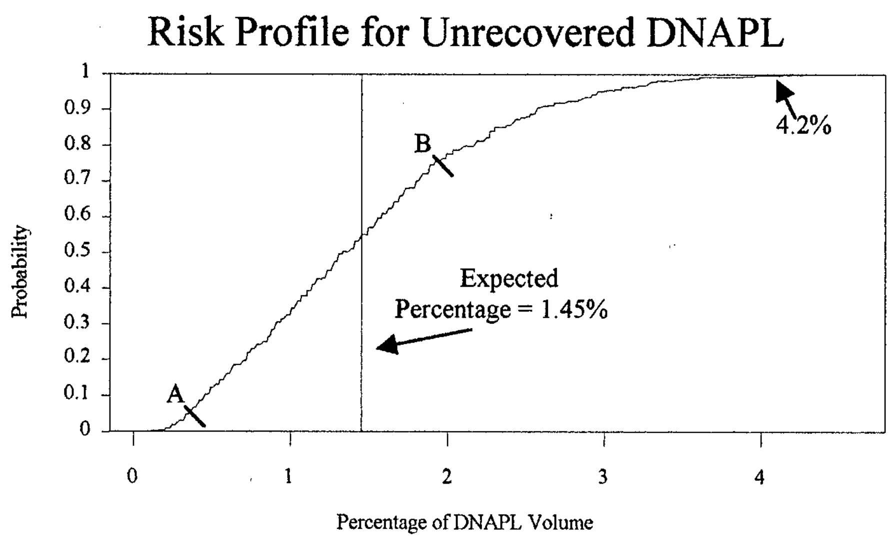


Figure 4-6 Unrecovered DNAPL Risk Profile Worse Case

When the volume uncertainty is included for the worst case possible, the amount of DNAPL migrating into the McNairy is between 0 and 11,627 gallons (Figure 4-7). There is a 100% chance of the DNAPL amount being less than or equal to 11,627 gallons and a 67% probability that the amount of unrecovered DNAPL is 1,671 gallons or less. The DNAPL amount of 11,627 gallons has a very small probability of occurring. The rapid rise of the curve indicates that there is a higher probability for smaller amounts of DNAPL being unrecovered than larger amounts.

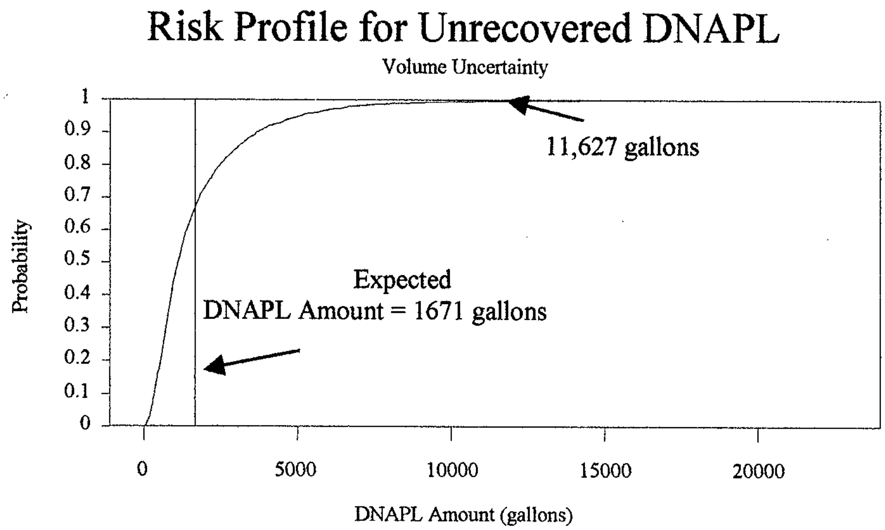


Figure 4-7 Unrecovered DNAPL Risk Profile Worse Case with Volume Uncertainty

4.4.2 DNAPL not Removed

The DNAPL not removed event only applies to DNAPL not encircled by the injection wells. DNAPL that is not removed from inside the circle of injection wells and does not migrate into the McNairy Formation has been handled by the evaluation measure, Percent of TCE left in the Subsurface.

The percent of affected DNAPL for the not removed event is a uniform distribution ranging from 0 to 10%. This is also its probability of occurrence. The risk profile in Figure 4-8 ranges from 0% to 8.87%, with a 95% chance of having no DNAPL affected.

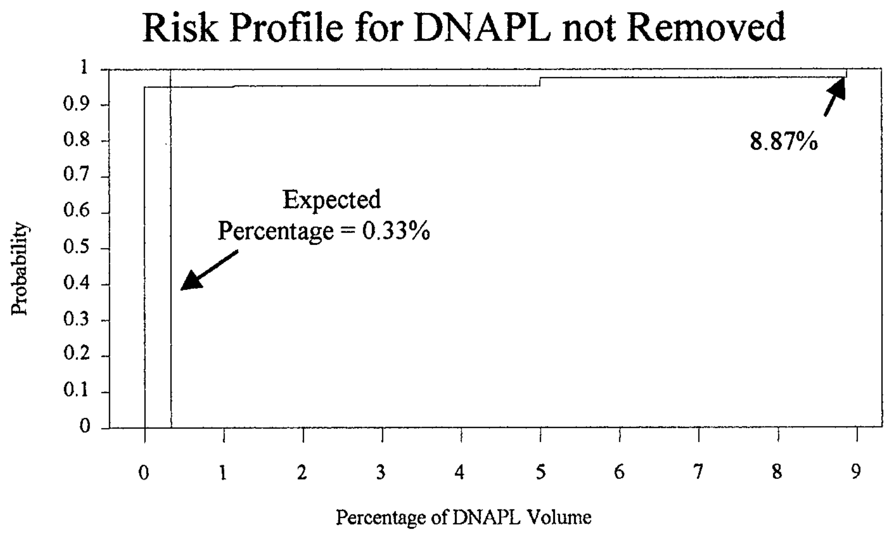


Figure 4-8 DNAPL not Removed Risk Profile

Figure 4-9 includes volume uncertainty. The range for this profile is 0 to 17,700 gallons (approximately), with a 95% chance of zero gallons. Given the volume uncertainty ranges from 10,000 to 500,000 DNAPL gallons, this is a low risk event.

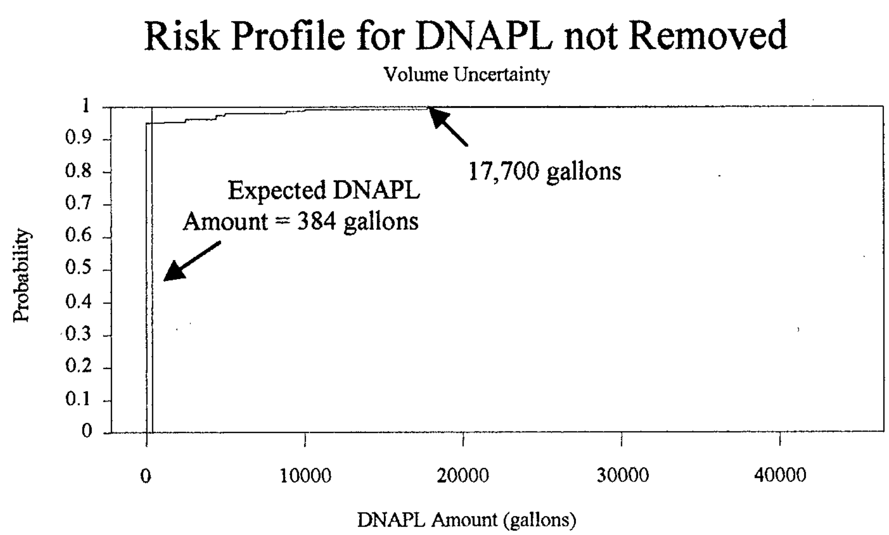


Figure 4-9 DNAPL not Removed Risk Profile with Volume Uncertainty

If the DNAPL not removed event occurred, the percentage of DNAPL volume affected would be a uniform distribution between 0 and 10%. This event is highly dependent on locating all the DNAPL sources in the subsurface. Although, the WAG 6 team believes that all the DNAPL sources have been pinpointed, they are not 100% certain, hence the uniform distribution. The worse case would be that 10% of the DNAPL volume has not been located, thus it is not encircled by the injection wells.

Including the volume uncertainty with the DNAPL not removed event produces the risk profile in Figure 4-10. The range of affected DNAPL is 0 to 36,000 gallons. There is a 90.5% probability of 9,860 gallons or less of DNAPL not removed. The volume uncertainty ranges from 10,000 to 500,000 DNAPL gallons, with an expected value of 115,000 gallons (approximately). If there were 115,000 gallons of DNAPL in the subsurface, the 9,860 gallons would be 9% of the DNAPL left in the subsurface. This is close to the optimistic level of cleanup desired for WAG 6. Even for the worst case, the risk is not as low as the unrecovered DNAPL event.

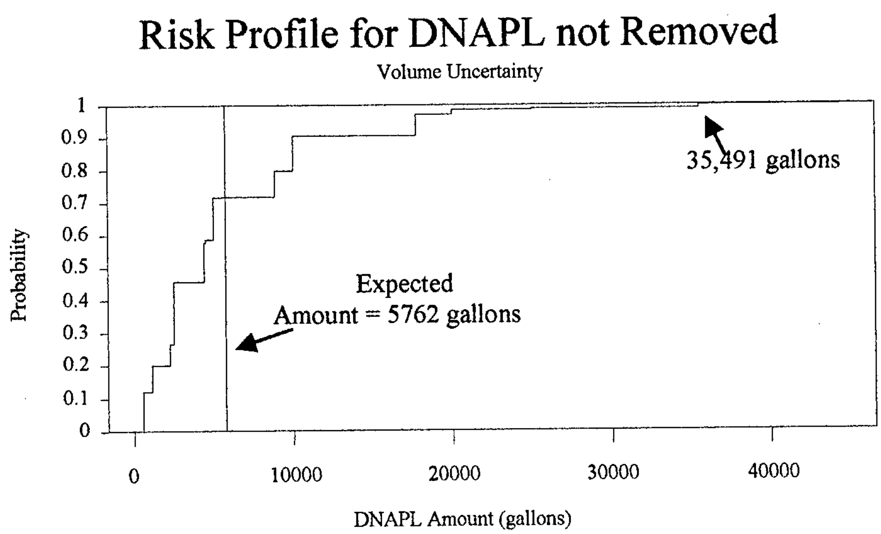


Figure 4-10 DNAPL not Removed Risk Profile Worse Case with Volume Uncertainty

4.4.3 TCE Plumes Outside Remediation Area

As previously mentioned in Section 3.3.3, the occurrence of TCE plumes outside remediation area event depends upon the DNAPL not removed event. Therefore there are two uncertainties involved with this technological risk: the DNAPL not removed occurrence and the TCE plumes outside the remediation area occurrence. If the probability of occurrence for both of these events is correct, then the expected probability for TCE plumes outside the remediation area is 1.33×10^{-5}. For all practical purposes this means the likelihood of the TCE plumes spreading outside the remediation area is effectively zero.

If the worst case happens and DNAPL is not completely encircled, the likelihood of the TCE plumes moving outside the remediation area increases to

0.0002%. Even in such a “worst case” scenario, it is highly unlikely that the TCE plumes will spread outside the current Pump and Treat containment system.

4.4.4 Steam Breakouts

Unlike the above events, the primary concern for steam breakouts is the probability of occurrence, not the amount of DNAPL affected. If a steam breakout occurs there is a possibility of endangering personnel and/or damaging structures. The number of steam breakouts depends upon the probabilities of three different types of breakouts: surface breakouts, building breakouts, and impact on utilities. Steam breakouts is a discrete event; it happens or it does not. Figure 4-11 shows the risk profile for the number of possible steam breakouts with their associated probability. This event is a low risk event since there is a 96% chance of no steam breakouts occurring.

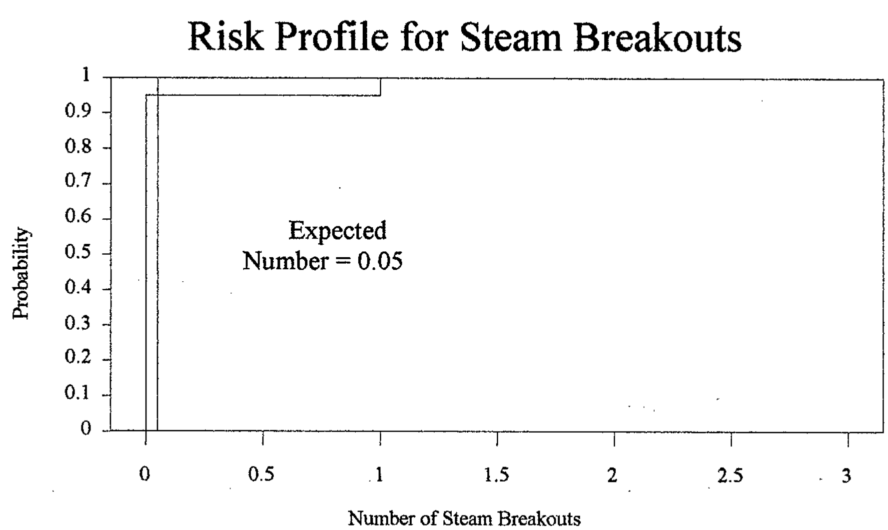


Figure 4-11 Steam Breakouts Risk Profile

4.4.5 Short Circuits

For the short circuit event, the probability of occurrence is high (75%) but the percent of affected DNAPL is low (Uniform (0, 0.1)). This event only applies to the UCRS and it is believed that only 10% of the DNAPL in the subsurface is located in the UCRS. Therefore, the total amount of affected DNAPL possible is 10% of the volume in the subsurface. Figure 4-12 presents the risk profile for the percent of affected DNAPL. As indicated by the risk profile there is a 100% probability of 0.9% or less of DNAPL affected by the short circuit event.

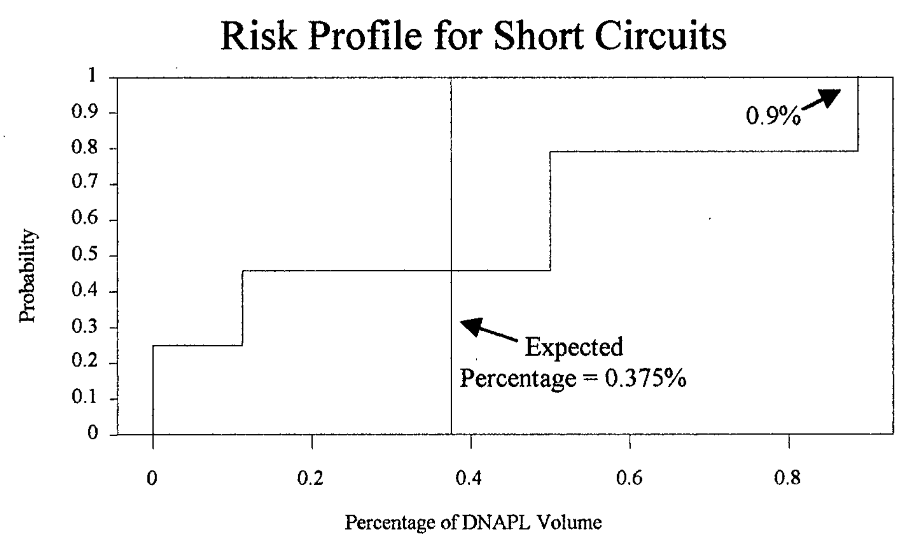


Figure 4-12 Short Circuits Risk Profile

Figure 4-13 presents the risk profile for short circuit event with the volume uncertainty. The possible range is 0 to 3,600 gallons with a 98% chance of 1,900 gallons or less of affected DNAPL. There is a 60% probability of 240 gallons or less.

Although there is more variance towards the higher DNAPL amounts, it is more likely for a lower amount of DNAPL to be affected by the short circuit event.

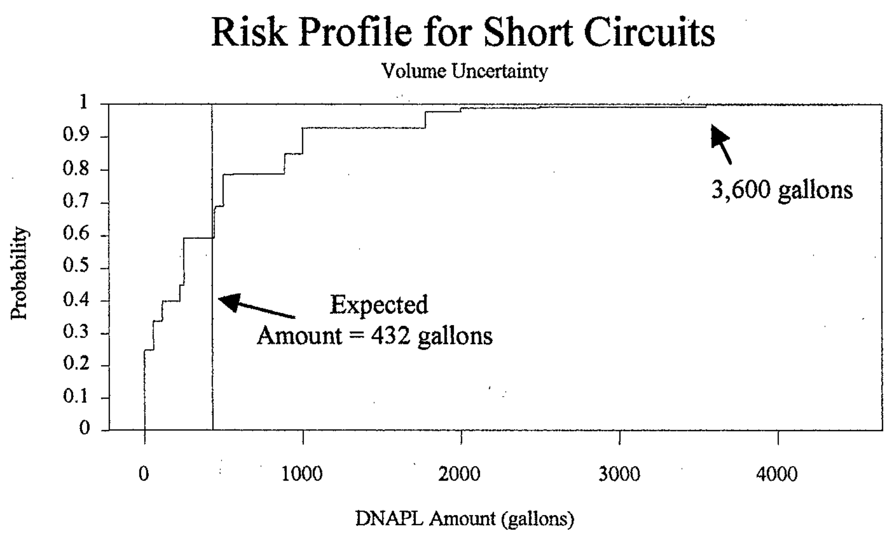


Figure 4-13 Short Circuits Risk Profile with Volume Uncertainty

Since the probability of occurrence is high for this event, there would only be a small increase in the expected value and range if this event definitely occurs. The percentage of affected DNAPL without the volume uncertainty would range from 0 to 1% with an expected value of 0.5%. The change in the expected value and the range of affected DNAPL when the volume uncertainty is included is also small. The expected amount of DNAPL would increase to 576 gallons with an upper boundary on the range of 4,450 gallons.

4.4.6 Event Summary

The technological risks have been evaluated to obtain a risk analysis of the technology train 2 Phase & DUS. Except for the DNAPL not removed event and

TCE plumes outside the remediation area event, all these occurrences are independent and it is possible for all, none or a combination of these events to occur. If more than one undesirable event occurred the effect would be additive.

Of the five events, the DNAPL not removed event has the largest possible range of affected DNAPL amount. However, the event with the highest expected affected DNAPL amount is the short circuit event. The two events with the lowest probability of occurrence are TCE plumes outside remediation area and steam breakouts.

4.5 2 Phase & DUS Probabilistic Model with Technological Risks

One of the most important comparisons for the 2 Phase & DUS technology train is the results from the CERCLA probabilistic model without technological risks against the results from the CERCLA probabilistic model with technological risks. The CERCLA probabilistic model with technological risks requires over 16.5 billion pathways to be evaluated, which would take more than two weeks to accomplish with a 90 MHz computer. In order to obtain results in a reasonable amount of time, the CERCLA probabilistic model with technological risks was simulated using an approach called distributed sampling. The explanation for this approach is in Appendix J.

After comparing the impact of technological risks to the overall CERCLA value, the probabilistic model was broken down into individual balancing criteria to determine which balancing criteria is the most sensitive to the technological risks. Figure 4-14 is a technological risk matrix that indicates which evaluation measures in each balancing criterion are affected by the technological risks.

Technological Risks, Evaluation Measures Matrix

EVENT MATRIX

Category	Criterion	DUS & 2P	1. Unrecovered DNAPL (RGA Only, McNairy)	2. DNAPL not Removed, Tc-99 not Removed	3. DNAPL outside Remediation Area (Event 2 Dependent)	4. Steam Breakouts (UCRS only)	5. Short Circuit (UCRS only)
Cost	Net Present Cost		X	X	X	X	X
Implementability	Minimum # of Contractors/Subcontractors						
Implementability	Treatment/Storage/Disposal Options for TCE and Tc-99						
Implementability	Effort Obtain Approvals						
Implementability	Risk of Exposure from Unmonitored Pathways						
Implementability	Effect/Impact on Future Remedial Action			X			
Implementability	# of Successful Applications						
Implementability	# of System Equivalents for the Treatment Train						
Implementability	Ability to Construct						
Short-Term	Year Until Protection is Achieved			X		X	X
Short-Term	Subsurface Injectants of Foreign Materials						
Short-Term	Surface Releases					X	
Short-Term	Worker Protection						
Short-Term	Community Protection					X	
Toxicity, Mobility, or Volume	%Tc-99 Irreversibly Treated/Removed from the Subsurface			X			
Toxicity, Mobility, or Volume	%TCE Irreversible Treated/Removed from the Subsurface		X	X			X
Toxicity, Mobility, or Volume	Reduction in Volume of Tc-99 Contaminated Zone			X			
Toxicity, Mobility, or Volume	Reduction in Volume of TCE Contaminated Zone		X	X			
Toxicity, Mobility, or Volume	Tc-99 Mobility Reduced						
Toxicity, Mobility, or Volume	TCE Mobility Reduced						
Toxicity, Mobility, or Volume	Reduction of Toxicity Through In-Situ Degradation						
Toxicity, Mobility, or Volume	%Tc-99 Destroyed, Treated, or Recycled			X			
Toxicity, Mobility, or Volume	%TCE Destroyed, Treated, or Recycled		X	X			X
Toxicity, Mobility, or Volume	PCOCs Addressed in the Treatments						
Long-Term	Replacement of Technical Components after Remedial Action						
Long-Term	Activity of Tc-99 Left in Ground Water			X			
Long-Term	% TCE Left in the Subsurface		X	X			X
Long-Term	HM Remaining in the Subsurface						

Events

Figure 4-14 Event Matrix

Due to size limitations of DPL, two technological risks were removed from the balancing criteria NPV's influence diagram when volume was included. By doing event sensitivity analysis, it was determined that these two events had an insignificant effect on the NPV value and therefore were excluded with minimum impact. These two technological risks were unrecovered DNAPL and short circuits. The NPV balancing criteria was the only one affected by this limitation.

4.5.1 CERCLA Value Risk Profiles

Comparing the risk profiles of the probabilistic model without technological risks, and the probabilistic model with those risks, illustrates the overall effect of the technological risks on the CERCLA value for 2 Phase & DUS. Figure 4-15 presents this comparison. As one might expect, the risk profile that includes the technological risk has a lower expected value and a wider possible range. However, the difference in value is small (Table 4-4). The technological risks do not seem to have much affect on the CERCLA value for 2 Phase & DUS, implying that the approach is robust.

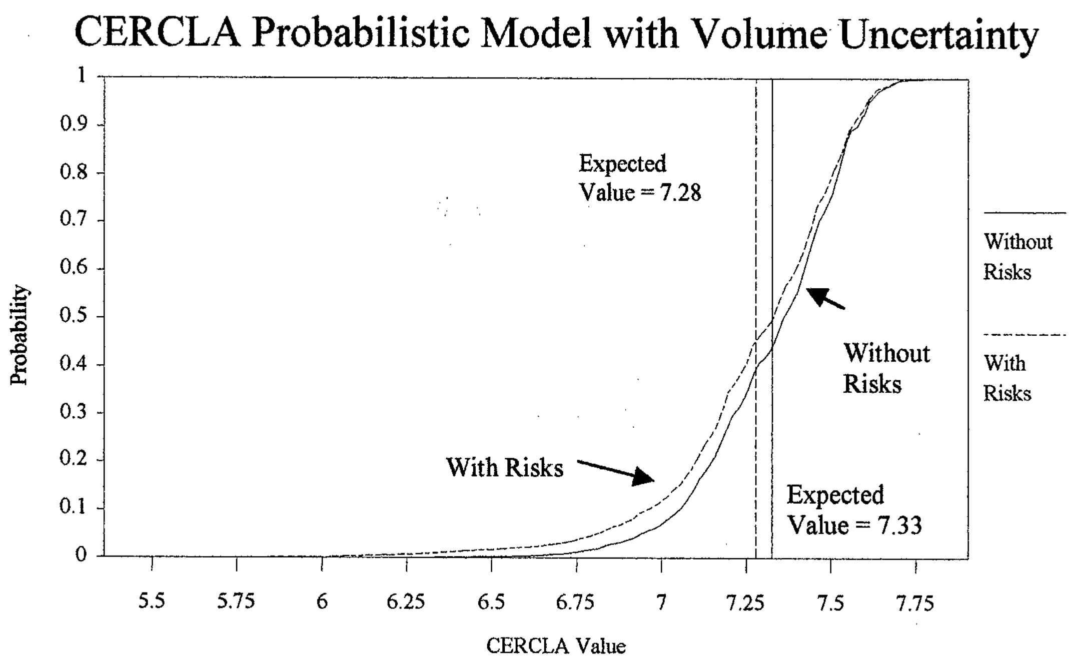


Figure 4-15 CERCLA Value for 2 Phase & DUS Technological Risk Comparison

Table 4-4 CERCLA Value for 2 Phase & DUS Technological Risk Comparison

Model	Expected Value	Lower Range	Upper Range
Without Risks	7.33	6.42	7.75
With Risks	7.28	5.98	7.75

The cost effectiveness graph has been updated to include the volume uncertainty and the technological risks for 2 Phase and DUS (Figure 4-16). To reduce the clutter some of the more expensive and less effective trains are not shown. Train 1 (2 Phase & DUS) has the longest possible NPV range. Trains 7, 18, 13, 19, and 9 all have similar possible NPV ranges. The Permeable Treatment Zone (PTZ) (trains 17, 5, and 11) technology is not affected by the volume uncertainty. PTZ technology is considered a containment strategy. The probability of the higher NPVs for most of these trains is low, but it is a possibility. If the chance of having a high

NPV is unacceptable, then a train that includes the PTZ technology should be used to remediate the WAG 6 site.

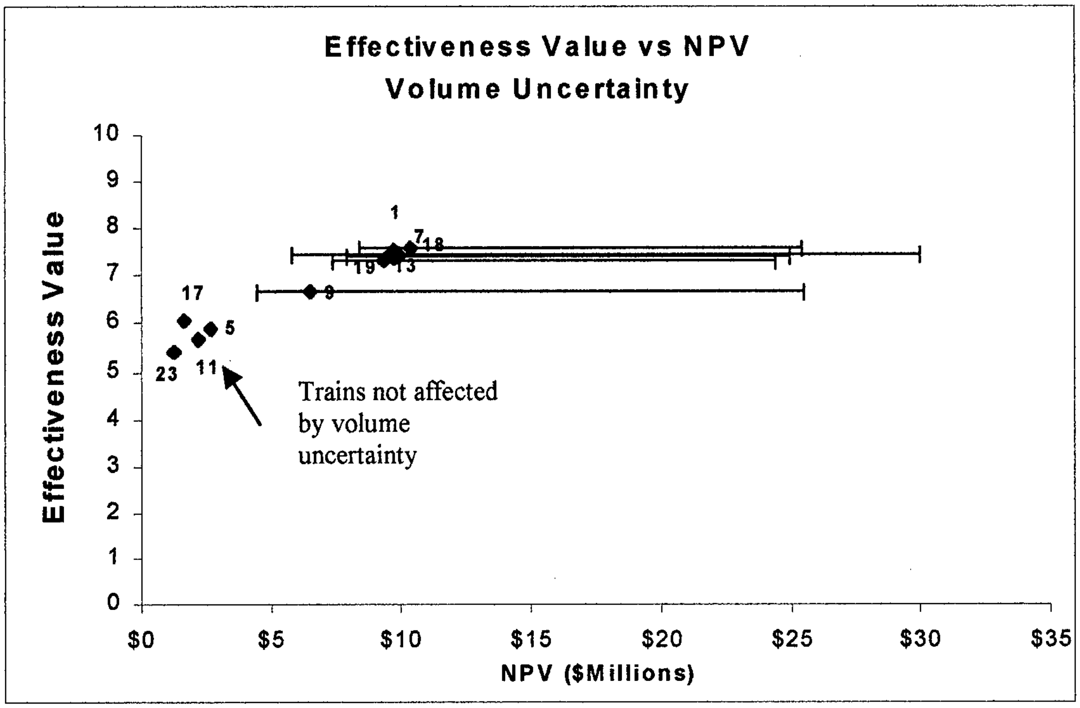


Figure 4-16 Effectiveness Value vs. NPV with Volume Uncertainty

4.5.2 Effect of Technological Risks on Individual Balancing Criteria

There are two balancing criteria which show a significant difference between the risk profile without the technological risks and the risk profile with technological risks, Short Term criteria and Net Present Value criteria. All other balancing criteria exhibit very little change between these two risk profiles. Comparison of the two risk profiles for Short Term and NPV criteria are shown here. All of the other balancing criteria risk profiles are presented in Appendix I.

Figure 4-17 show risk profiles for both the Short Term criteria with and without technological risks. The risk profile without technological risks is a straight vertical line at a 5.25 value. The risk profile with technological risks has an expected value of 5.19 and ranges from 3.9 to 5.25. As indicated by the graph the addition of technological risks increases the possible range of the Short Term CERCLA value. There is a 0.5% chance of a CERCLA Short Term value of 3.9 and a 100% probability of a CERCLA Short Term value of 5.25 or less.

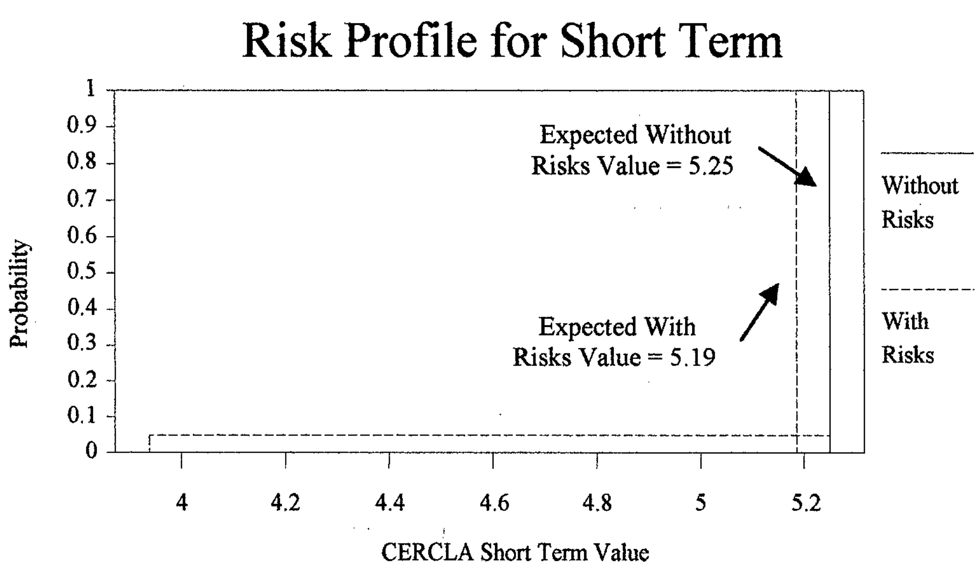


Figure 4-17 Short Term Risk Profiles

The NPV risk profiles for both with and without technological risks are presented in Figure 4-18. These profiles are set at the DNAPL volume of 100,000 gallons and the x-axis is in dollar amounts. The risk profile without technological risks has an expected NPV of $8.7 million dollars and a range from $8.3 to $10.2 million dollars. With the addition of technological risks the expected NPV increases to $9.1 million dollars and the range spreads from $8.3 to $20.4 million dollars. When technological risks are not included, there is an 82% chance of a NPV of $8.3 million and a 100% probability of $10.2 million or less. The addition of the technological risks increases the range of possible NPVs. The probability for $8.3 million dollars has decreased to 33% and there is now a 94% chance of $9.8 million dollars or less.

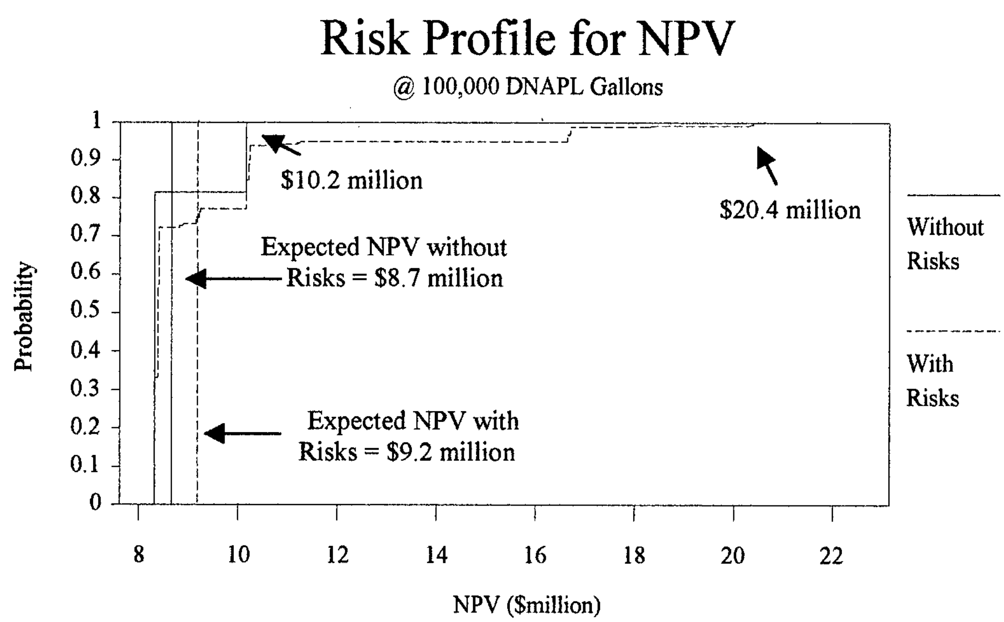


Figure 4-18 NPV Risk Profiles

Figure 4-19 presents the NPV risk profiles with the volume uncertainty included. The expected NPV for the two risk profiles are closer together when the volume uncertainty is included for the 100,000 DNAPL gallons portrayed in Figure 4-18. The range for the risk profile without risks is $5.8 million to $25 million and the range for the risk profile with technological risk is $5.8 million to $30 million.

The range difference between the two risk profiles is only about 5 million dollars. The similarity between the two risk profiles indicates that the volume uncertainty over shadows the technological risks.

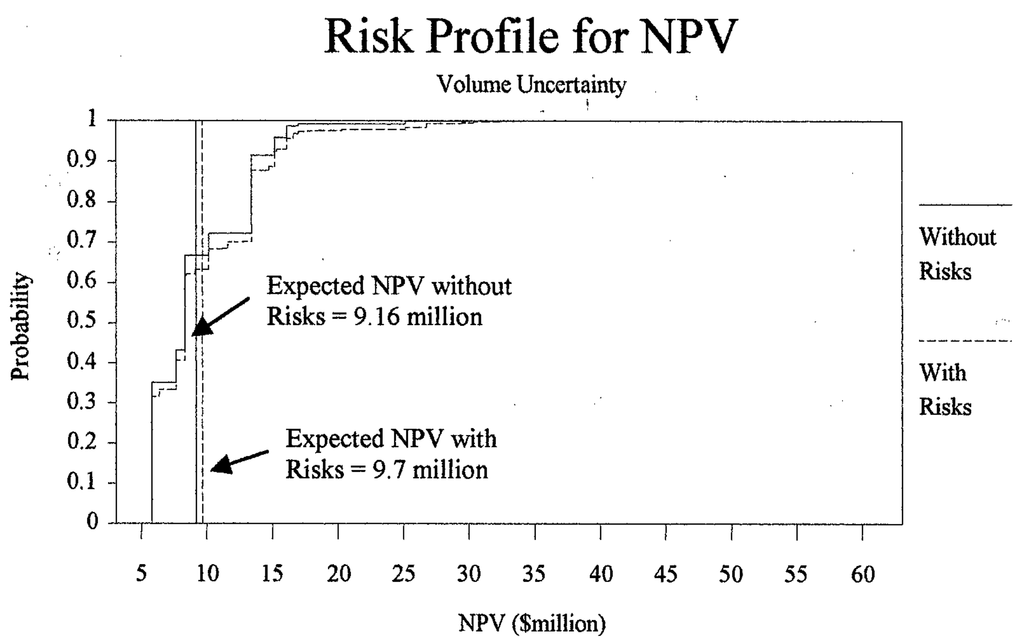


Figure 4-19 NPV Risk Profiles with Volume Uncertainty

The technological risks have a significant impact on Short Term balancing criteria. Although the expected value does not change significantly for the Short Term balancing criteria, the probability of obtaining a lower value has increased. If the volume uncertainty is excluded from the model the NPV risk profiles indicates a significant impact from the technological risks. However, when the volume uncertainty is included the technological risks' impact on the NPV is less obvious.

4.6 Conclusions

The investigation into technological risks for 2 Phase & DUS has indicated five areas of concern. Based upon the data and assumptions used these undesirable events produce a range in CERCLA value from 5.98 to 7.75 with the volume uncertainty included. Exactly how much risk these events denote depends upon an individual's viewpoint. In this analysis, the overall effect on the CERCLA value for 2 Phase & DUS was minimal. Therefore, the 2 Phase & DUS technology train is still one of the top alternatives for the WAG 6 site. Clearly, a detailed analysis of the risks for the top candidate technologies is required in order to provide a complete comparison between all of the top alternatives.

5 Conclusions and Recommendations

5.1 Conclusions

Selecting a technology train is a crucial part of the remediation process. Decision analysis (DA) methodology provides structure and guidance in this selection process. The WAG 6 team began with over 16.8 million remediation options. By using the DA process this was reduced to 22 technology trains [Papatyi, 1997; Kerschus 1997]. Of these 22 trains, the WAG 6 team desired further detailed analysis on two of the top ranking technologies, DUS and ISCO.

The primary goal of this research was to develop a method to determine the technological risks for the DUS technology and to analyze their effect on the CERCLA values. The secondary goal was to identify technological risks applicable to ISCO in order to provide the WAG 6 team areas to investigate during the ISCO's treatability study.

Using a variety of sources this research identified four key technological risks for DUS:

Unrecovered DNAPL

DNAPL not Removed

TCE Plumes Outside Remediation Area

Steam Breakouts

These four technological risks were further investigated to determine their probability and their effect on the performance of the technology. In the course of this investigation, it was determine that steam breakouts was an unacceptable risk because of its high probability of occurrence. The consequences of a steam breakout could range from an untreated release to exposing personnel to contaminated vapor. If a solution was not found for this unacceptable risk, consideration of DUS as a viable alternative would be curtailed. Fortunately, a technology existed that increased control over steam migration. The high probability of steam breakouts was reduced to an acceptable level by the addition of 2 Phase to the DUS technology train.

There is another possible benefit to incorporating the 2 Phase technology with the DUS technology. It is believed that the heating of the subsurface by steam will increase the efficiency of the 2 Phase technology. How much of a performance boost there will be requires further investigation. A minor negative aspect to adding 2 Phase to the DUS technology train is the technological risk called short circuit. However, this additional technological risk does not outweigh the benefit gained in the increased control over the steam migration.

Since the new alternative had to be scored and evaluated against the CERCLA value hierarchy, it was decided to obtain a range of scores for the evaluation measures in order to provide a probabilistic analysis. In addition to an expected CERCLA value, a probabilistic analysis provided possible minimum and maximum CERCLA values for the 2 Phase & DUS alternative. Table 5-1 presents these values along with their ranking. The first row in Figure 5-1 is the expected, minimum and maximum CERCLA values for the 100,000 DNAPL volume. The 100,000 gallons is close to the expected DNAPL volume obtained from the cumulative probability distribution presented in Chapter 3. The second row presents the expected, minimum and maximum CERCLA values obtained from the probabilistic model with the volume uncertainty included which ranges from 10,000 to 500,000 DNAPL gallons.

Table 5-1 Probabilistic Analysis of 2 Phase & DUS

2 Phase & DUS	Expected Value	Minimum	Maximum
@ 100,000 Gallons	7.35 (4th)	6.89 (8th)	7.65 (2nd)
Volume Uncertainty	7.33 (4th)	6.42 (11th)	7.75 (1st)

Each technological risk was analyzed separately to determine its effect on remediation, and the amount of risk involved. Of the five technological risks investigated, three undesirable events affect the amount of DNAPL remediated: unrecovered DNAPL, DNAPL not removed, and short circuit. The other two undesirable events, TCE plumes outside remediation area and steam breakouts are technological risks because of their probability of occurrence. Table 5-2 provides a summary of the technological risks' affect on the remediation.

Table 5-2 Summary of the Technological Risks Affects

2 Phase & DUS	Expected Value	Minimum	Maximum
Unrecovered DNAPL (%)	0.028%	0%	2.6%
Unrecovered DNAPL (gallons)	31.9 gallons	0 gallons	2975 gallons
DNAPL not Removed (%)	0.33%	0%	8.9%
DNAPL not Removed (gallons)	384 gallons	0 gallons	17,700 gallons
Short Circuit (%)	0.38%	0%	0.9%
Short Circuit (gallons)	432 gallons	0 gallons	3,600 gallons
TCE Plumes outside RA	0	N/A	N/A
Steam Breakouts (#)	0	0	1

The worst case scenario is for the technological risks to occur. In order to determine the most unfavorable outcome possible, the worst case was analyzed for the undesirable events. The results are summarized in Table 5-3.

Table 5-3 Summary of the Worse Case Technological Risks Affects

2 Phase & DUS	Expected Value	Minimum	Maximum
Unrecovered DNAPL (%)	1.45%	0.12%	4.2%
Unrecovered DNAPL (gallons)	1671 gallons	0 gallons	11,630 gallons
DNAPL not Removed (%)	5%	0%	10%
DNAPL not Removed (gallons)	5760 gallons	470 gallons	35,500 gallons
Short Circuit (%)	0.5%	0%	1%
Short Circuit (gallons)	576 gallons	0 gallons	4,450 gallons
TCE Plumes outside RA	0.0002%	N/A	N/A
Steam Breakouts (#)	0	0	1

All technological risk models were incorporated into the probabilistic CERCLA model to determine the effect undesirable events had on the CERCLA value for 2 Phase & DUS. Based upon the data and assumptions used, the overall effect was a slight increase in the probability of a lower CERCLA value, but nothing to definitely exclude 2 Phase & DUS from consideration for the WAG 6 site. Table 5-4 (Table 4-4) provides a comparison between the CERCLA probabilistic model without the technological risks and the CERCLA probabilistic model with the technological risks included.

Table 5-4 CERCLA Value for 2 Phase & DUS Technological Risk Comparison

Model	Expected Value	Lower Range	Upper Range
Without Risks	7.33	6.42	7.75
With Risks	7.28	5.98	7.75

The effect of the technological risks on the NPV for the 2 Phase & DUS technology is summarized in Table 5-5. The effect of the technological risks on the NPV for a volume amount of 100,000 gallons produces an increase in the expected NPV and the maximum NPV. However, the probability of a maximum cost of $20.4 million is low. The effect of the technological risks is less obvious when volume uncertainty is included. Volume uncertainty decreases the minimum and increases the maximum for both NPV without technological risks and NPV with technological risks.

Table 5-5 Summary of Technological Risks on NPV

2 Phase & DUS	Expected Value	Minimum	Maximum
@ 100,000 DNAPL gallons			
Without Risks	$8.7 million	$8.3 million	$10.2 million
With Risks	$9.2 million	$8.3 million	$20.4 million
Volume Uncertainty			
Without Risks	$9.2 million	$5.8 million	$25 million
With Risks	$9.7 million	$5.8 million	$30 million

The investigation into the ISCO technological risks provided WAG 6 with four areas of concern, unrecovered DNAPL, DNAPL not removed, TCE plumes outside the remediation area and steam breakouts. The definitions for these undesirable events are the same as described in Chapter 3 for DUS. However, there are different effects leading up to these events. Explanations of these events as they apply to ISCO are in Appendix A. During the investigation it was determined that one of the technology trains which contained the ISCO technology did not provide enough control over the steam migration, LASAGNA & ISCO. This technology train was eliminated from consideration, thus reducing the number of alternatives to 21 technology trains.

5.2 Recommendations

It is highly recommended this type of risk analysis be performed on all the key technologies under serious consideration for remediating a contaminated site, especially for technologies that are new and unproven. The insight gained by going through a risk analysis leads to better judgements about the performance of a technology. In addition, the time and effort spent on investigations of this type will help support the decision for a particular technology train.

The detailed analysis accomplished in this research was limited to one technology. Other top ranking trains should be investigated, especially trains 9, 7, and 6 whose expected CERCLA value (with volume uncertainty) was higher than the expected CERCLA value for 2 Phase & DUS. Obtaining risk profiles for the other top ranking technology trains will provide a better analysis of these alternatives.

The time and cost data used as penalties for the technological risks need to be redefined to reflect the actual amount of time and money involved in recovering from an occurrence of an undesirable event. Given the significant influence the technological risks have on the NPV it is important to obtain better information.

The performance and cost data for the 2 Phase & DUS technology train requires further investigation. According to the WAG 6 team, 2 Phase & DUS have never been operated together. Therefore, the data used in this model is based upon the understanding of these two technologies operating separately. While it is believed that the two operating together will improve the overall performance of the remediation process; there is no real evidence to support this belief. Although grouping these two technologies together was to prevent an unacceptable event from happening, the benefits of these two technologies operating together might be more than just increasing control over steam migration. Further, detailed study of their joint performance is warranted.

Appendix A: In Situ Chemical Oxidation

The technological risks for In Situ Chemical Oxidation (ISCO) are similar to DUS, unrecovered DNAPL, DNAPL not removed, TCE plumes outside the remediation area, and steam breakouts. Although the definitions for these events are the same for both DUS and ISCO, there are different effects leading up to these events.

Unrecovered DNAPL

The three main effects associated with unrecovered DNAPL are DNAPL migration into the McNairy Formation, soil blockage and dead spots.

During the ISCO process DNAPL could migrate into the McNairy Formation due to the same factors as with DUS: reduction of interfacial tension, recondensing of TCE into four feet pools or greater, and/or the presence of fissures or sand lenses at the bottom of the RGA. The major difference between DUS and ISCO is the way the soil is heated. In DUS, the injection of steam heats the soil. In ISCO, the exothermic reaction caused by the oxidation heats the soil. For ISCO, the heat generated by the exothermic reaction is not constant which increases the number of opportunities for DNAPL to migrate into the McNairy Formation. In addition, DUS has more control over the movement of the TCE, because the extraction pumps pull the TCE towards the extraction wells. There are no extraction wells in the ISCO process.

The gases produced from the ISCO process can also form a temporary and /or permanent blockage. A temporary blockage will diminish as the gases move upward.

A permanent blockage, due to the heating of the soil and oxidation of reduced minerals, could prevent the oxidant from reaching pools of DNAPL [Richards, 1997].

Dead spots are unreachable areas in the subsurface, such as cracks and rock fissures. DNAPL located in these dead spots will not be oxidized. Although this impedes the efficiency of the ISCO process, these dead spots are a small percentage of soil makeup.

DNAPL not Removed

For the chemical oxidation process to work properly it is very important to locate DNAPL sources within the subsurface. Failure to locate pools and completely encircle the contaminant increases the chance of pushing DNAPL away from the WAG 6 area. This occurs when the oxidizing agent pushes the DNAPL away from the injection site instead of neutralizing it [Sayler et al, June 1996, 18]. There is some concern that the C-400 building could hinder the placement of the injection wells. However, the WAG 6 team believes that the process can be designed in such a way as to limit the negative affect of the building and completely surround the DNAPL.

TCE Plumes Outside Remediation Area

For TCE plumes outside the remediation area, the DNAPL not removed event has to occur. Except for the different pushing mechanisms, this event is similar to the description provided in section 3.3.3. The potential for this to occur is the same for both DUS and ISCO.

Steam Breakouts

Since ISCO is an exothermic reaction, it produces steam. A comparable event to the DUS steam breakout described in section 3.3.4 can occur. The advantage ISCO has over DUS is the heat is not constant and therefore the potential for a steam breakout is less.

Other Technological Risks

In addition to the above technological risks, two other undesirable events were considered but were determined to be non-critical. These risks: possible structural damage and high organic carbon content are discussed in the following paragraphs.

When chemical oxidation occurs under buildings or utility lines, there is a risk of damaging these structures because chemical oxidation reactions are inherently exothermic. This type of reaction may increase the pressure under or in these structures to a point where structural damage occurs [Sayler et al, June 1996: 15]. This would be a major concern for WAG 6, since there is an operational building with associated utilities overlying the contaminated soil. However, the contaminants are believed to be at depths where this will not be an issue.

If the subsurface has a high organic carbon content, the efficiency of the oxidation decreases because the oxidant will react to the organic carbon instead of the TCE. Although there is evidence of an organic carbon content layer in the top layer of the McNairy Formation, this should not be a problem for WAG 6 because the major areas of contamination are relatively free of organic materials.

Technological Risks Summary

A summary of the technological risks associated with ISCO is in Table A-1. Unlike DUS, steam breakouts is not an unacceptable risk for ISCO, since the two technology trains that contain ISCO already have a vacuum technology included: ISCO & 2 Phase and ISCO & 6 Phase. During this investigation a technology train was taken out of consideration, LASAGNA & ISCO. The probability of a steam breakout was higher for the LASAGNA technology as opposed to the 2 Phase and 6 Phase technologies.

Table A-1 Summary of ISCO Technological Risks

	Risk Events	Critical?	Acceptable?	Fixes for Unacceptable
	In-Situ Chemical Oxidation			
1	Unrecovered DNAPL (McNairy, Blockage, Dead Spots)	YES	YES	
2	DNAPL, Tc-99 not Removed	YES	YES	
3	Plumes Outside Remediation Area (Depends upon Event 2)	YES	YES	
4	Steam Breakouts (UCRS Only)	YES	YES	
5	Structural Damage	NO	N/A	
6	High Organic Carbon Content	NO	N/A	

Appendix B: TCE Spill Volume

This appendix is an updated version of Kerschus' Appendix A.

The total TCE spill is currently estimated to be between 10,000 and 500,000 gallons. The following cumulative distribution function (CDF) was initially presented in Kerschus' research and has been updated to reflect current data on the amount of DNAPL in the subsurface (Figure B-1). A CDF is interpreted in the following fashion; there is a 60% probability of 100,000 gallons or less of DNAPL in the subsurface. It is also important to realize that there is zero probability of a spill volume being less than 10,000 gallons and a zero probability of a spill volume exceeding 500,000 gallons.

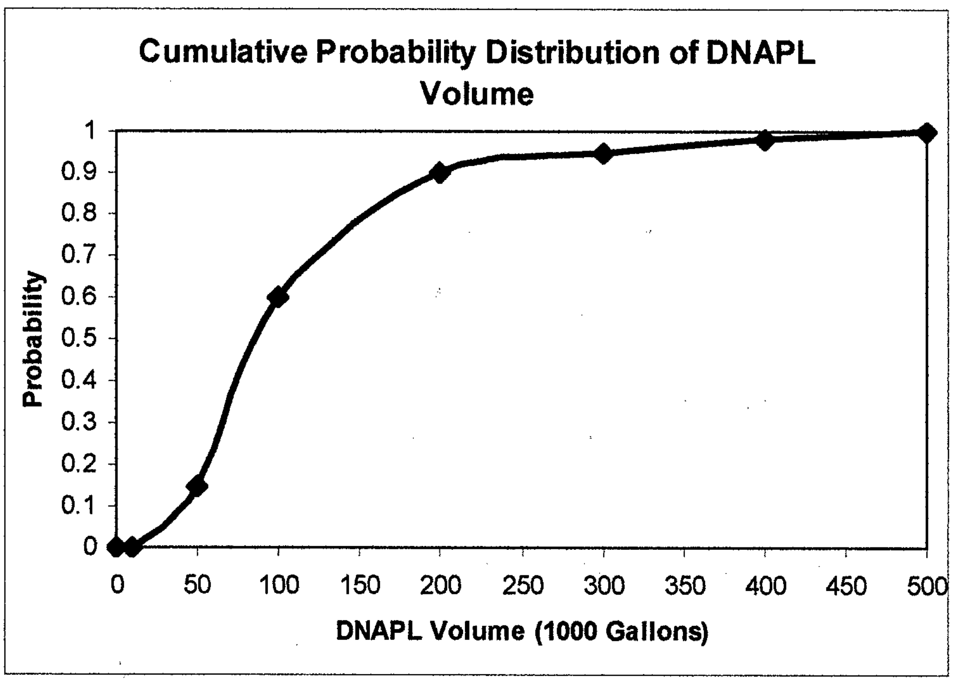


Figure B-1 Cumulative Probability Distribution for TCE Spill Volume

As with the initial CDF obtained by Kerschus the updated CDF is discretized by transforming the CDF into a probability density function and using the moment generating function to match the five moments. This is accomplished to obtain probabilities for 50,000, 100,000, 200,000, 300,000, 400,000 and 500,000 gallons of DNAPL volume.

The probability density function (Figure B-2) is used to produce piece-wise, linear functions for the moment-generating equation.

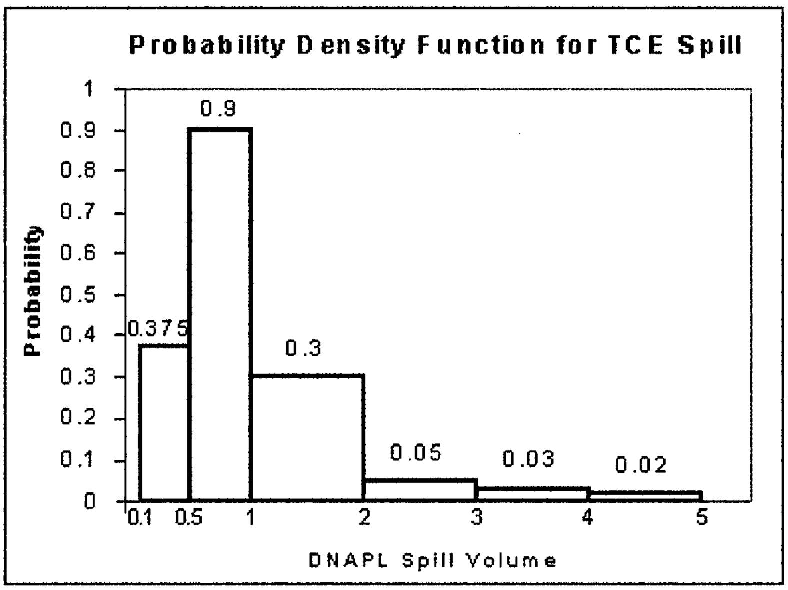


Figure B-2 Probability Density Function for DNAPL (hundreds of thousands of gallons)

The moment-generating function:

$$M_r = E(X^r) = \int_{-\infty}^{\infty} x^r f(x)dx \qquad \textbf{(B.1)}$$

where $E(X^r)$ is the r^{th} moment about the origin of the continuous random variable X [Walpole & Myers 1985: 173]

The first moment using the above information is:

$$E(X) = \int_{0.1}^{0.5} 0.375xdx + \int_{0.5}^{1} 0.9xdx + \int_{1}^{2} 0.3xdx + \int_{2}^{3} 0.05xdx + \int_{3}^{4} 0.03xdx + \int_{4}^{5} 0.02xdx$$

$$E(X) = 1.15250$$

The first moment is the expected value, in this case 115,250 gallons is the expected DNAPL volume. The second moment is $E(X^2) = 2.07133$. The variance is equal to $E(X^2) - E(X)^2 = 0.74308$ or 74,308 gallons.

We can assert for any discretized probability function which has the same r^{th} moment as the continuous probability function [Kloeber, 1997]:

$$\sum_s P_s X_s^r = \int_{-\infty}^{\infty} x^r f(x)dx \quad \textbf{(B.2)}$$

where P_s = the probability of the s^{th} discrete volume where s ranges from 50,000, through 500,000 gallons, and r is the r^{th} moment. In other words, if we had a discrete probability which had the same first moment then we could make the assumption that this expected value is also equal to the sum of the discrete probabilities multiplied by their corresponding spill amounts [Kloeber, 1997]:

$$E(X) = \sum_s (P_s X_s) = 115.250 \quad \textbf{(B.3)}$$

which expands to,

$$E(X^r)=P_{50K}*50K^r+P_{100K}*100K^r+P_{200K}*200K^r+P_{300K}*300K^r+P_{400K}*400K^r+P_{500K}*500K^r$$

where P_s denotes the unknown discrete probability at each corresponding spill volume, x_s, and r represents the r^{th} moment. In the expanded form, P_{50K} represents the unknown, discrete probability for a 50,000 gallon spill, which is being solved for, and x_s is replaced with the corresponding spill volume amount of 50,000. The first five moments are calculated using Equation B.1 and are set equal to the expansion of Equation B.3, as shown by Equation B.2, to establish five equations and six unknown probabilities. The final constraint needed to fully solve the equations simultaneously is that the sum of the discrete probabilities must equal one.

An optimization program called LINDO was used to solve the six equations and unknown probabilities described above. The LINDO model below list the equations to be solved. The idea here is to match the first four moments by allowing some slack in the fifth moment, since the fifth moment is the least important of the five moments. The LINDO model will match the four moments with minimal slack or error in the fifth moment.

LINDO MODEL:

```
MIN SO+SO1
ST
A+B+C+D+E+F=1
0.5A+B+2C+3D+4E+5F = 1.1525
0.25A+B+4C+9D+16E+25F=2.071333334
0.125A+B+8C+27D+64E+125F = 5.3117875
0.0625A+B+16C+81D+256E+625F = 17.236718
```

0.03125A+B+32C+243D+1024E+3125F-SO+SO1 = 64.105294166667

END

Note: Volumes and Moments multiplied by 1 x 10^{-2}.

LINDO OUTPUT:

LP OPTIMUM FOUND AT STEP 9

OBJECTIVE FUNCTION VALUE

1) 0.4695255

VARIABLE	VALUE	REDUCED COST
SO	0.469525	0.000000
SO1	0.000000	2.000000
A	0.431374	0.000000
B	0.290556	0.000000
C	0.236337	0.000000
D	0.000000	10.000000
E	0.035082	0.000000
F	0.006651	0.000000
ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	-20.000000
3	0.000000	79.000000
4)	0.000000	-102.500000
5)	0.000000	55.000000
6)	0.000000	-12.500000
7)	0.000000	1.000000

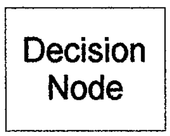
where $p_{50K} = A = 0.43$, $p_{100K} = B = 0.29$, $p_{200K} = C = 0.24$, $p_{300K} = D = 0$, $p_{400K} = E = 0.04$, $p_{500K} = F = 0.01$.

These are the updated discrete probabilities for the 50,000, 100,000, 200,000, 300,000, 400,000, and 500,000 TCE spill volumes. By using these probabilities the volume uncertainty was incorporated into the event models and CERCLA probabilistic model.

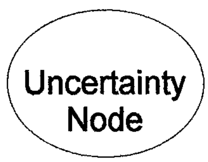
Appendix C: Influence Diagrams

This appendix gives a brief explanation of influence diagrams. The influence diagrams were built in Decision Programming Language (DPL), a decision analysis computer program.

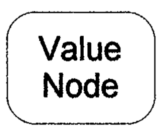
Influence Diagram Nodes:



The decision node indicates the decision that needs to be made, i.e. yes/no or which alternative.



The uncertainty node indicates that the outcome of a specific event is not known with certainty.



The Value or Calculation node is used for calculations or to identify constants within model.

An influence diagram is used to develop a clear view of the decisions, uncertainties and values involved and to specify their relationship. For the models used in this research, the decision has already been made to use DUS and 2 Phase and so the decision node is not included. The arrows in an influence diagram represent the influence between the two connected nodes. The influence arrows can show chronological order or indicated various types of dependencies.

Appendix D: Technology Descriptions

The purpose of this appendix is to provide a brief description of the other technologies being considered at WAG 6. The original work for these technology descriptions is credited to Papatyi [Papatyi, 1997: D-1]. Kerschus updated them for her research [Kerschus, 1997: C-1].

6 Phase Heating

This technology uses a six-pointed star configuration of electrodes placed in the ground to enhance the mobility of contaminants. When power is applied to the electrodes in the unsaturated zone the resistive heat volatizes the contaminants and in the saturated zone the resistive heat produces steam that in-turn strips the pollutant from the formation. The volatized contaminants are then removed via soil vapor extraction (SVE).

The six pointed star configuration allows for the uniform heating of the soil, although other patterns have been used. Multiple configurations may be necessary to get around buildings. The patented process breaks the conventional 3 phase electricity into a six phase system. This reduces the amount of soil heating needed, which is estimated to cost approximately 100 kWh per cubic meter of soil [DOE/EM-0248, 1995: 206]. Some Tc-99 removal occurs, though minimal.

Cosolvent Enhanced Treatment

Cosolvents, like surfactants, are used to enhance conventional pump and treat systems. Cosolvents are substances that, when mixed with water, can enhance the solubility of the contaminant. Typical cosolvents are methanol, and acetone alcohols. The idea behind this technology is similar to that of surfactant flooding. The cosolvent agent is injected into the ground and the area is flooded. The cosolvent then acts to strip contaminant from the soil. Then the pump and treat systems pump the liberated contaminant and the cosolvent to the surface for treatment. The cosolvent acts to increase the solubility of the contaminant as well as decrease the contaminant sorption, and is especially effective for DNAPLs [National Research Council, 1995: 148 - 149]. This technology will also address Tc-99. The volume of Hazardous Waste (HW) generated in the short term may be greater than other technologies that do not inject chemicals to flush contaminants.

LASAGNA™ or Electro-Osmosis

Electro-osmosis is a process that uses electrodes placed into the soil to mobilize DNAPL contaminants. Once power is applied to the electrodes, the DNAPL contaminant will migrate in the direction of current flow. The induced contaminant movement may be used with other extraction technologies or contaminants may be destroyed in situ. Typically, the contaminant is removed via adsorption or destroyed in situ. The technology appears to be most beneficial when contaminants are located in the saturated zone and where the soil has a low permeability. Tc-99 will be adsorbed as a precipitate within a permeable treatment zone, so the technology can address Tc-99.

The term LASAGNA™ was derived by a consortium of private companies that were researching methods to speed VOC contaminant cleanup. The researchers determined that a *layered* application of Electro-osmotic probes would speed the migration of the contaminants to the destructive zones and thus increase the speed at which cleanup could occur. The biggest uncertainty with LASAGNA is the vertical layering. Monsanto (one of the consortium members) patented and trademarked the process [Falta et al. 1996: 24]. The layering effect may be horizontally or vertically oriented.

Pump and Treat

Conventional pump and treat systems operate by pumping ground water to the surface, for treatment and returning the water to the ground or discharging it to a permitted outfall. Because organic contaminants have low solubility and sorb to the soil, this technology requires large volumes of water to be pumped out of the ground. The residual contaminants that adhere to subsurface particles may require extremely long periods of operation to completely clean up a site. Therefore, pump and treat is often used for plume containment [National Research Council, 1995: 29]. This technology will also address Tc-99.

Permeable Treatment Zones

This technology makes use of a permeable "wall" that is excavated into the subsurface. The wall allows ground water to flow through it. As the groundwater flows through, reactive media in the "wall" chemically treats the contaminant. The most common type of PTZ media is iron filings. The iron filings cause chlorinated hydrocarbons to degrade to less harmful substances [Clayton, 1997]. Depending on the reactive media used, this technology will also address Tc-99. While this technology provides in situ treatment, it is generally considered a containment strategy.

Radio Frequency (RF) Heating

Radio Frequency (RF) heating uses the heat energy induced by the application of RF energy into the soil to enhance conventional vapor extraction methods. The heat applied to the soil through RF causes a liberation of the contaminants, especially Volatile Organic Compounds (VOCs) like TCE. This technology is most applicable to remediation of the vadose zone (unsaturated) [DOE/EM-0248, 1995: 215 - 217]. It is not a stand alone technology and must be coupled with another technology, such as SVE, to extract the liberated contaminants. Overheating of the formation can occur if the soil becomes sufficiently desiccated. This technology does not treat Tc-99.

Surfactant Enhanced Treatment

Surfactants (surface active agents) are used to enhance conventional pump and treat systems. They are used to enhance soil flushing techniques. The idea behind this technology is to inject a surfactant into the ground and flood the area with a surfactant agent. Once the flood is complete, conventional pump and treat systems are used to recover both the contaminant and the surfactant. The surfactant acts as a loosening agent to separate the contaminant from the water saturated soil [Falta et al., 1996:26 - 29 and National Research Council, 1995: 148 - 149]. This technology will also address Tc-99.

Two Phase

This technology makes use of a powerful vacuum system that extracts soil vapor and liquids. It is typically used in low to moderate permeability soils. As the vacuum is applied through a screened well, soil vapors are extracted and groundwater is entrained in the extracted vapors. Therefore, no pumps are required in the well. It can accelerate remediation by dewatering the site and removing contaminants in the vapor phase. Once the vapors and groundwater are above ground, they are separated and treated individually. It is more effective than using SVE singularly since it treats soil above and below the water table and extracts contaminated groundwater. This is a patented technology, requiring licensed contractors and royalty fees per wellhead. [EPA/542/B-94/013, 1994: 4.145 - 4.147].

Dual Phase

Very similar to Two Phase with regard to effectiveness, but is not a patented technology. A pump is required in the well to convey ground water to the surface.

UVB (Unterdruck-Verdampfer-Brunnen)

This technology is similar to pump and treat except that it treats captured ground water inside the well and reintroduces it to the formation after the treatment. The technology treats the groundwater inside the well using air stripping and then injects it back into the surface. Typically, this technology is used to affect an area no larger than 50' in diameter per well. Typically effective for formations with high to moderate hydraulic conductivity. [Gelb 1997, Clayton, 1997].

Redox

This technology reduces an aquifer's redox potential, which allows a variety of redox sensitive contaminants to be treated. The goal is to create a permeable treatment zone downstream of the contaminant plume by injecting appropriate reagents and buffers to chemically reduce the structural iron in the sediments; or by injection of microbial nutrients to stimulate microbial reduction of the sediments. The reducing zone can also be created by the injection of colloidal iron or chemically reduced colloidal clays. The reducing zone created can either immobilize contaminants or degrade them to less harmful substances. Once inorganic contaminants are immobilized they can be destroyed through reduction. [Fruchter,1996] This technology is generally used for containment. This technology is primary used to extract Tc-99 although it may extract minimum amounts of TCE.

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Appendix E: WAG 6 CERCLA Hierarchy, Evaluation Measures, and Weights

This appendix was taken from Kerschus' research [1997: Appendix B].

This appendix is based upon the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980. The primary guidance document for CERCLA response actions is the National Contingency Plan (or NCP). The NCP (40 CFR S300) establishes criteria for determining the appropriate environmental response by outlining the procedures to be followed in performing cleanups, remedial actions or removals.

The purpose of this appendix is to provide rationale for the development of a value hierarchy developed specifically for WAG 6 based upon the original CERCLA criteria as stated in the NCP. This value hierarchy [was] used to rank remedial technologies or trains. According to CERCLA and the NCP, there are nine specified criteria; they are depicted in Figure E-1 (40 CFR S300.430(e)(9)(iii)):

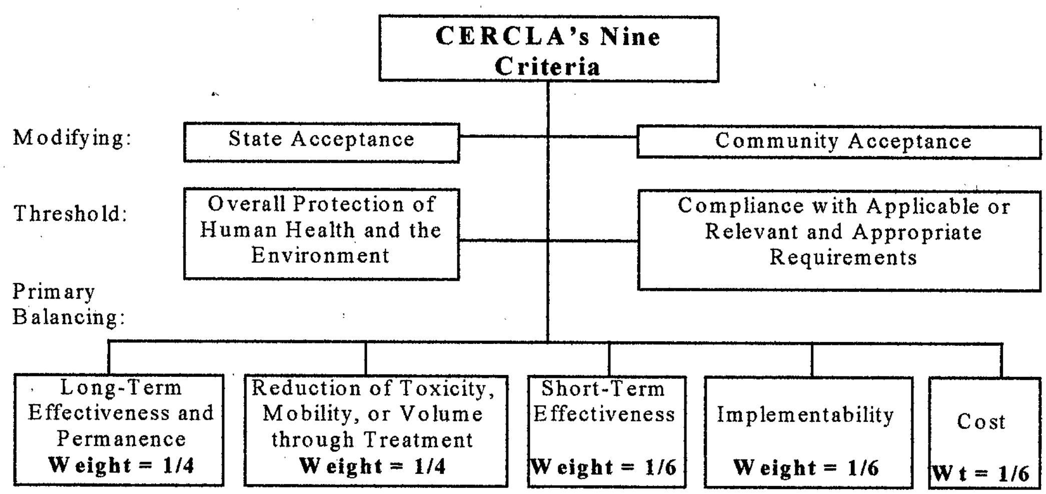


Figure E-1 - CERCLA Value Hierarchy and Associated Weights

Modifying and Threshold Criteria:

The CERCLA criteria are divided into the following three distinct groups: Modifying Criteria, Threshold Criteria, and Primary Balancing Criteria (40 CFR S300.430(f)(1)). The Modifying Criteria, State and Community Acceptance, are not included in this analysis. The Modifying Criteria should be considered after the Record of Decision (ROD) has been released to the public for review. The Threshold Criteria, consisting of the Overall Protection of Human Health and the Environment, and Compliance with Applicable or Relevant and Appropriate Requirements (ARARs) are threshold objectives that all evaluated remediation trains must meet in order to be eligible for selection. Therefore, in order for a remediation train to be considered and used in this analysis, it will have already been examined to ensure it has met the Threshold Criteria.

CERCLA Value Hierarchy and Weights:

In the following sections are the WAG 6 CERCLA Balancing Criteria (capitalized and bolded-the first box in the hierarchy) and subcriteria (subsequent solid lined boxes with Roman numerals) with their associated evaluation measures (dashed boxes) and weights. Immediately following this hierarchy is a brief discussion on the assignment of weights, along with each evaluation measure's single dimensional value (or scoring) function. Note that for each evaluation measure, a value of ten indicates the best possible outcome for that measure while a value of zero indicates the worst possible outcome. These measures will later be used, in combination with the weights shown, to compare each remediation train and determine which train provides the greatest value under the

CERCLA based measures. **Balancing Criteria 1: LONG-TERM EFFECTIVENESS AND PERMANENCE** (40 CFR S300.430(e)(9)(iii)(C)): CERCLA states that "alternatives shall be assessed for the long-term effectiveness and permanence they afford, along with the degree of certainty that the alternative will prove successful."

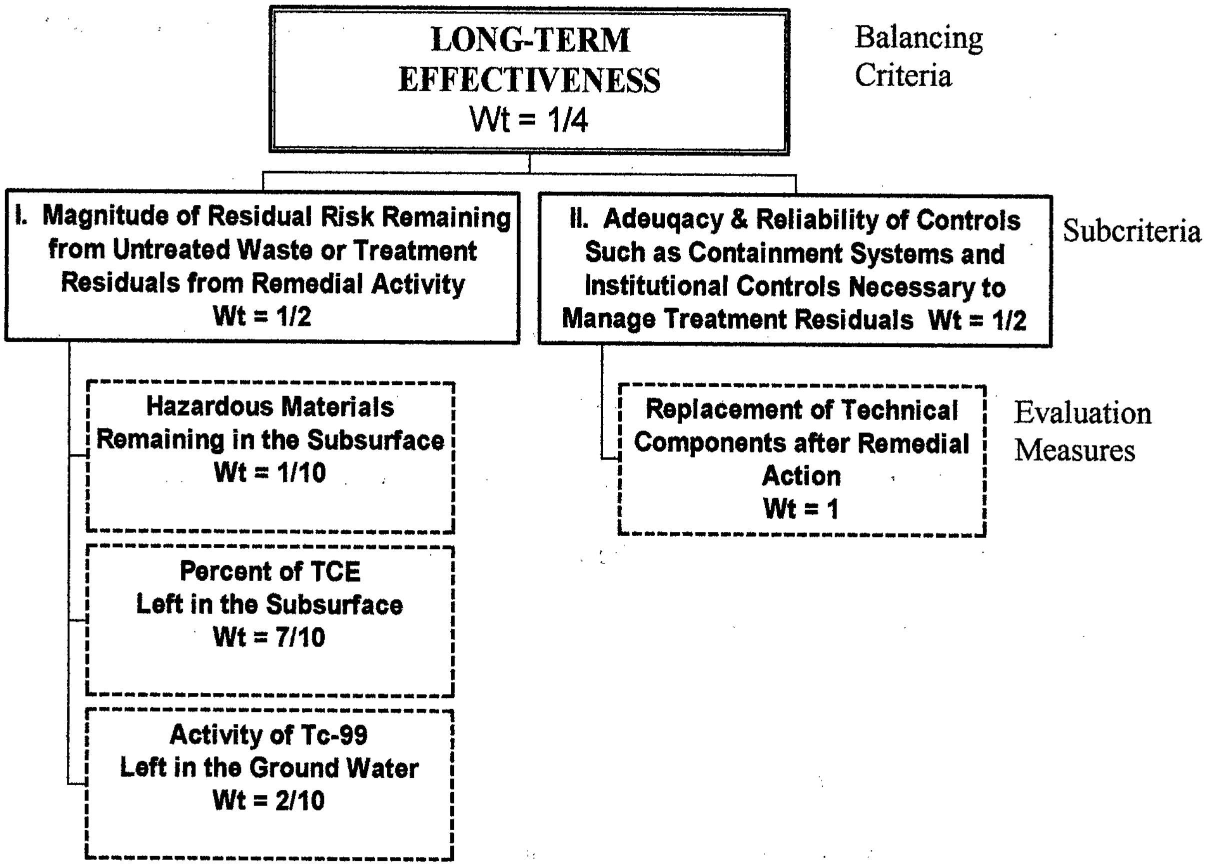


Figure E-2 - Long-Term Effectiveness and Permanence Hierarchy

EPA guidance suggests that long-term effectiveness and permanence "...addresses the results of a remedial action in terms of the risk remaining at the site after response objectives have been met." The weight for Long-Term Effectiveness and Permanence was derived directly from CERCLA (40 CFR S300.430(f)(1)(ii)(E)), as stated earlier in [Kerschus'] Chapter 3. Unfortunately, CERCLA does not go on to distinguish or provide additional guidance for balancing/weighting the subcriteria. The WAG 6 team members applied the following decision rules, noting the restriction that weights at each level of the hierarchy must sum to one: all weights are equally divided among the subcriteria, and all evaluation measure weights were also equally divided, except when there were separate measures for TCE and Tc-99, then the TCE weight would be three times as large as the Tc-99 weight.

Referencing CERCLA (40 CFR S300.430(f)(1)(ii)(E)), it states, "The balancing shall also consider the preference for treatment as a principal element and the bias against off-site land disposal of untreated waste." The WAG 6 team members interpreted this to mean that treating a waste was three times more valuable then disposing of it. Hence, TCE, which can be treated or destroyed, and does not need to be disposed of off-site in a landfill weighs 7/10 (about 3 times the weight for Tc-99). Tc-99 cannot be readily destroyed, however, and in high concentrations it must be landfilled so it receives a weight of 2/10. The remaining weight of 1/10 was then assigned to the evaluation measure for hazardous materials remaining in the subsurface.

The overall weight for any evaluation measure is the weight assigned to that evaluation measure, multiplied by all the criterion weights above it in the CERCLA hierarchy. For example, to calculate the overall weight for the evaluation measure of the Percent of Tc-99 Left in the Subsurface, simply multiply $2/10 * 1/2 * 1/4 = 1/40$.

I. Magnitude of Residual Risk Remaining from Untreated Waste or Treatment Residuals Remaining at the Conclusion of the Remedial Activities (40 CFR S300.430(e)(9)(iii)(C)(1)): The WAG 6 team assumed that there would be no long term, on-site storage of Potential Contaminants Of Concern (PCOCs); all waste will be treated or sent off-site for disposal. However, treatment residuals may be left within the subsurface. The first measure, applicable to both TCE and Tc-99, evaluates the effect of hazardous materials (HM) remaining in the subsurface of the site. These HM may include treatment residuals, degradation products, or unreacted materials. HM are also those materials brought to the site to be used as part of the treatment but are defined hazardous under Department of Transportation definitions. As stated earlier, the best outcome has a value of 10 (or an answer of "no" in this case), when there are no HM remaining in the subsurface of the site, and the worst outcome has a value of zero (or "yes"), when there are HM remaining in the subsurface at the site. There is no continuous relationship between these two points (no straight line) because there are only two, discrete possibilities, either there are HM remaining in the subsurface or there are not.

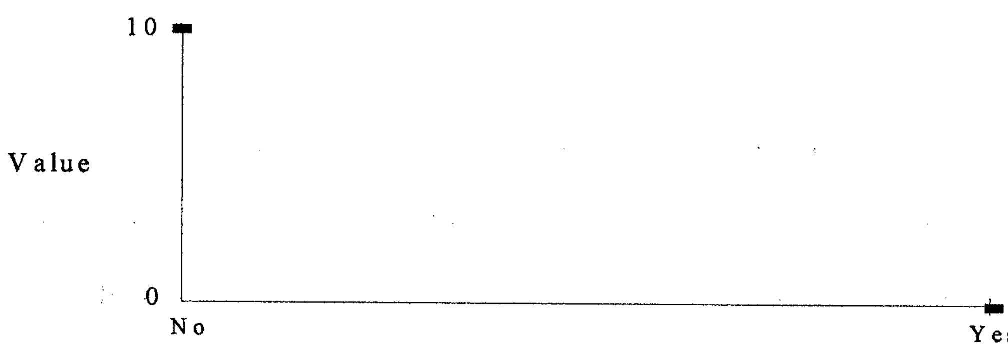


Figure E-3 Evaluation Measure for Residual Risk from Hazardous Materials

The long-term magnitude of residual risk for TCE can best be described by the Percent of TCE left in the ground. The preliminary goal of this project is to remove/destroy at least 95% of the TCE contamination. A technology that removes 95% or greater (therefore, leaving less than 5% in-situ) receives a score of 10. Because it is uncertain whether a 95% performance standard can be achieved in a cost effective manner, remediation trains will receive a positive score if more than 30% of the contaminant is removed (70% is remaining). This standard was chosen from examining other remedial action sites which have shown that, at a minimum, 30% removal/destruction of Non-Aqueous Phase Liquids (NAPLs) is achievable.

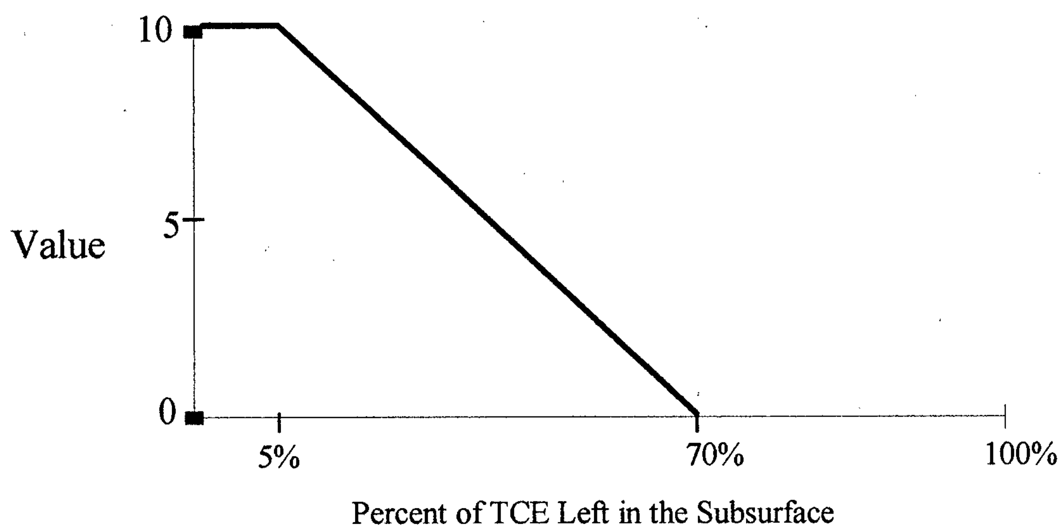


Figure E-4 Evaluation Measure for Residual Risk from TCE

The long-term magnitude of residual risk for Tc-99 can best be measured by the Percent Removal of Tc-99. Since Tc-99 will never be completely destroyed, the more that is removed the better. Therefore, a linear scoring function is used. The upper limit of this scale is the highest known concentration of Tc-99 found to date at the site (43,922 piC/L). Any train that accomplishes a reduction from this initial amount will have value. The lower limit of this scale represents the current, regulatory limit (900 piC/L). Any train that can reduce the concentration of Tc-99 to the regulatory limit, or less, would receive a value of 10.

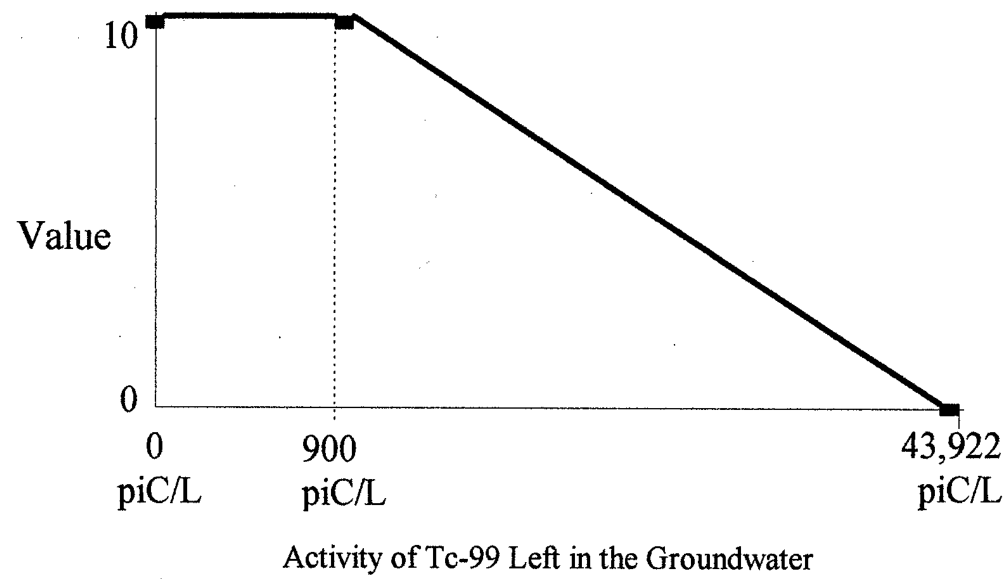


Figure E-5 Evaluation Measure for Residual Risk from Tc-99

II. Adequacy and Reliability of Controls Such as Containment Systems and Institutional Controls that are Necessary to Manage Treatment Residuals and Untreated Waste (40 CFR S300.430(e)(9)(iii)(C)(2)): CERCLA lists three subcriteria under this criteria:

1. Uncertainties associated with land disposal for providing long-term protection from residuals were not evaluated because there are no significant differences between the trains in this area.

2. The assessment of potential need to replace technical components of the alternative, such as a cap, a slurry wall, or a treatment system was combined with the third subcriteria:

3. The potential exposure pathways and risk posed should the remedial action need replacement.

The second and third criteria can be succinctly measured by the need for technical component replacement and whether there will be any threat of exposure or release when the replacement is occurring. This measure considers both TCE and Tc-99 and combines both frequency and risk of exposure during replacement. Note that the most value can be obtained from this measure when there is no replacement required (10). Replacement without risk of release follows rather closely at 7. However, any replacement that could occur with a risk of release is considered to have a very low value at 1.

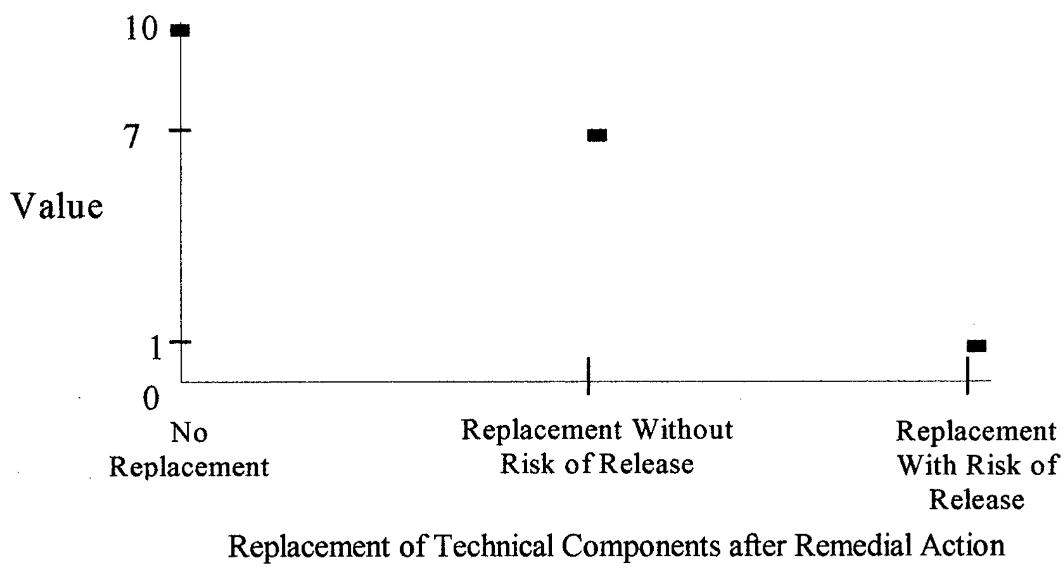


Figure E-6 Evaluation Measure for Adequacy and Reliability of Controls

Balancing Criteria 2: REDUCTION OF TOXICITY, MOBILITY, OR VOLUME THROUGH TREATMENT (40 CFR S300.430(e)(9)(iii)(D)): CERCLA states that "the degree to which alternatives employ recycling or treatment that reduces toxicity, mobility, or volume (TMV) shall be assessed, including how treatment is used to address the principal threats posed by the site. Factors that shall be considered, as appropriate, include the following …" CERCLA then lists six subcriteria.

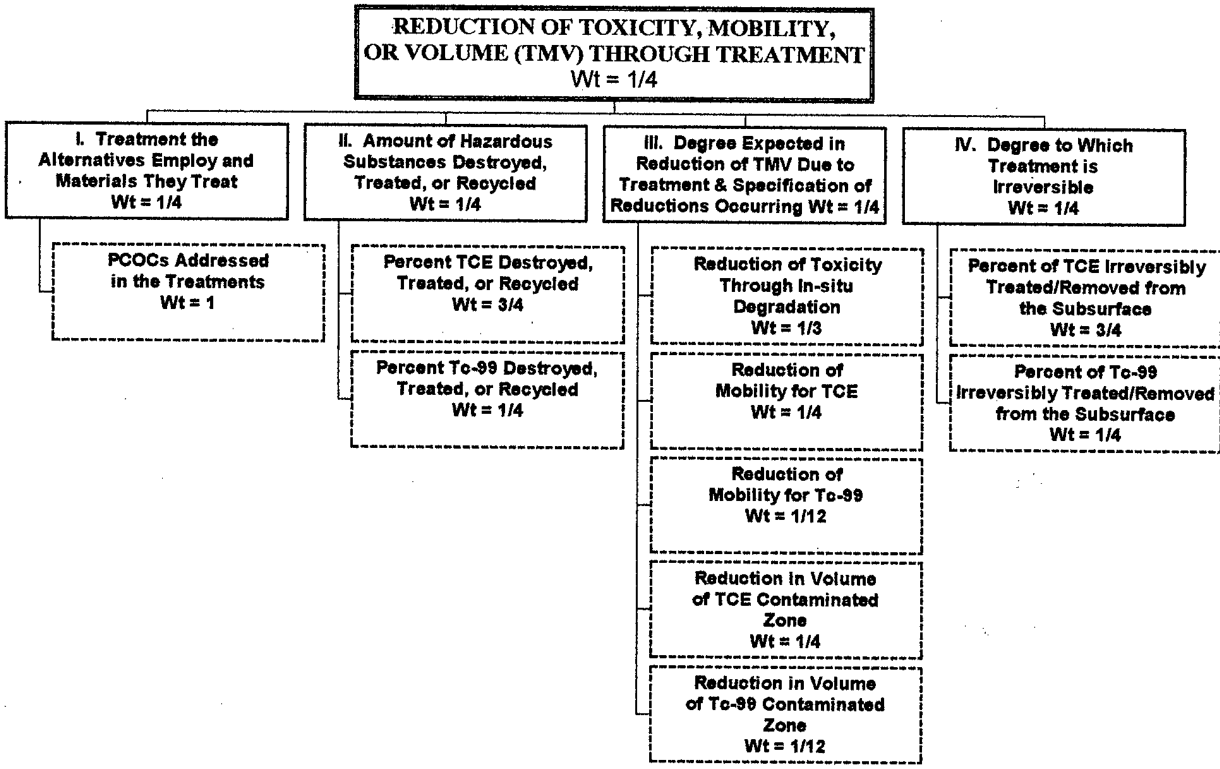


Figure E-7 - Reduction of Toxicity, Mobility, or Volume Hierarchy

The first four subcriteria CERCLA lists directly correspond to the four subcriteria shown in the hierarchy that the WAG 6 team developed (Figure E-7). However, the evaluation measure that would quantify subcriterion five, which is "the type and quantity of residuals that will remain following treatment, considering the persistence, toxicity, mobility, and propensity to bioaccumulate of such hazardous substances and their constituents", was seen as redundant with the measures developed for subcriterion 1 under Long-Term Effectiveness. The evaluation measure that would best characterize subcriterion six, which is "the degree to which treatment reduces the inherent hazards posed by principal threats at the site," was seen as redundant with the evaluation measure developed for subcriteria III.

EPA Guidance suggests that Reduction of Toxicity, Mobility, or Volume Through Treatment "...address the statutory preference for selecting remedial actions that employ treatment technologies that permanently and significantly reduce toxicity, mobility, or volume of the hazardous substances as their principal element. This preference is satisfied when treatment is used to reduce the principal threats at a site through destruction of toxic contaminants, reduction of the total mass of toxic contaminants, irreversible reduction in contaminant mobility, or reduction of total volume of contaminant media." The guidance also suggested incorporating treatment residuals, but the issue of residual risk has already been addressed under Long-Term Effectiveness and Permanence.

The weight for Reduction of Toxicity, Mobility, or Volume Through Treatment was derived directly from CERCLA (40 CFR S300.430(f)(1)(ii)(E)), as stated earlier. The weights for the subcriteria level of the hierarchy are equally weighted at 1/4 each (meeting the requirement that they sum to one), as explained previously. The next level of weights are those assigned to the evaluation measures. The same "rule of thumb" developed earlier continues to apply, with the TCE measure outweighing the Tc-99 measure by a factor of three. Under subcriteria III, the degree expected in reduction of TMV, the evaluation measures for the reduction of toxicity, mobility, and volume are each weighted 1/3. In the cases of mobility and volume, where there are separate measures for TCE and Tc-99, than the weight of 1/3 is divided such that the TCE measure holds three times more weight then Tc-99 measure, hence the weight of 1/4 for TCE measures and 1/12 for Tc-99 measures.

I. Treatment or Recycling Processes the Alternatives Employ and Materials They Will Treat (40 CFR S300.430(e)(9)(iii)(D)(1))**:** This measure indicates that treating both principal contaminants of concern (PCOCs), TCE and Tc-99, is preferable to treating only one. It also reflects the increased importance of addressing TCE compared to Tc-99, by giving three times the value to technologies that treat only TCE.

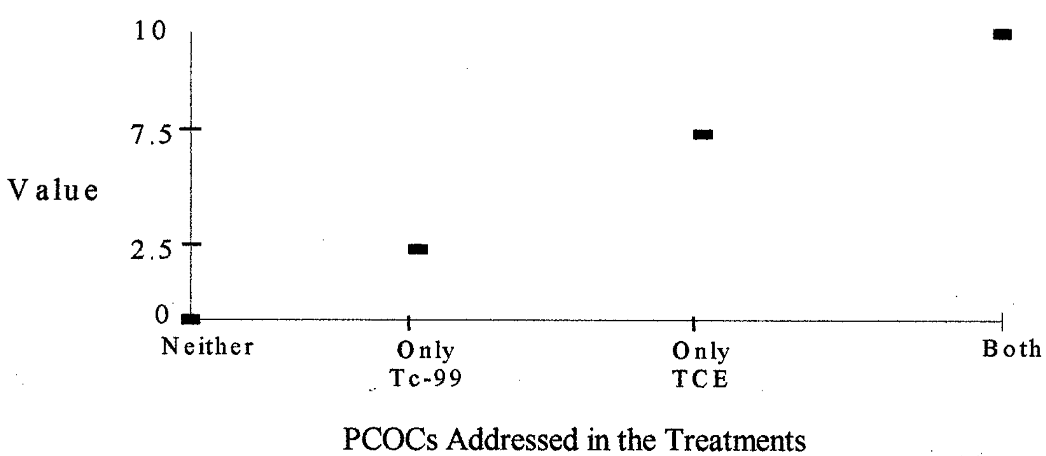


Figure E-8 Evaluation Measure for Treatment Employed and Materials Treated

II. Amount of Hazardous Substances, Pollutants, or Contaminants that will be Destroyed, Treated, or Recycled (40 CFR S300.430(e)(9)(iii)(D)(2)): Note that TCE and Tc-99 are evaluated separately and the evaluation measures developed only apply to technologies/treatments that address the PCOCs. The team agreed that Amount could be interpreted to mean Volume of hazardous substances, pollutants, or contaminants that will be destroyed, treated or recycled.

Amount (or Volume) of Principal Threat Treated for TCE: 30% was considered to be a minimum recovery factor for TCE (as explained previously under Long-Term Effectiveness, subcriteria I).

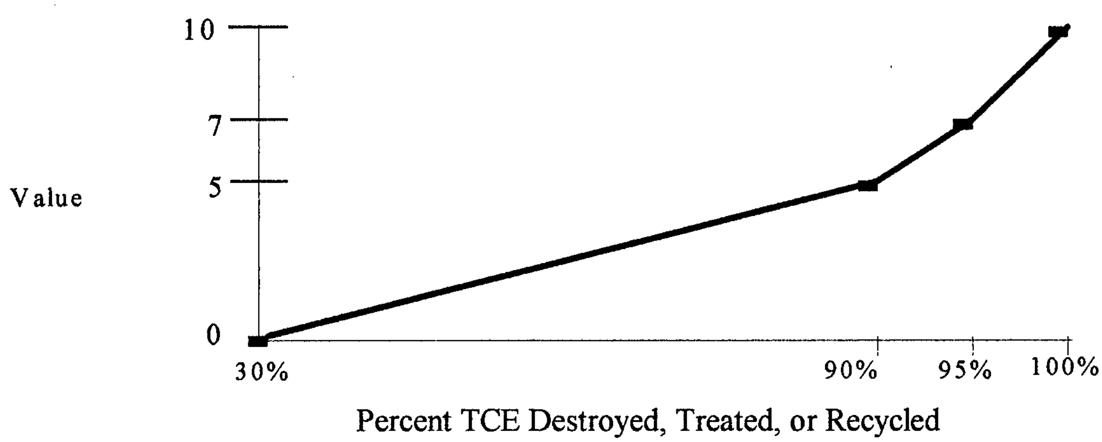


Figure E-9 Evaluation Measure for Amount of TCE Destroyed, Treated or Recycled

Amount (or Volume) of Principal Threat Treated for Tc-99 : Removing Tc-99 from the subsurface is considered treatment because the substance changes status from uncontrolled to controlled because of the removal. The WAG 6 team agreed that 95% of the value would be obtained when 91.1% of the Tc-99 was destroyed, treated, or recycled. The 91.1% removal is based on the draft regulatory limit of 3,900 pico Curies per liter (pCi/L) and the Tc-99 activity observed at C-400 (43,922 pCi/L). Note to reach the current regulatory limit of 900 pCi/L, 98% would need to be destroyed, treated or recycled.

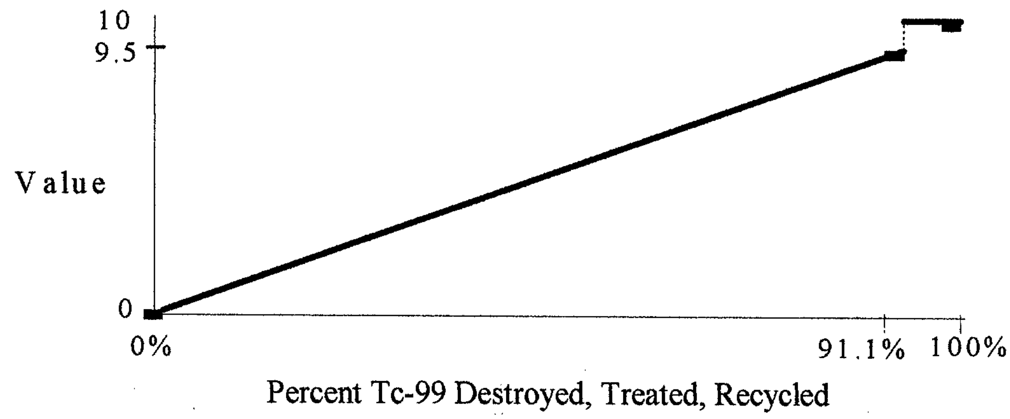


Figure E-10 Evaluation Measure for Amount of Tc-99 Destroyed, Treated or Recycled

III. The Degree of Expected Reduction in Toxicity, Mobility, and Volume of the Waste Due to Treatment or Recycling and the Specification of Which Reduction(s) are Occurring (40 CFR S300.430(e)(9)(iii)(D)(3)):

Measure for the Reduction of Toxicity: There is no measure for the reduction of toxicity for Tc-99 because Tc-99 cannot be destroyed. However, the reduction of total mass of contaminant (as stated in Table 6-2 in EPA Guidance) can be applied to TCE. The evaluation measure developed considers whether a treatment relies totally on the degradation of TCE to reduce toxicity. The concern being if degradation is not complete and there are some residuals, those residuals may be more toxic than TCE. Hence, the three distinct categories; where if degradation is not possible with a technology, (like excavation) the score for that technology would be a 10. If degradation may occur, but is not the inherent focus of the technology (like surfactants) then it would score a 7. If the primary focus of the technology is degradation (like oxidation) then it would score a 3.

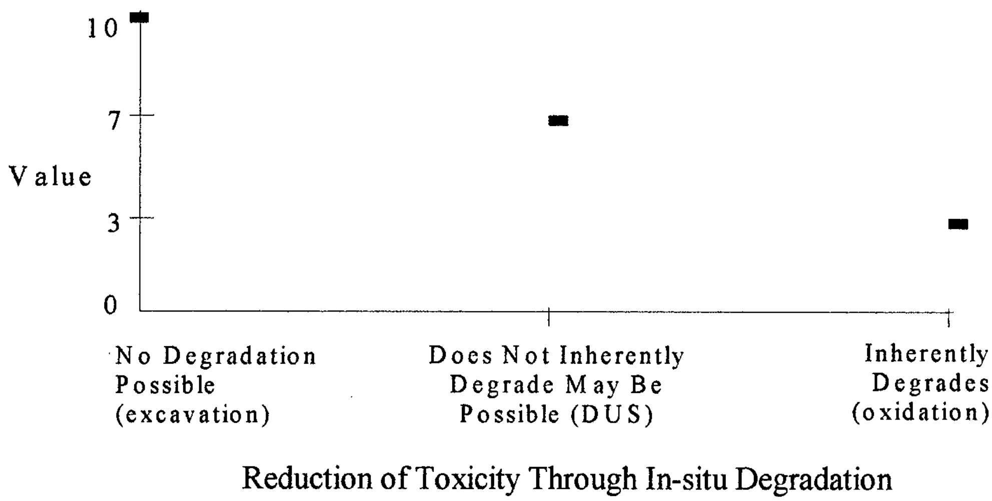


Figure E-11 Evaluation Measure for Reduction of Toxicity

Measures for the Reduction of Mobility: The team quantified this evaluation measure assuming successful treatment, because an unsuccessful treatment may increase mobility with some technologies. Separate evaluation measures were created to evaluate the mobility of TCE and Tc-99. The best situation would be to reduce the mobility of TCE and keep it from migrating off site, and so it was given the highest value of 10. Conversely, increasing the mobility of TCE may increase the risk of off site migration and hence escape treatment. However, increased mobility could also facilitate the extraction of TCE, which would mean that increasing mobility may not necessarily be all that negative. For these reasons, stated above, increasing the mobility of TCE gets a value of 7. Not changing the mobility, but allowing it to remain the same, yields a value of 9. This measure is less sensitive to the extremes in mobility because these extremes do not necessarily warrant extremes in scores.

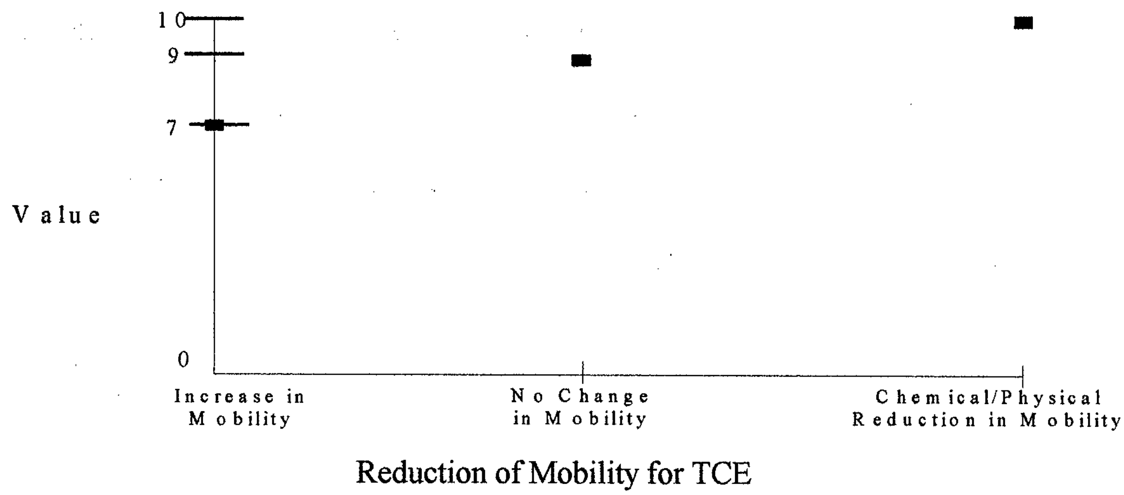


Figure E-12 Evaluation Measure for Reduction of Mobility of TCE

A similar measure was created for Tc-99. The most effective means for reducing the mobility of Tc-99 is to cause it to chemically change (precipitate) and this is given a value of 10. Since Tc-99 is already soluble, there is not much difference in value from increasing its mobility (7) then allowing no change in mobility (8) .

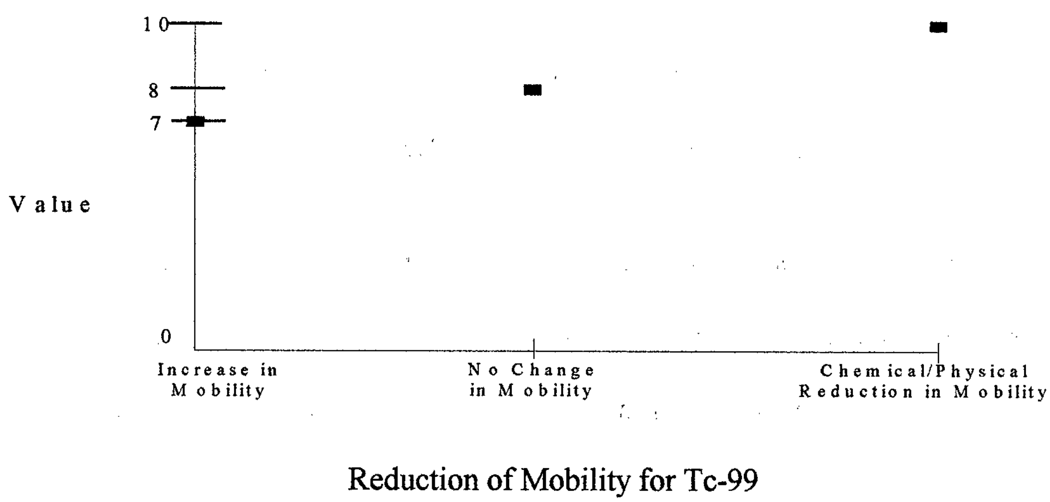


Figure E-13 Evaluation Measure for Reduction of Mobility of Tc-99

Measures for the Reduction in Volume: The focus of the remedial action is the source not the plume; emphasis is on reduction of mass/volume (EPA Guidance Table 6-

2). However, a technology that increases the volume of the source zone, such as a steam flood, is less desirable in this criteria than one that decreases the volume. The source is the media contaminated with DNAPL/TCE. Note: TCE and Tc-99 each have their own evaluation measure for this subcriteria.

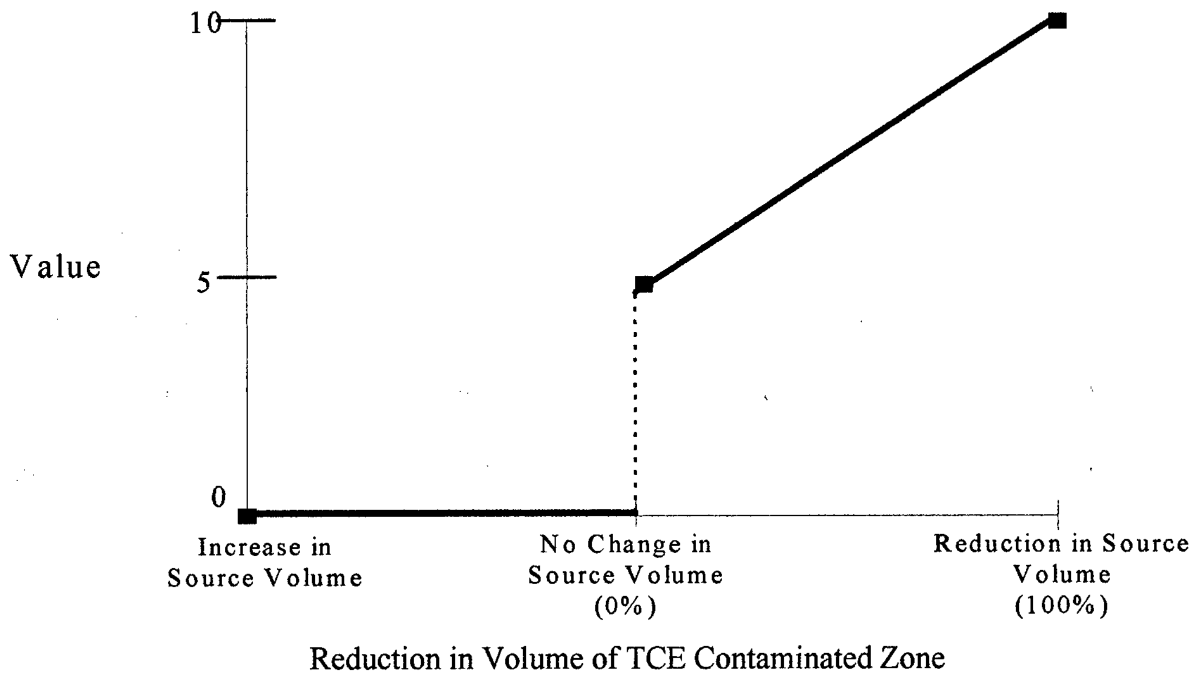
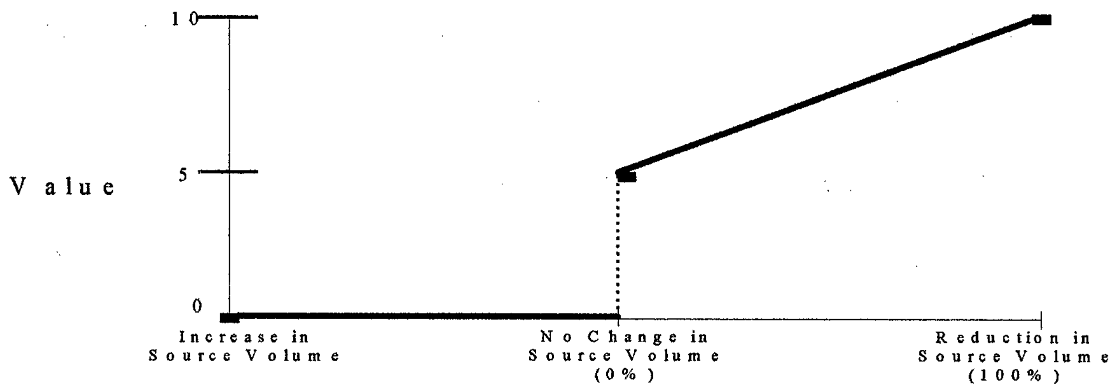


Figure E-14 Evaluation Measure for the Reduction of Volume of TCE Zone

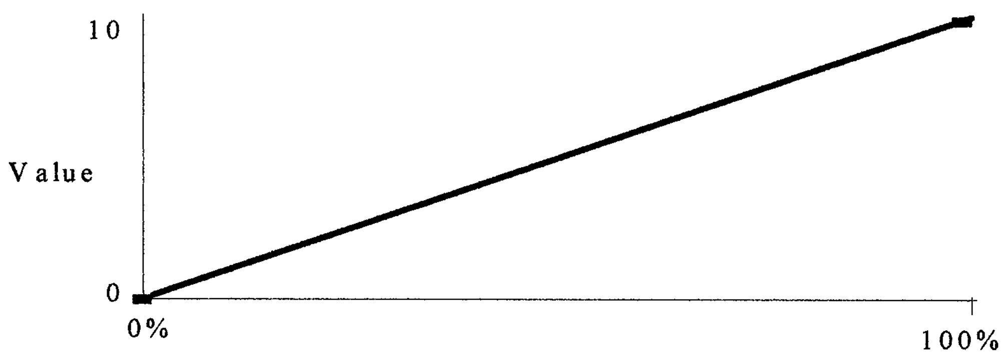
A similar measure was created for Tc-99, where the emphasis is on the reduction of mass and volume (EPA Guidance Table 6-2). Once again, a technology that increases the volume of the source zone; such as a steam flood, will be considered worse in this criteria than one that decreases the overall volume. The source, in this case, is the media contaminated with Tc-99.



Reduction in Volume of Tc-99 Contaminated Zone

Figure E-15 Evaluation Measure for the Reduction of Volume of Tc-99 Zone

IV. The Degree to Which the Treatment is Irreversible (40 CFR S300.430(e)(9)(iii)(D)(4))**:** Note distinct evaluation measures for TCE and Tc-99. The WAG 6 team assumed that once TCE was removed or treated, it would not be reinjected into the subsurface and, therefore, it would have been treated irreversibly. Treatment could also include in-situ treatment where the TCE has been irreversibly altered or destroyed. The more TCE removed the better.



Percent of TCE Irreversibly Treated/Removed from the Subsurface

Figure E-16 Evaluation Measure For Irreversible Treatment of TCE

A similar evaluation measure was developed for Tc-99. Again, the team assumed that once the Tc-99 was removed, it would not be reinjected into the subsurface and so it could be considered to have been treated irreversibly. It is important to note that Tc-99 cannot be treated irreversibly other than to be removed from the subsurface for this evaluation measure. The more Tc-99 removed the better.

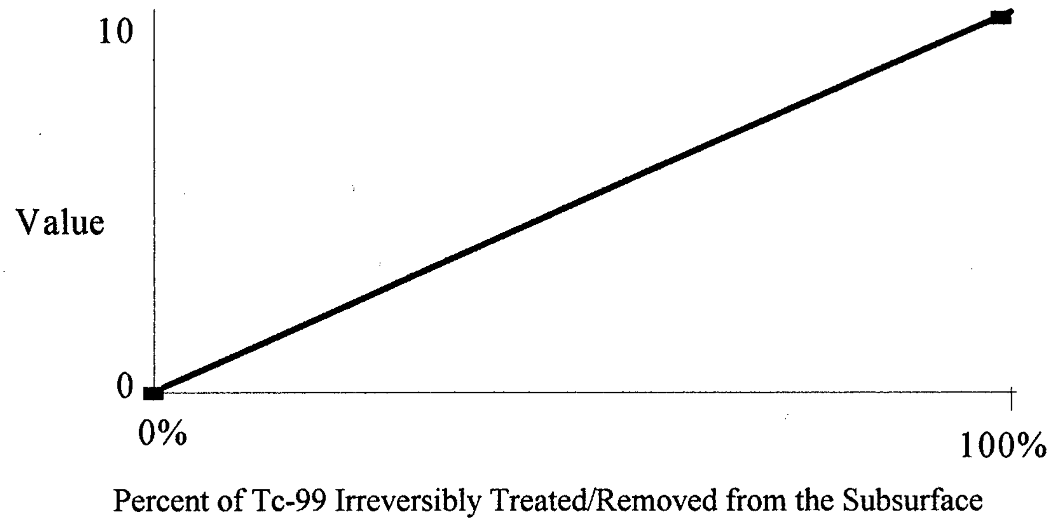


Figure E-17 Evaluation Measure For Irreversible Treatment of Tc-99

Balancing Criteria 3 SHORT-TERM EFFECTIVENESS (40 CFR **S300.430(e)(9)(iii)(E)):** CERCLA states that "the short-term impacts of alternatives shall be assessed by considering the following subcriteria..." and then lists the four subcriteria depicted below:

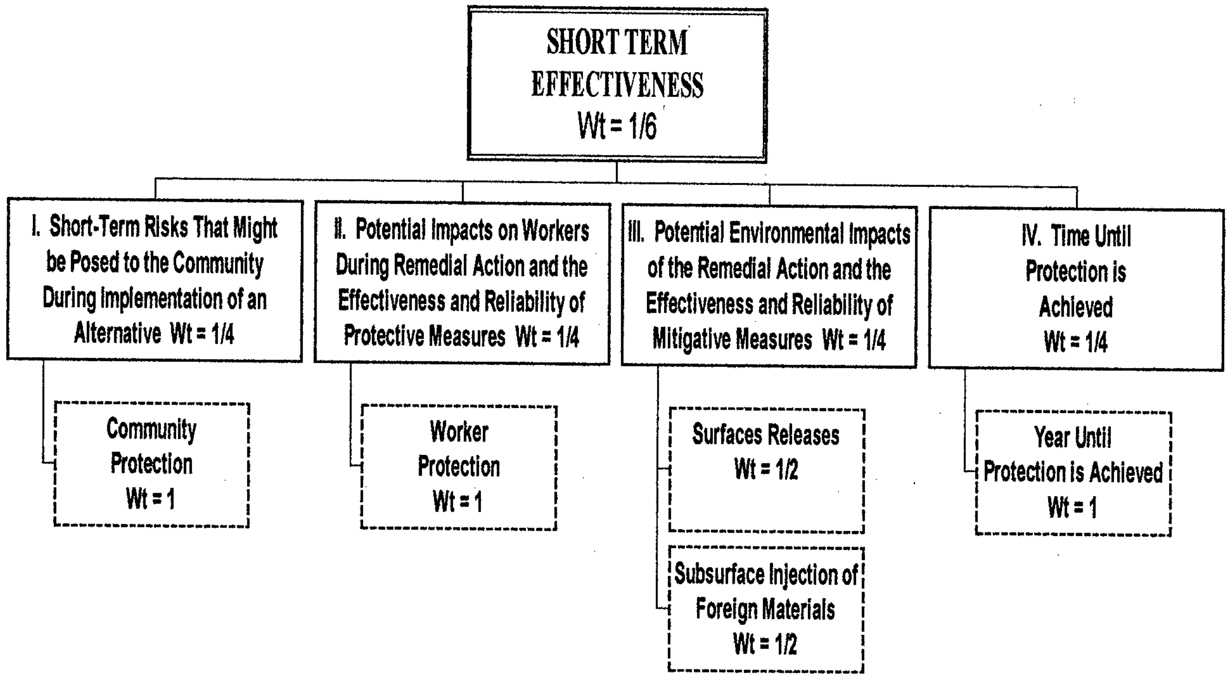


Figure E-18 - Short-Term Effectiveness Hierarchy

EPA guidance suggests that "short-term effectiveness addresses the effects of the alternative during the construction and implementation phase until remedial response objectives are met."

The weights were derived as explained previously, where the subcriteria are equally weighted and the evaluation measures are also evenly weighted (as there is no distinction between TCE and Tc-99 in the evaluation measures for Short-Term Effectiveness).

I. Short-Term Risks that Might be Posed to the Community During Implementation of an Alternative (40 CFR S300.430(e)(9)(iii)(E)(1)): The evaluation measure of Community Protection is a constructed measure, developed because there was no standard way of evaluating Community Protection. This evaluation measure uses the requirements of air emission monitoring and hazardous waste (HW) and hazardous material (HM) shipment both on and off site. HM has previously been defined, and HW is considered any waste generated at the site that meets the RCRA definition of a HW. The "community" is defined to be both those individuals who are employed at the site and the local community in the vicinity of the site. The team believed that the occurrences shown in Figure E-19, represent the entire range of possible events during any remedial action. The best score is achieved when there are no emissions and no transportation of HW/HM. The worst score is when there are untreated radiological emissions to the air/water.

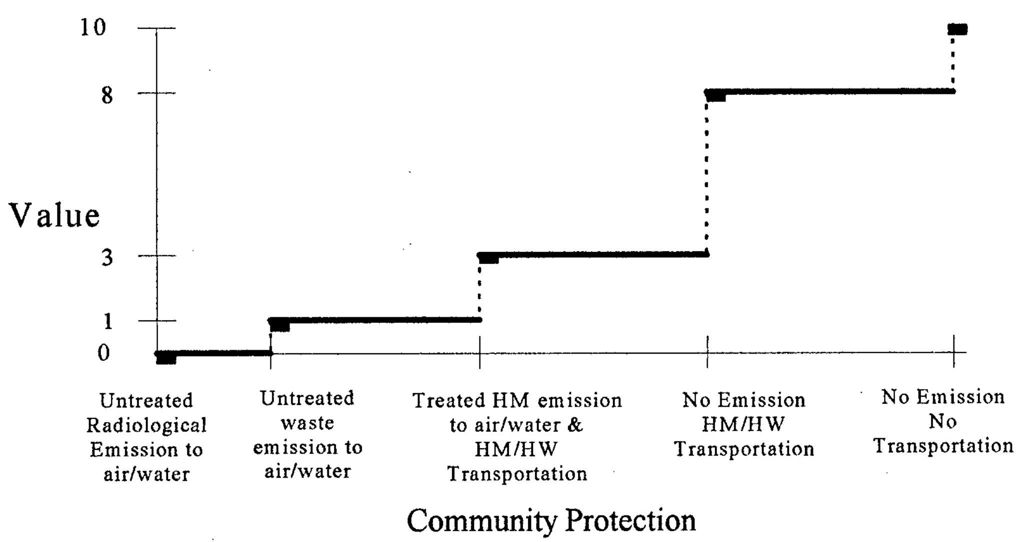


Figure E-19 Evaluation Measure for Risks Posed to the Community

II. Potential Impacts on Workers During Remedial Action and the Effectiveness and Reliability of Protective Measures (40 CFR S300.430(e)(9)(iii)(E)(2)):

The evaluation measure of Worker Protection is a constructed measure which uses radiation, mechanical, chemical, heat, and electrical risks to cover the range of hazards workers may face. The best value is no exposure to hazards for the remediation workers on site (those workers specifically performing tasks related to the remedial action). The worst value (not expected for any of the trains) is zero, when all five hazards cannot be readily controlled.

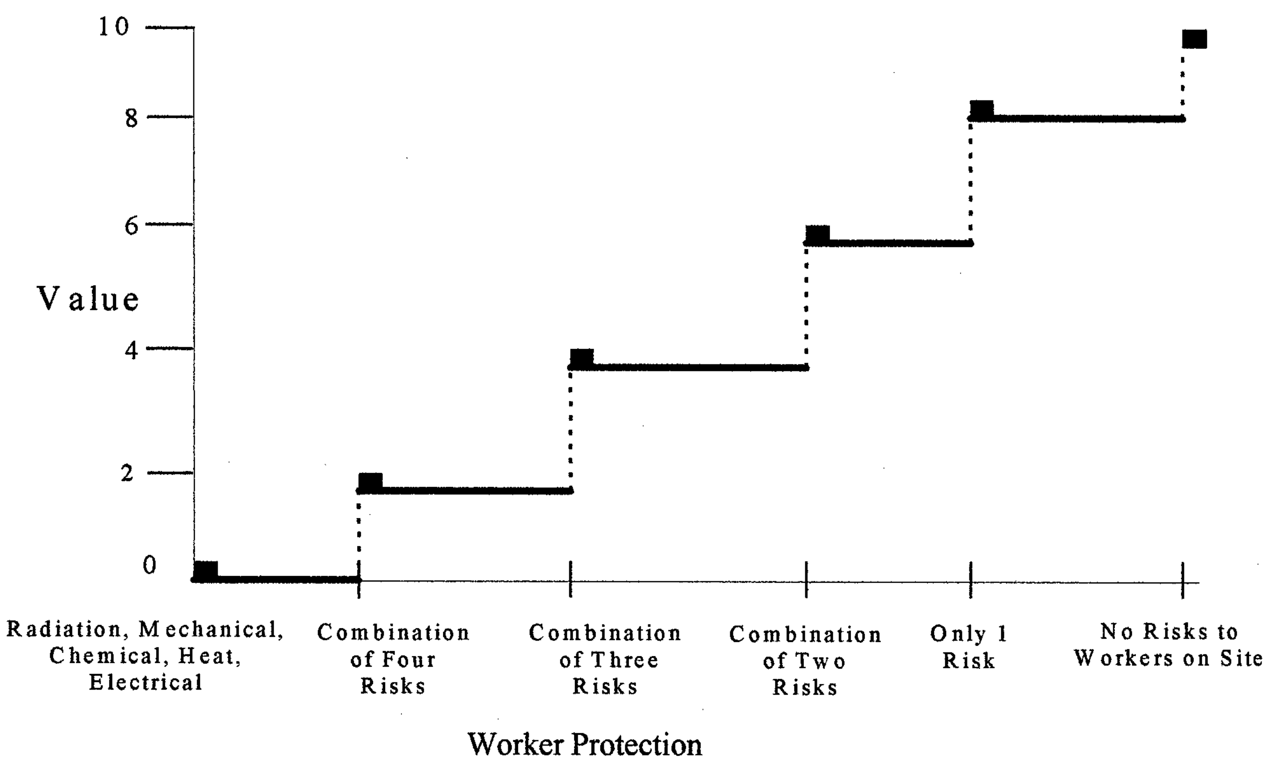


Figure E-20 Evaluation Measure for Potential Impact on Workers

III. Potential Environmental Impacts of the Remedial Action and the Effectiveness and Reliability of Mitigating Measures During Implementation (40 CFR S300.430(e)(9)(iii)(E)(3))**:** The team decomposed this evaluation measure to produce two measures - surface release and subsurface injection of foreign materials.

Surface Release: At the surface, no release is considered best and receives a value of 10. An uncontrolled air and uncontrolled water release is considered the worst case and receives no value (0). Water releases are considered less dangerous and pose less risk than air releases. The largest increase in value is between uncontrolled and controlled releases as shown below:

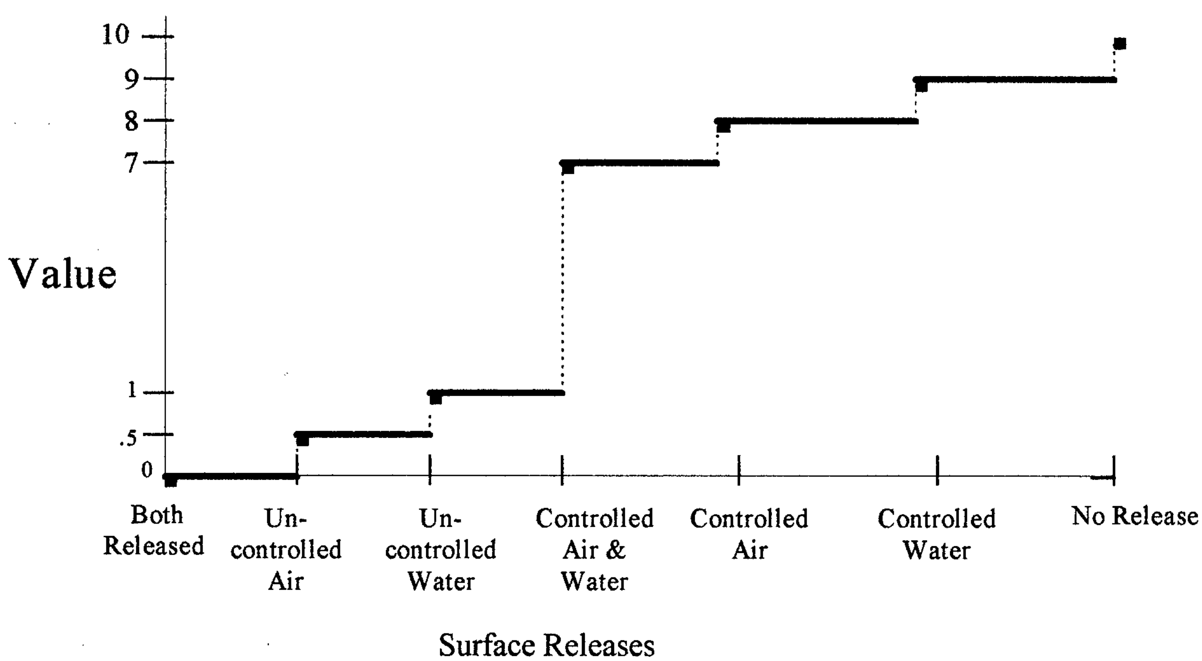


Figure E-21 Evaluation Measure for Potential Surface Releases

Subsurface Injection of Foreign Materials: The step function for this evaluation measure assumes that the risk due to injection increases as the material injected changes from air, to water, to steam, to surfactants, to solvents, and, finally, to toxic materials which rate the worst value (0). The best value is assigned to the alternative that does not inject anything into the subsurface.

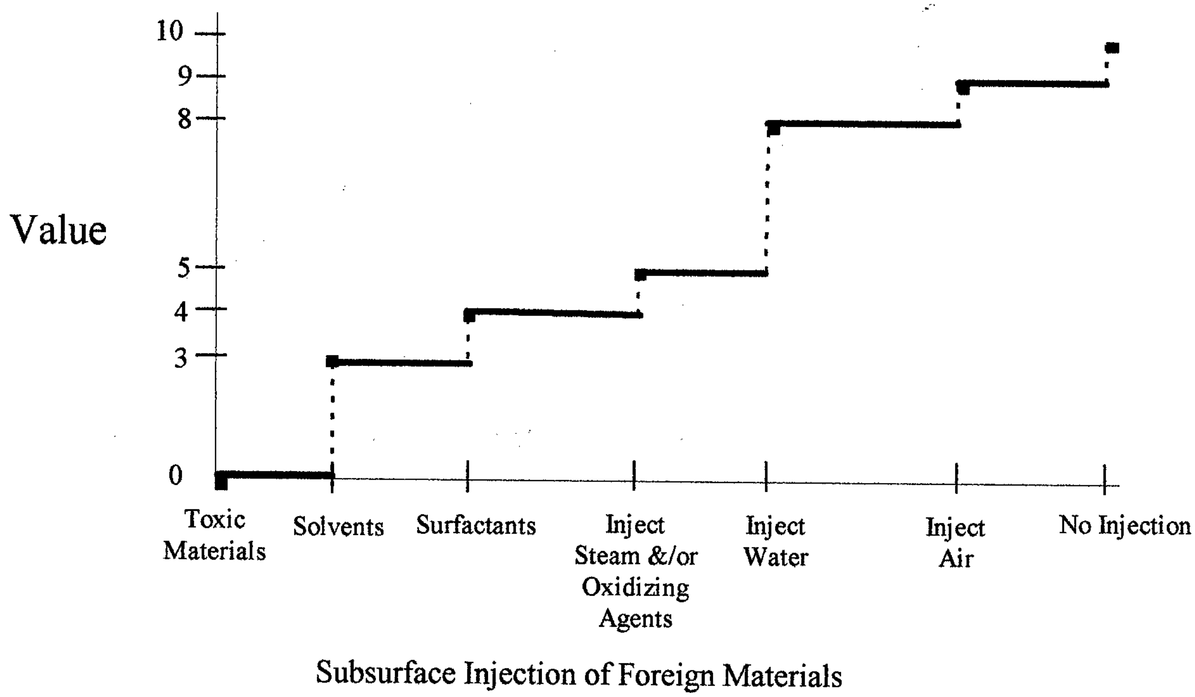


Figure E-22 Evaluation Measure for Potential Subsurface Injection of Materials

IV. Time Until Protection is Achieved (40 CFR S300.430(e)(9)(iii)(E)(4))**:** The 10-year plan, beginning in 1996, provides the rationale for the evaluation measure assigning a train a value of 10 at the 2006 milestone. Assuming construction would finish by 2002, if the Remedial Action (RA) was completed in eight years (i.e. 2010) it would be considered an extremely successful project with respect to time. Any remedial actions that require more than thirty years past construction completion would have little or no added value with respect to time. Therefore, any project that takes longer to complete than 2032 scores a 0. The value is considered to reduce linearly with each year beginning in 2010 until 2032 is reached.

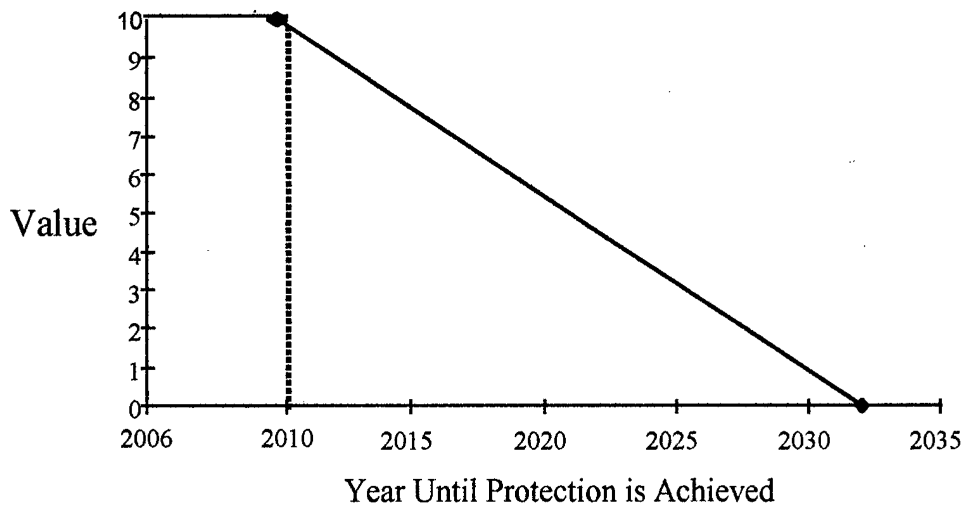


Figure E-23 Evaluation Measure for Time Until Protection is Achieved

Balancing Criteria 4: IMPLEMENTABILITY (40 CFR S300.430(e)(9)(iii)(F)):

CERCLA states that "the ease or difficulty of implementing the alternatives shall be assessed by considering the following types of factors as appropriate" and then lists the three subcriteria expressed below:

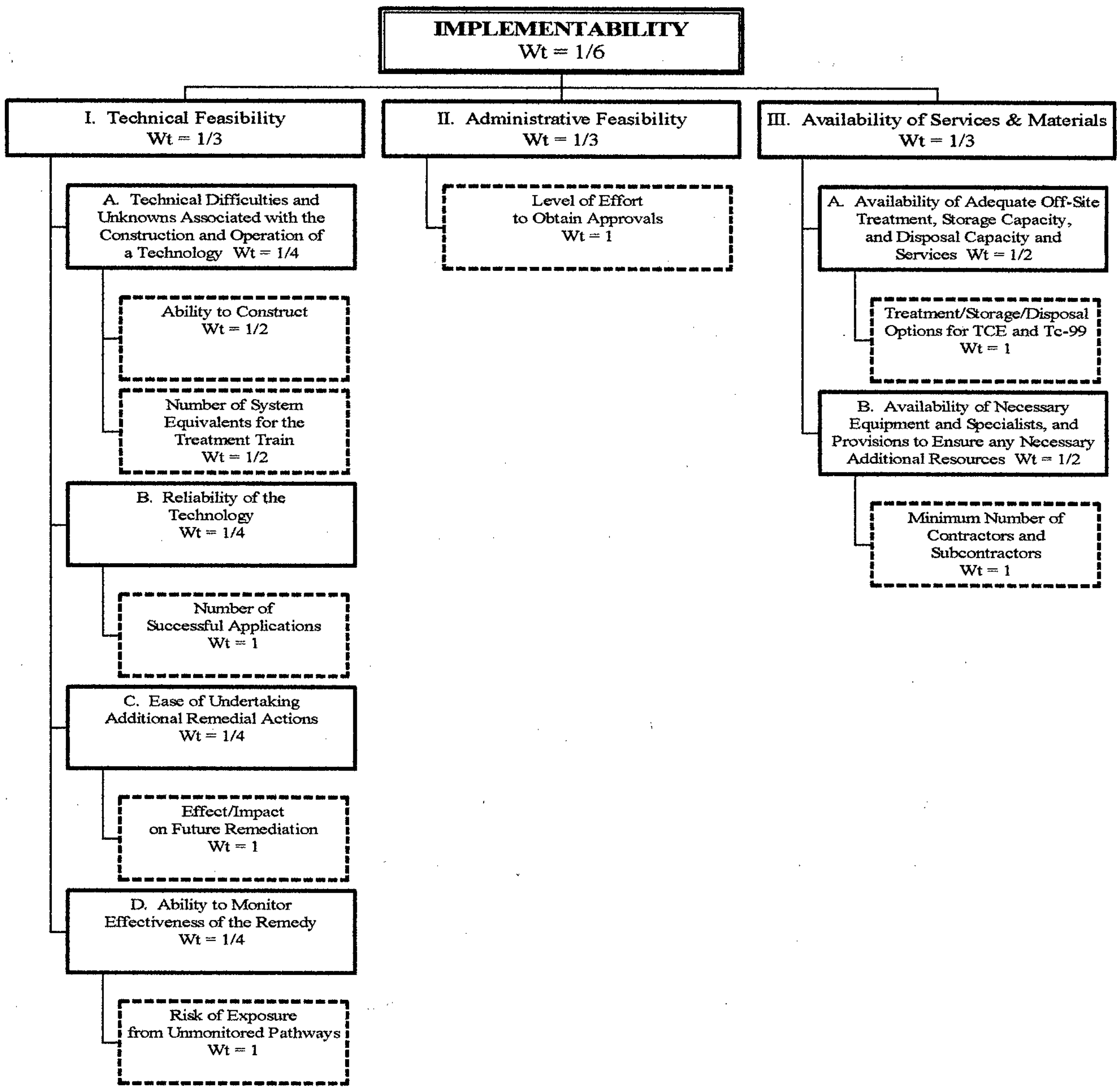


Figure E-24 Implementability Hierarchy

The weights were derived as before; the subcriteria are equally weighted and the evaluation measures are also evenly weighted (as there is no distinction between TCE and Tc-99 in the Implementability criteria, each evaluation measure considers both PCOCs).

I. Technical Feasibility (40 CFR S300.430(e)(9)(iii)(F)(1))**:** CERCLA further subdivides Technical Feasibility into the subcriteria presented in the preceding hierarchy (A, B, C, and D - solid lined boxes).

IA. Technical Difficulties and Unknowns Associated with the Construction and Operation of a Technology. This section is evaluated using two measures. The first measure addresses the difficulty of construction and is scored by giving one point for each "yes" to the following questions:

1. Is the technology sensitive to obstructions? (yes = 1, no = 0)
2. Does the technology require unconventional techniques/equipment? (y=1, n=0)
3. Does the technology have unconventional operational requirements? (y=1, n=0)

Unconventional is defined to mean that which is not readily available or previously applied in the field of environmental restoration. The scores for these three questions are then added and their total is used to enter into the x-axis of the figure below to calculate the corresponding value. For example, to score the DUS technology, the answer to question 1 would be yes (score = 1) because DUS requires well emplacement which could be sensitive to obstructions (like the C-400 building located at the site). The answers to questions 2 and 3 would both be no (score = 1 + 0 + 0 = 1), because the emplacement of the DUS technology does not require any unconventional/extraordinary techniques or operational requirements above and beyond standard construction/operation procedures.

The total score for DUS of 1 corresponds to a value of 6.67.

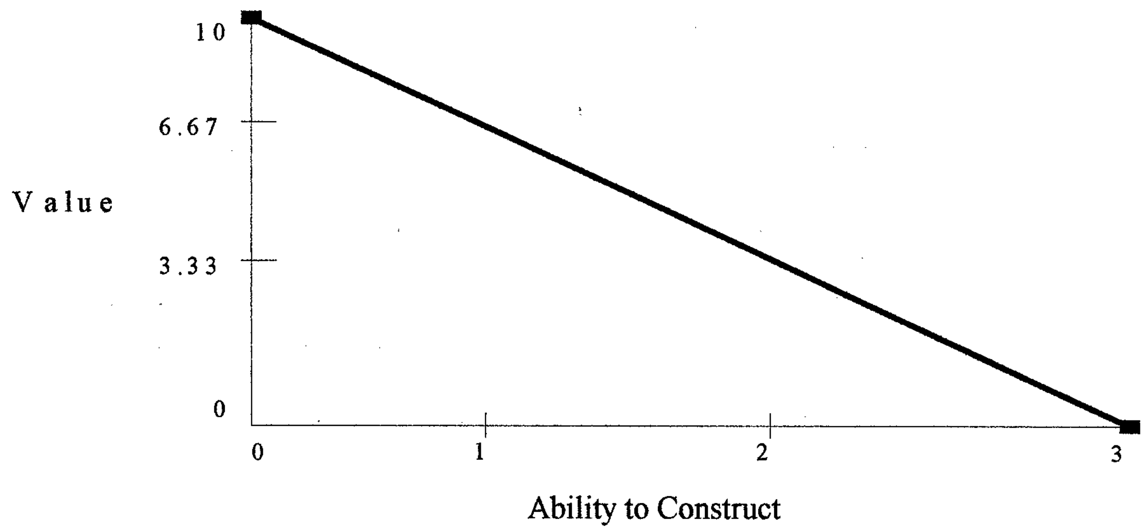


Figure E-25 Evaluation Measure for Unknowns Associated with Construction and Operation

The second measure used to evaluate this criteria is the complexity of the treatment trains being considered. The complexity of a system can be estimated by the number of systems components, which vary greatly for each alternative. A method was designed to count the number of system components by using system equivalents where an estimated 1 system equivalent is viewed as the simplest technology and receives a value of 10, and the most complicated technology is estimated at 20 system equivalents and receives a value of 0. The following system equivalents guide was proposed for scoring alternatives:

3 system equivalents	SVE
1 system equivalent	air movement
1 system equivalent	treatment
1 system equivalent	wells

4 system equivalents — Pump & Treat
- 1 system equivalent — pump
- 1 system equivalent — well
- 1 system equivalent — water treatment
- 1 system equivalent — vapor treatment

10 system equivalents — DUS
- 2 system equivalents — pump (liquid and vacuum)
- 1 system equivalents — injection wells
- 1 system equivalents — extraction wells
- 1 system equivalent — injection system
- 2 system equivalents — controlling monitoring system
- 2 system equivalents — remove vapor extraction treatment (steam & water)
- 1 system equivalent — steam generation package

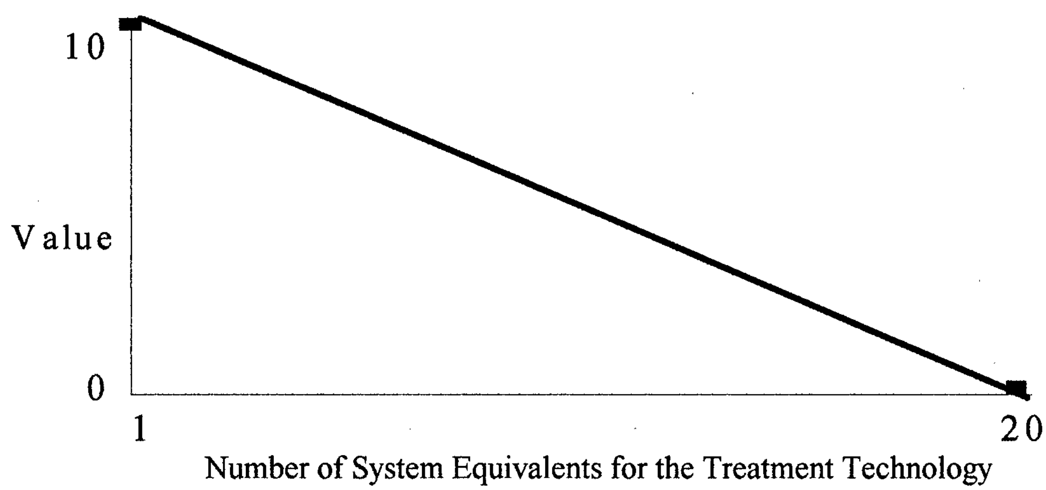


Figure E-26 Evaluation Measure for Technical Difficulties Associated With Construction and Operation

IB. The Reliability of the Technology: This evaluation measure focuses on the likelihood that technical problems associated with implementation will lead to schedule delays (EPA Guidance, Table 6-4). The number of times the technology being considered has been successfully used in a similar medium is a good proxy measure. A conservative measure of reliability of a treatment train is the reliability of the component technology that has been successfully implemented the least number of times. After a technology has been successfully implemented 10 times, there is little additional perceived increase in reliability and therefore no increase in value for this measure. The lowest value case would be for a treatment train that includes a technology that has never been successfully implemented.

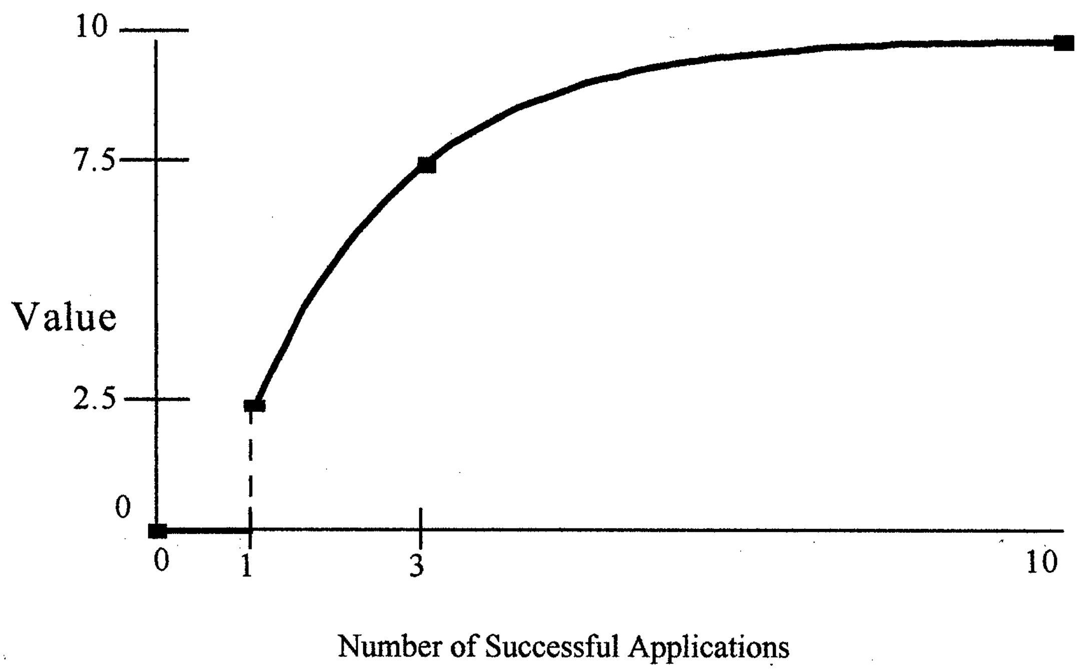


Figure E-27 Evaluation Measure for the Reliability of the Technology

IC. Ease of Undertaking Additional Remedial Actions: This evaluation measure estimates the impact on potential future additional remediation activities either for other principal threats or for other overlapping or nearby operable units. We developed a constructed scale ranging from no impact on additional remedial activities to alternatives that have a major impact on additional remedial activities. For example, injecting a chemical into the aquifer which precipitates the Tc-99 may actually increase the mobility of TCE and therefore hinder the TCE remediation activities which would result in a minor negative impact. A major negative impact would be the plugging of the aquifer; a major positive impact would be leaving an operational system in place that could be used for future remediation activities; and a minor positive impact would be putting in wells which could be used for future remediation activities.

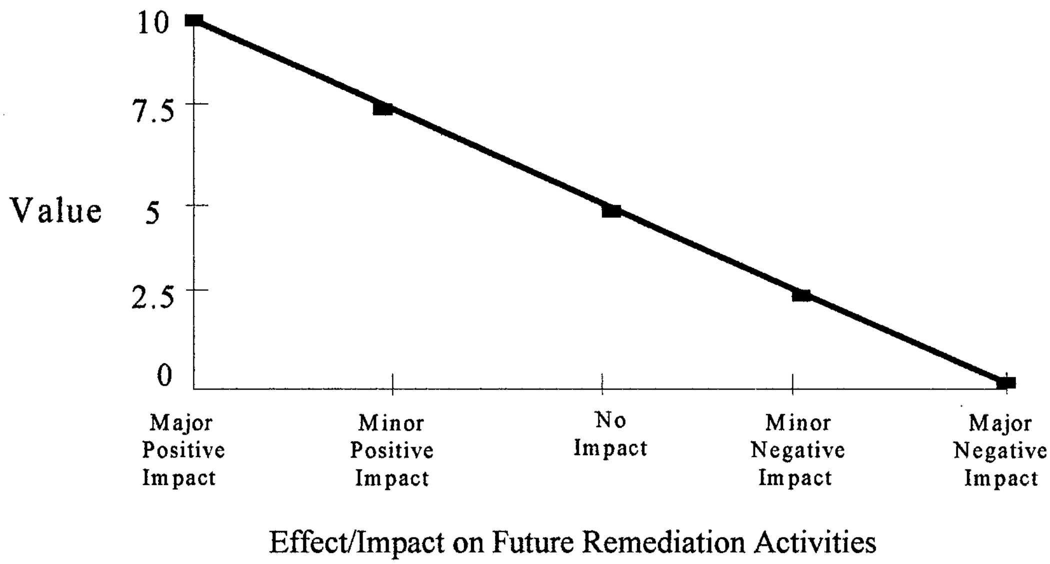


Figure E-28 Evaluation Measure for the Ease of Undertaking Future Remediation

ID. Ability to Monitor the Effectiveness of the Remedy: The ability to monitor a pathway combined with the risk associated with that pathway is important. The ability to monitor the effectiveness of a remedial action varies with each hydrogeological zone and with each train. The proposed evaluation measure is a subjective assessment over all three zones for a given treatment train. The largest potential risk is not being able to completely monitor all pathways to the aquifer. For example, a surfactant that is inserted into one zone breaks into another geological zone that is not monitored. The three categories created were: low probability of exposure and low health and safety risk which receives a value of 10, low probability of exposure and high health and safety risk which receives a value of 5, and high probability of exposure with a high health and safety risk which receives a value of 0.

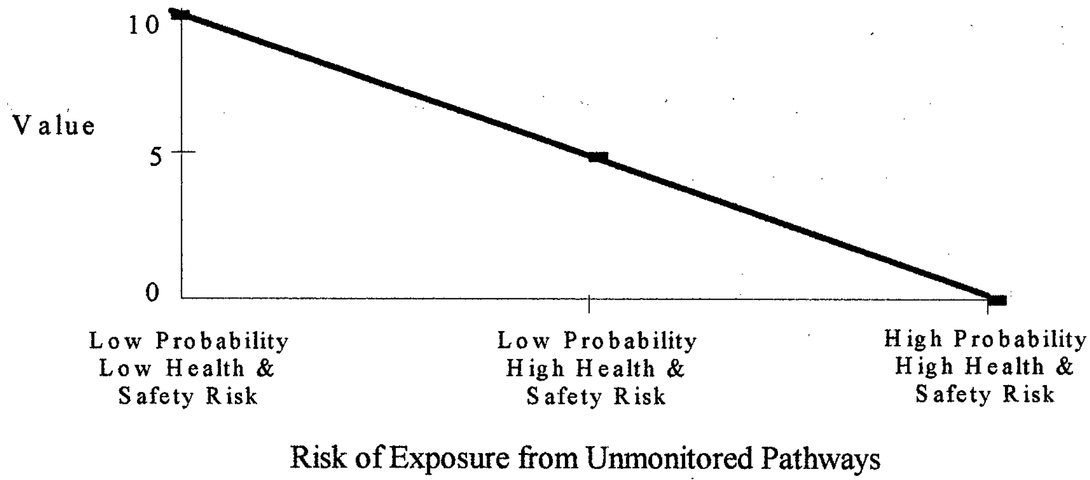


Figure E-29 Evaluation Measure for the Ability to Monitor Effectiveness of Remedy

II. Administrative Feasibility (40 CFR S300.430(e)(9)(iii)(F)(2)): CERCLA further subdivides Administrative Feasibility into two subcriteria: "activities needed to coordinate with other offices and agencies and the ability and time required to obtain any necessary approvals and permits from other agencies (for off-site actions)". The team decided that one evaluation measure, Level of Effort to Obtain Approvals, could adequately cover this subcriteria.

It was decided that the Level of Effort to Obtain Critical Approvals for the pump and treat remediation train would serve as the ideal base case (receives a value of 10), from which all other treatments would be compared. If any one of the following five approvals are needed in addition to the approvals needed for the pump and treat base case, the remediation train would receive a score of one with a corresponding value of 8. Likewise, if three out of the five approvals were needed above the base case, then the train would score a three with a corresponding value of 4. The following list of approvals is not comprehensive, approvals may exist that are not on the list below, but will be counted against the technology when it is scored.

Additional Approvals That May be Needed in Addition to Pump and Treat Approvals:

1) Requires Underground Injection
2) Requires Electrodes
3) Interferes With Building
4) Interferes With Existing Utilities
5) Requires New Utilities

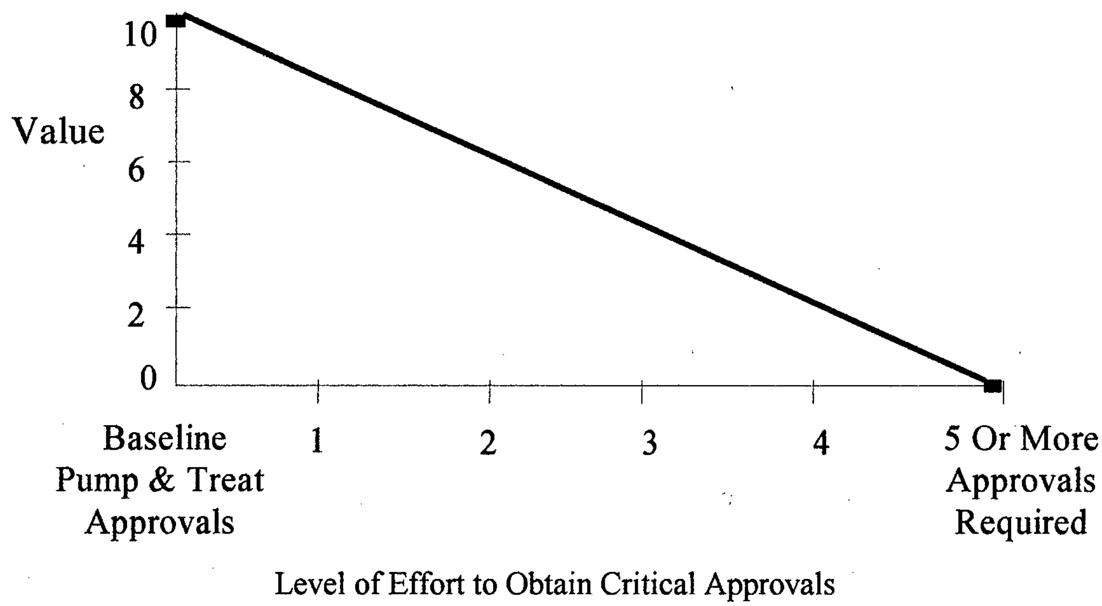


Figure E-30 Evaluation Measure for Administrative Feasibility

III. Availability of Services and Materials (40 CFR S300.430(e)(9)(iii)(F)(3)):

CERCLA further subdivides Availability of Services and Materials into four subcriteria, the first two were presented in the preceding hierarchy (A & B; solid lined boxes in Fig. E-24). The remaining two subcriteria: availability of services and materials and availability of prospective technologies were considered redundant by the team. The team felt these last two criteria were adequately addressed by the evaluation measures developed for A, B, C, and D under the Technical Feasibility subcriteria branch.

III A. Availability of Adequate Off-Site Treatment, Storage Capacity and Disposal Capacity and Services: The team agreed that if there was adequate off-site treatment, storage capacity, or disposal capacity, then this criteria would be considered satisfied. For example, the score of zero would be given if there was no adequate off-site treatment, storage, or disposal and a score of one would be given if any one of the three were available. Currently, all trains score a ten on this evaluation measure.

The team noted that the off-site treatment for Tc-99 was limited to low level waste and that the TSCA incinerator requires mostly pure TCE. Furthermore, the team expected there to be a preference from some Treatment, Storage, and Disposal (TSD) facilities for waste with higher TCE concentration and lower Tc-99 activity.

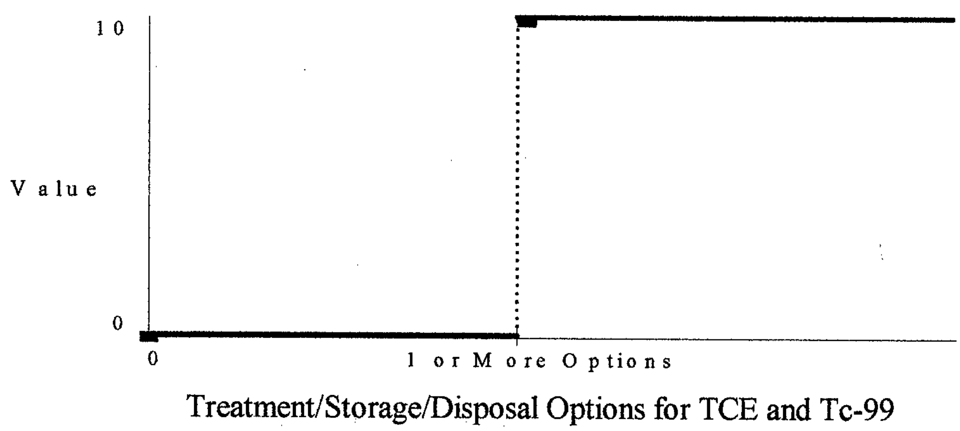
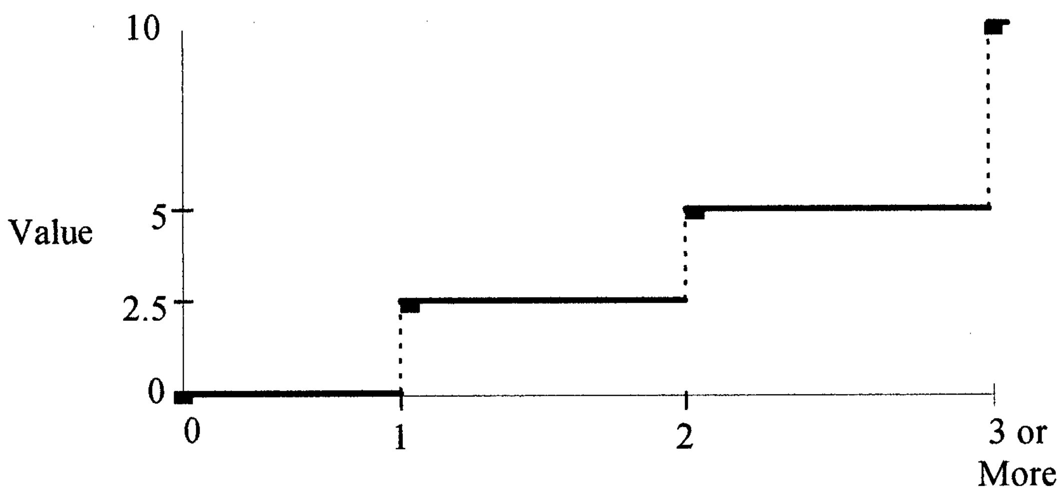


Figure E-31 Evaluation Measure for Availability of Off-Site Treatment, etc.

IIIB. Availability of Necessary Equipment and Specialists and Provisions to Ensure Any Necessary Additional Resources: The team agreed upon the evaluation measure of the number of contractors/subcontractors/specialists available for the limiting treatment/technology within a given train. Each train would be examined, and the train would score based on the treatment/technology, within that train, that had the minimum number of contractors, subcontractors or specialists.

The team agreed that if space were a limiting factor in implementing a particular technology, the technology would have already been screened out of the acceptable alternatives, prior to this evaluation. A score of zero indicates that DOE is developing the technology and there are no commercial contractors available.



Minimum Number of Contractors/Subs/Specialists Available

Figure E-32 Evaluation Measure for Availability of Necessary Equipment and Specialists

Balancing Criteria 5 COST (40 CFR S300.430(e)(9)(iii)(G)): CERCLA states "the following types of costs shall be assessed: capital costs, including both direct and indirect costs; annual operation and maintenance costs: and net present value of capital and O&M costs." The team agreed that the best way to develop and evaluation measure for cost was to consider Net Present Cost, which is the discounted sum of Capital Costs and the Annual O&M Costs.

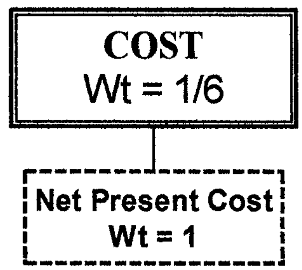


Figure E-33 - Cost Hierarchy

Since there is only one evaluation measure with no distinction between TCE and Tc-99, the measure is assigned the weight of one. The most expensive alternative would receive the lowest (0) value and the least expensive alternative would receive the highest (10) value. MSE cost data provided the thresholds demonstrated below:

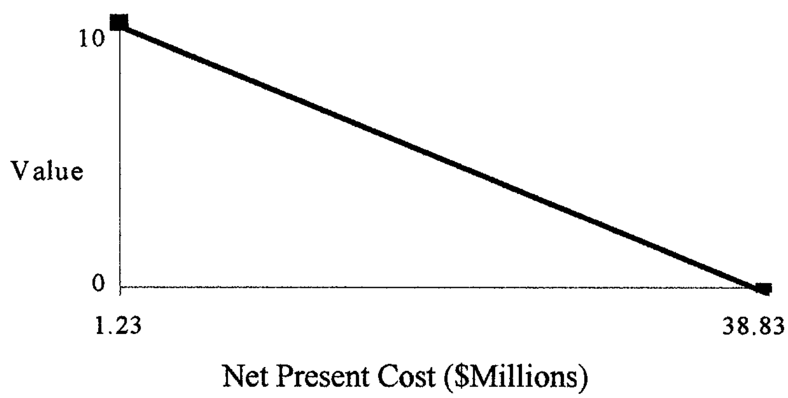


Figure E-34 Evaluation Measure for Net Present Cost

Appendix F: DUS & 2 Phase Scores

This appendix contains the scores for DUS and 2 Phase.

Table F-1 DUS & 2 Phase Evaluation Measures

	Evaluation Measure	Best	Most Likely	Worse
Long-Term	HM Remaining in the Subsurface	No	No	No
	% of TCE Left in the Subsurface	5%	10%	30%
	Activity of Tc-99 Left in Ground Water	0	50	5000
	Component Replacement after Remedial Action	No Replace	No Replace	No Replace
Toxicity, Mobility, or Volume	PCOCs Addressed in the Treatments	Both	Both	Both
	% TCE Destroyed, Treated, or Recycled	95%	90%	70%
	% Tc-99 Destroyed, Treated, or Recycled	100%	100%	90%
	Reduction of Toxicity Thru In-Situ Degradation	Inherently Degrades	Inherently Degrades	Inherently Degrades
	Reduction of Mobility for TCE	Increase	Increase	Increase
	Reduction of Mobility of Tc-99	Increase	Increase	Increase
	Volume Reduction of TCE Contaminated Zone	0%	0%	0%
	Volume Reduction of Tc-99 Contaminated Zone	0%	0%	0%
	% of TCE Irreversibly Treated/Removed	95%	90%	70%
	% of Tc-99 Irreversibly Treated/Removed from	100%	100%	90%
Short-Term	Community Protection	Treated	Treated	Treated
	Worker Protection	Four Risks	Four Risks	Four Risks
	Surfaces Releases	Controlled Air & Water	Controlled Air & Water	Controlled Air & Water
	Subsurface Injection of Foreign Materials	Inject Steam	Inject Steam	Inject Steam
	Year Until Protection is Achieved	2003.33	2003.33	2006.33
Implementability	Ability to Construct	1	1	1
	# of System Equivalents for the Treatment Trains	13	13	13
	# of Successful Applications	2	2	2
	Effect/Impact on Future Remediation	Minor Positive	Minor Positive	Minor Positive
	Risk of Exposure from Unmonitored Pathways	Low/Low	Low/High	High/High
	Level of Effort to Obtain Approvals	4	4	4
	TCE & Tc-99 Treatment/Storage/Disposal	Yes	Yes	Yes
Cost	NPV	See Below		

Table F-2 NPV for Different Volumes

Net Present Value*	Shortest (2.33 years)	Most Likely (2.33 years)	Longest (5.33 years)
50,000 gallons	$5,789,556	$5,789,556	$7,665,530
100,000 gallons	$8,317,449	$8,317,449	$10,161,644
200,000 gallons	$13,382,767	$13,382,767	$15,165,989
300,000 gallons	$15,200,619	$15,200,619	$20,164,276
400,000 gallons	$16,093,252	$16,093,252	$25,162,562
500,000 gallons	$16,986,106	$16,986,106	$30,160,849

These NPV are based upon 90% expected performance for both DUS and 2 Phase. Although the evaluation measures that indicate performance show different performance ranges, it was decided to use the 90% NPV since this is the performance level being targeted. In addition, the best and worst case are viewed as follows:

1. The best case would be to spend the money in order to obtain the 90% performance level and obtain a 95% cleanup.
2. The worst case would be to spend the money trying to obtain the 90% performance level and only obtain 70% cleanup.

These NPVs also include an ion exchange cost.

NPV (2.33) = $2,795,192

NPV (5.33) = $4,710,522

Appendix G: CERCLA Probabilistic Model with Technological Risks

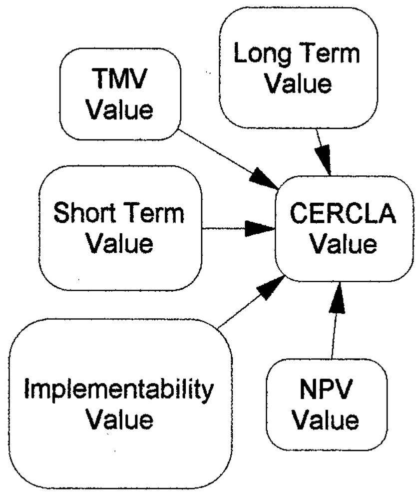


Figure G-1 CERCLA Value Influence Diagram

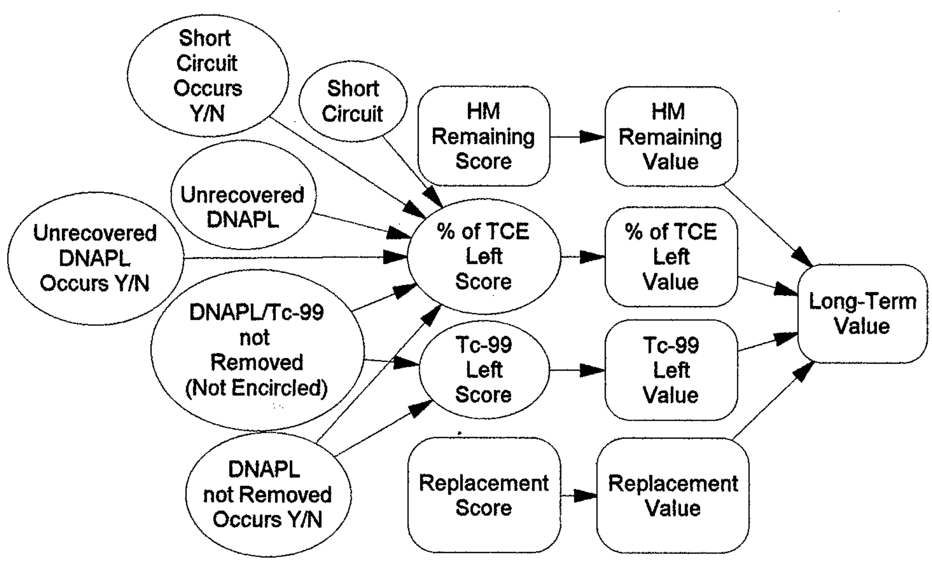


Figure G-2 Long Term Value Influence Diagram

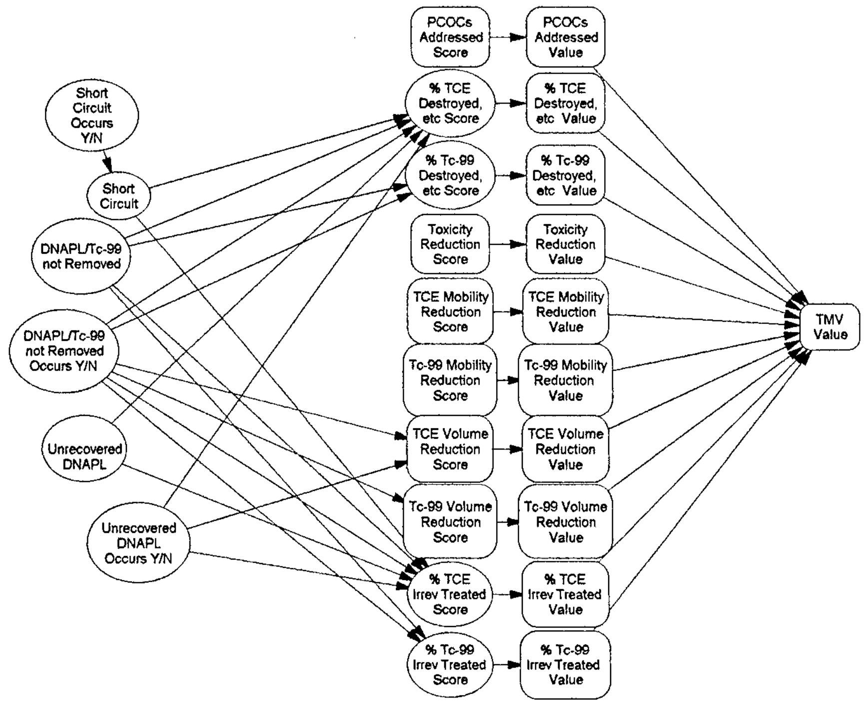


Figure G-3 TMV Value Influence Diagram

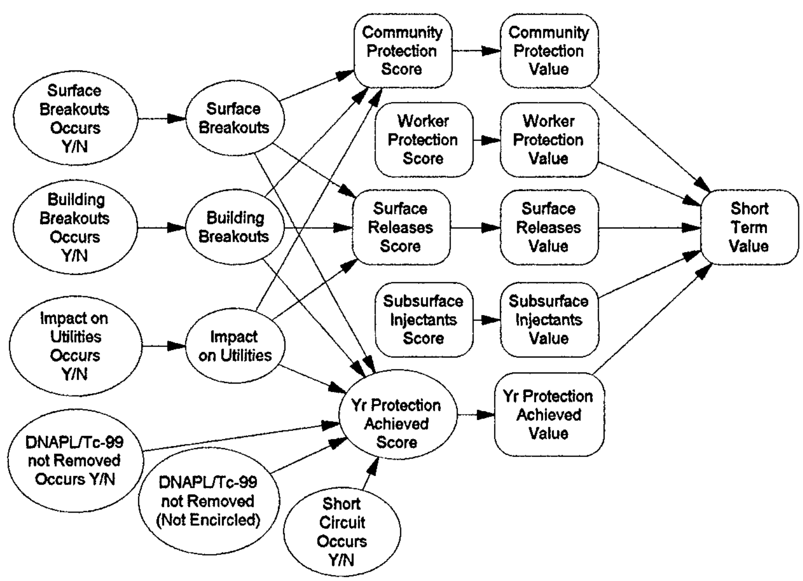


Figure G-4 Short Term Value Influence Diagram

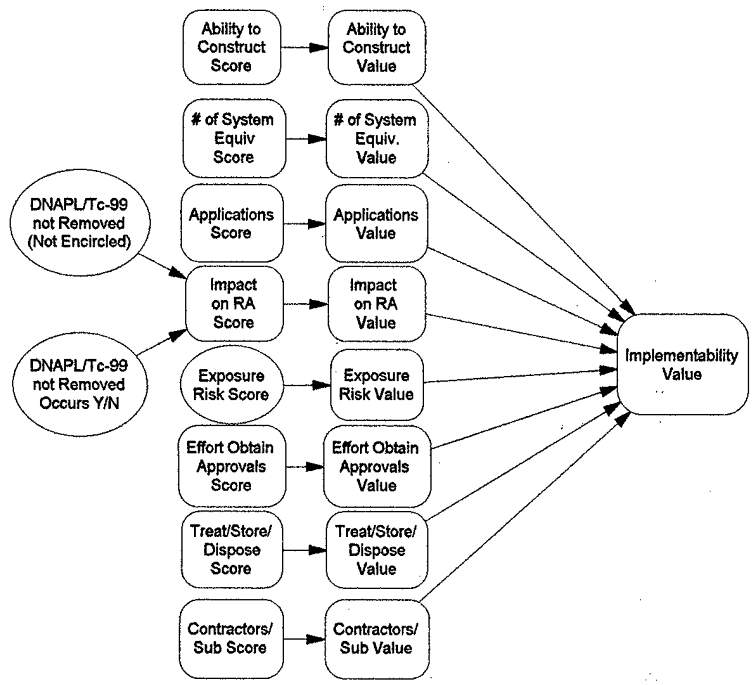


Figure G-5 Implementability Value Influence Diagram

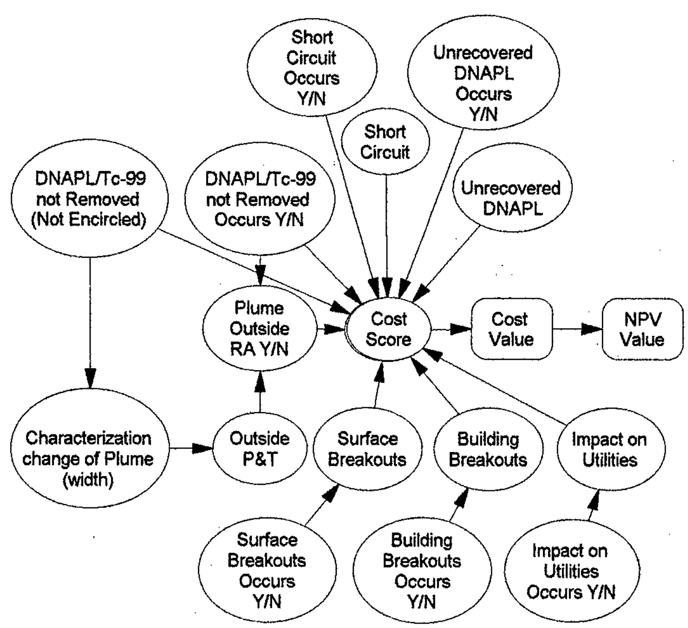


Figure G-6 NPV Influence Diagram

Below is the DPL program for the CERCLA probabilistic model with Technological Risks and Volume Uncertainty.

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// TMV
excel(Excel_1,"xaxis!TMV1_1") value TMV1_1;
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        0.012632,                       // Unrecovered_DNAPL.Nominal
        0.029848;                       // Unrecovered_DNAPL.High
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```

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      N_TCE_Destroyed__etc_Score.Worse
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```
        TMV9_3;                         //N_TCE_Irrev_Treated_Score.Worse
chance N_Tc_99_Irrev_Treated_Score.{Best,Most_Likely,Worse}=
{0.185,0.63,0.185};
value N_Tc_99_Irrev_Treated_Score|DNAPL_Tc_99_not_Removed_Occurs_Y_N,
N_Tc_99_Irrev_Treated_Score=
                                //NAPL_Tc_99_not_Removed_Occurs_Y_N.Yes
        TMV10_1-DNAPL_Tc_99_not_Removed,
        //N_Tc_99_Irrev_Treated_Score.Best
        TMV10_2-DNAPL_Tc_99_not_Removed,
        //N_Tc_99_Irrev_Treated_Score.Most_Likely
        TMV10_3-DNAPL_Tc_99_not_Removed,
        //N_Tc_99_Irrev_Treated_Score.Worse
                                //NAPL_Tc_99_not_Removed_Occurs_Y_N.No
        TMV10_1,                        //N_Tc_99_Irrev_Treated_Score.Best
        TMV10_2,                        //N_Tc_99_Irrev_Treated_Score.Most_Likely
        TMV10_3;                        //N_Tc_99_Irrev_Treated_Score.Worse
value N_TCE_Destroyed__etc__Value=@if(N_TCE_Destroyed__etc_Score<=90,
5/60*(N_TCE_Destroyed__etc_Score-30),@if(N_TCE_Destroyed__etc_Score>90
&& N_TCE_Destroyed__etc_Score<=95,2/5*(N_TCE_Destroyed__etc_Score-
90)+5,@if(N_TCE_Destroyed__etc_Score>95 && N_TCE_Destroyed__etc_
Score<=100,3/5*(N_TCE_Destroyed__etc_Score-95)+7,"error")));
value N_Tc_99_Destroyed__etc__Value=@if(N_Tc_99_Destroyed__etc_
Score>91.1,10,9.5/91.1*(N_Tc_99_Destroyed__etc_Score));
value N_TCE_Irrev_Treated_Value=10/100*N_TCE_Irrev_Treated_Score;
value N_Tc_99_Irrev_Treated_Value=10/100*N_Tc_99_Irrev_Treated_Score;
value PCOCs_Addressed_Score=TMV1_1;
value Toxicity_Reduction_Score=TMV4_1;
value TCE_Mobility_Reduction_Score=TMV5_1;
value Tc_99_Mobility_Reduction_Score=TMV6_1;
value TCE_Volume_Reduction_Score|Unrecovered_DNAPL_Occurs_Y_N,
DNAPL_Tc_99_not_Removed_Occurs_Y_N=
                        //Unrecovered_DNAPL_Occurs_Y_N.Yes
        -1,                     //DNAPL_Tc_99_not_Removed_Occurs_Y_N.Yes
        -1,                     //DNAPL_Tc_99_not_Removed_Occurs_Y_N.No
                        //Unrecovered_DNAPL_Occurs_Y_N.No
        -1,                     //DNAPL_Tc_99_not_Removed_Occurs_Y_N.Yes
        TMV7_1;                 //DNAPL_Tc_99_not_Removed_Occurs_Y_N.No
value Tc_99_Volume_Reduction_Score|DNAPL_Tc_99_not_Removed_
Occurs_Y_N=
        -1,                     //DNAPL_Tc_99_not_Removed_Occurs_Y_N.Yes
        TMV8_1;                 //DNAPL_Tc_99_not_Removed_Occurs_Y_N.No
value PCOCs_Addressed_Value=@if(PCOCs_Addressed_Score==3,10,@if(PCOCs_
Addressed_Score==2,7.5,@if(PCOCs_Addressed_Score==1,2.5,@if(PCOCs_
Addressed_Score==0,0,"error"))));
```

```
value Toxicity_Reduction_Value=@if(Toxicity_Reduction_Score==3,3,@if(
Toxicity_Reduction_Score==2,7,@if(Toxicity_Reduction_Score==1,10,"error")));
value TCE_Mobility_Reduction_Value=@if(TCE_Mobility_Reduction_Score==1,7,
@if(TCE_Mobility_Reduction_Score==2,9,@if(TCE_Mobility_Reduction_Score==
3,10,"error")));
value Tc_99_Mobility_Reduction_Value=@if(Tc_99_Mobility_Reduction_
Score==1,7,@if(Tc_99_Mobility_Reduction_Score==2,8,@if(Tc_99_Mobility_Redu
ction_Score==3,10,"error")));
value TCE_Volume_Reduction_Value=@if(TCE_Volume_Reduction_Score<0,0,
5/100*TCE_Volume_Reduction_Score+5);
value Tc_99_Volume_Reduction_Value=@if(Tc_99_Volume_Reduction_Score<0,0,
5/100*Tc_99_Volume_Reduction_Score+5);
value TMV_Value=(1/4*PCOCs_Addressed_Value+1/4*(3/4*N_TCE_Destroyed__
etc__Value+1/4*N_Tc_99_Destroyed__etc__Value)+1/4*(1/3*Toxicity_Reduction_
Value+1/4*TCE_Mobility_Reduction_Value+1/12*Tc_99_Mobility_Reduction_
Value+1/4*TCE_Volume_Reduction_Value+1/12*Tc_99_Volume_Reduction_
Value)+1/4*(3/4*N_TCE_Irrev_Treated_Value+1/4*N_Tc_99_Irrev_Treated_Value));

// Short Term
excel(Excel_1,"xaxis!ST2_1") value ST2_1;
value Worker_Protection_Score=ST2_1;
excel(Excel_1,"xaxis!ST1_1") value ST1_1;
excel(Excel_1,"xaxis!ST3_1") value ST3_1;
excel(Excel_1,"xaxis!ST4_1") value ST4_1;
excel(Excel_1,"xaxis!ST5_1") value ST5_1;
excel(Excel_1,"xaxis!ST1_2") value ST1_2;
excel(Excel_1,"xaxis!ST2_2") value ST2_2;
excel(Excel_1,"xaxis!ST3_2") value ST3_2;
excel(Excel_1,"xaxis!ST4_2") value ST4_2;
excel(Excel_1,"xaxis!ST5_2") value ST5_2;
excel(Excel_1,"xaxis!ST1_3") value ST1_3;
excel(Excel_1,"xaxis!ST2_3") value ST2_3;
excel(Excel_1,"xaxis!ST3_3") value ST3_3;
excel(Excel_1,"xaxis!ST4_3") value ST4_3;
excel(Excel_1,"xaxis!ST5_3") value ST5_3;
value Worker_Protection_Value=@if(Worker_Protection_Score==0,10,
@if(Worker_Protection_Score==1,8,@if(Worker_Protection_Score==2,6,
@if(Worker_Protection_Score==3,4,@if(Worker_Protection_Score==4,2,
@if(Worker_Protection_Score==5,0,"error"))))));
value Subsurface_Injectants_Score=ST4_1;
value Subsurface_Injectants_Value=@if(Subsurface_Injectants_Score==1,0,
@if(Subsurface_Injectants_Score==2,3,@if(Subsurface_Injectants_Score==3,4,
@if(Subsurface_Injectants_Score==4,5,@if(Subsurface_Injectants_Score==5,8,
@if(Subsurface_Injectants_Score==6,9,@if(Subsurface_Injectants_Score==7,
10,"error")))))));
```

```
chance Surface_Breakouts_Occurs_Y_N.{Low,Nominal,High}=uniform(0,0.04);
chance Building_Breakouts_Occurs_Y_N.{Low,Nominal,High}=uniform(0,0.04);
chance Impact_on_Utilities_Occurs_Y_N.{Low,Nominal,High}=uniform(0,0.02);
chance Building_Breakouts.{Yes,No}={Building_Breakouts_Occurs_Y_N};
chance Surface_Breakouts.{Yes,No}={Surface_Breakouts_Occurs_Y_N};
chance Impact_on_Utilities.{Yes,No}={Impact_on_Utilities_Occurs_Y_N};
value Community_Protection_Score|Building_Breakouts,Surface_Breakouts,
Impact_on_Utilities=
                              //Building_Breakouts.Yes
                              //Surface_Breakouts.Yes
     2,                              //Impact_on_Utilities.Yes
     2,                              //Impact_on_Utilities.No
                              //Surface_Breakouts.No
     2,                              //Impact_on_Utilities.Yes
     2,                              //Impact_on_Utilities.No
                              //Building_Breakouts.No
                              //Surface_Breakouts.Yes
     2,                              //Impact_on_Utilities.Yes
     2,                              //Impact_on_Utilities.No
                              //Surface_Breakouts.No
     2,                              //Impact_on_Utilities.Yes
     3;                              //Impact_on_Utilities.No
value Surface_Releases_Score|Surface_Breakouts,Building_Breakouts,
Impact_on_Utilities=
                              //Surface_Breakouts.Yes
                              //Building_Breakouts.Yes
     2,                              //Impact_on_Utilities.Yes
     2,                              //Impact_on_Utilities.No
                              //Building_Breakouts.No
     2,                              //Impact_on_Utilities.Yes
     2,                              //Impact_on_Utilities.No
                              //Surface_Breakouts.No
                              //Building_Breakouts.Yes
     2,                              //Impact_on_Utilities.Yes
     2,                              //Impact_on_Utilities.No
                              //Building_Breakouts.No
     2,                              //Impact_on_Utilities.Yes
     4;                              //Impact_on_Utilities.No
value Community_Protection_Value=@if(Community_Protection_Score==1,0,
@if(Community_Protection_Score==2,1,@if(Community_Protection_Score==3,3,
@if(Community_Protection_Score==4,8,@if(Community_Protection_Score==5,10,"
error")))));
value Surface_Releases_Value=@if(Surface_Releases_Score==1,0,@if(Surface_
Releases_Score==2,0.5,@if(Surface_Releases_Score==3,1,@if(Surface_Releases_
```

```
Score==4,7,@if(Surface_Releases_Score==5,8,@if(Surface_Releases_Score==6,9,
@if(Surface_Releases_Score==7,10,"error")))))));
chance Yr_Protection_Achieved_Score.{Low,Nominal,High}={0.185,0.63,0.185};
value Yr_Protection_Achieved_Score|Impact_on_Utilities,Building_Breakouts,
Surface_Breakouts,DNAPL_Tc_99_not_Removed_Occurs_Y_N,Short_Circuit_
Occurs_Y_N,Yr_Protection_Achieved_Score=
                //Impact_on_Utilities.Yes
                //Building_Breakouts.Yes
                //Surface_Breakouts.Yes
                //DNAPL_Tc_99_not_Removed_Occurs_Y_N.Yes
                        //Short_Circuit_Occurs_Y_N.Yes
    ST5_1+.75+1.33+1,           //Yr_Protection_Achieved_Score.Low
    ST5_2+.75+1.33+1,           //Yr_Protection_Achieved_Score.Nominal
    ST5_3+.75+1.33+1,           //Yr_Protection_Achieved_Score.High
                        //Short_Circuit_Occurs_Y_N.No
    ST5_1+.75+1.33,             //Yr_Protection_Achieved_Score.Low
    ST5_2+.75+1.33,             //Yr_Protection_Achieved_Score.Nominal
    ST5_3+.75+1.33,             //Yr_Protection_Achieved_Score.High
                //DNAPL_Tc_99_not_Removed_Occurs_Y_N.No
                        //Short_Circuit_Occurs_Y_N.Yes
    ST5_1+.75+1,                //Yr_Protection_Achieved_Score.Low
    ST5_2+.75+1,                //Yr_Protection_Achieved_Score.Nominal
    ST5_3+.75+1,                //Yr_Protection_Achieved_Score.High
                        //Short_Circuit_Occurs_Y_N.No
    ST5_1+.75,                  //Yr_Protection_Achieved_Score.Low
    ST5_2+.75,                  //Yr_Protection_Achieved_Score.Nominal
    ST5_3+.75,                  //Yr_Protection_Achieved_Score.High
                //Surface_Breakouts.No
                //DNAPL_Tc_99_not_Removed_Occurs_Y_N.Yes
                        //Short_Circuit_Occurs_Y_N.Yes
    ST5_1+.5+1.33+1,            //Yr_Protection_Achieved_Score.Low
    ST5_2+0.5+1.33+1,           //Yr_Protection_Achieved_Score.Nominal
    ST5_3+0.5+1.33+1,           //Yr_Protection_Achieved_Score.High
                        //Short_Circuit_Occurs_Y_N.No
    ST5_1+.5+1.33,              //Yr_Protection_Achieved_Score.Low
    ST5_2+0.5+1.33,             //Yr_Protection_Achieved_Score.Nominal
    ST5_3+0.5+1.33,             //Yr_Protection_Achieved_Score.High
                //DNAPL_Tc_99_not_Removed_Occurs_Y_N.No
                        //Short_Circuit_Occurs_Y_N.Yes
    ST5_1+0.5+1,                //Yr_Protection_Achieved_Score.Low
    ST5_2+0.5+1,                //Yr_Protection_Achieved_Score.Nominal
    ST5_3+0.5+1,                //Yr_Protection_Achieved_Score.High
                        //Short_Circuit_Occurs_Y_N.No
    ST5_1+0.5,                  //Yr_Protection_Achieved_Score.Low
    ST5_2+0.5,                  //Yr_Protection_Achieved_Score.Nominal
```

```
ST5_3+0.5,              //Yr_Protection_Achieved_Score.High
          //Building_Breakouts.No
          //Surface_Breakouts.Yes
          //DNAPL_Tc_99_not_Removed_Occurs_Y_N.Yes
               //Short_Circuit_Occurs_Y_N.Yes
ST5_1+0.5+1.33+1,       //Yr_Protection_Achieved_Score.Low
ST5_2+0.5+1.33+1,       //Yr_Protection_Achieved_Score.Nominal
ST5_3+0.5+1.33+1,       //Yr_Protection_Achieved_Score.High
               //Short_Circuit_Occurs_Y_N.No
ST5_1+0.5+1.33,         //Yr_Protection_Achieved_Score.Low
ST5_2+0.5+1.33,         //Yr_Protection_Achieved_Score.Nominal
ST5_3+0.5+1.33,         //Yr_Protection_Achieved_Score.High
          //DNAPL_Tc_99_not_Removed_Occurs_Y_N.No
               //Short_Circuit_Occurs_Y_N.Yes
ST5_1+0.5+1,            //Yr_Protection_Achieved_Score.Low
ST5_2+0.5+1,            //Yr_Protection_Achieved_Score.Nominal
ST5_3+0.5+1,            //Yr_Protection_Achieved_Score.High
               //Short_Circuit_Occurs_Y_N.No
ST5_1+0.5,              //Yr_Protection_Achieved_Score.Low
ST5_2+0.5,              //Yr_Protection_Achieved_Score.Nominal
ST5_3+0.5,              //Yr_Protection_Achieved_Score.High
          //Surface_Breakouts.No
          //DNAPL_Tc_99_not_Removed_Occurs_Y_N.Yes
               //Short_Circuit_Occurs_Y_N.Yes
ST5_1+0.25+1.33+1,      //Yr_Protection_Achieved_Score.Low
ST5_2+0.25+1.33+1,      //Yr_Protection_Achieved_Score.Nominal
ST5_3+0.25+1.33+1,      //Yr_Protection_Achieved_Score.High
               //Short_Circuit_Occurs_Y_N.No
ST5_1+0.25+1.33,        //Yr_Protection_Achieved_Score.Low
ST5_2+0.25+1.33,        //Yr_Protection_Achieved_Score.Nominal
ST5_3+0.25+1.33,        //Yr_Protection_Achieved_Score.High
          //DNAPL_Tc_99_not_Removed_Occurs_Y_N.No
               //Short_Circuit_Occurs_Y_N.Yes
ST5_1+0.25+1,           //Yr_Protection_Achieved_Score.Low
ST5_2+0.25+1,           //Yr_Protection_Achieved_Score.Nominal
ST5_3+0.25+1,           //Yr_Protection_Achieved_Score.High
               //Short_Circuit_Occurs_Y_N.No
ST5_1+0.25,             //Yr_Protection_Achieved_Score.Low
ST5_2+0.25,             //Yr_Protection_Achieved_Score.Nominal
ST5_3+0.25,             //Yr_Protection_Achieved_Score.High
          //Impact_on_Utilities.No
          //Building_Breakouts.Yes
          //Surface_Breakouts.Yes
          //DNAPL_Tc_99_not_Removed_Occurs_Y_N.Yes
               //Short_Circuit_Occurs_Y_N.Yes
```

```
ST5_1+0.5+1.33+1,          //Yr_Protection_Achieved_Score.Low
ST5_2+0.5+1.33+1,          //Yr_Protection_Achieved_Score.Nominal
ST5_3+0.5+1.33+1,          //Yr_Protection_Achieved_Score.High
                   //Short_Circuit_Occurs_Y_N.No
ST5_1+0.5+1.33,            //Yr_Protection_Achieved_Score.Low
ST5_2+0.5+1.33,            //Yr_Protection_Achieved_Score.Nominal
ST5_3+0.5+1.33,            //Yr_Protection_Achieved_Score.High
              //DNAPL_Tc_99_not_Removed_Occurs_Y_N.No
                   //Short_Circuit_Occurs_Y_N.Yes
ST5_1+0.5+1,               //Yr_Protection_Achieved_Score.Low
ST5_2+0.5+1,               //Yr_Protection_Achieved_Score.Nominal
ST5_3+0.5+1,               //Yr_Protection_Achieved_Score.High
                   //Short_Circuit_Occurs_Y_N.No
ST5_1+0.5,                 //Yr_Protection_Achieved_Score.Low
ST5_2+0.5,                 //Yr_Protection_Achieved_Score.Nominal
ST5_3+0.5,                 //Yr_Protection_Achieved_Score.High
              //Surface_Breakouts.No
              //DNAPL_Tc_99_not_Removed_Occurs_Y_N.Yes
                   //Short_Circuit_Occurs_Y_N.Yes
ST5_1+0.25+1.33+1,         //Yr_Protection_Achieved_Score.Low
ST5_2+0.25+1.33+1,         //Yr_Protection_Achieved_Score.Nominal
ST5_3+0.25+1.33+1,         //Yr_Protection_Achieved_Score.High
                   //Short_Circuit_Occurs_Y_N.No
ST5_1+0.25+1.33,           //Yr_Protection_Achieved_Score.Low
ST5_2+0.25+1.33,           //Yr_Protection_Achieved_Score.Nominal
ST5_3+0.25+1.33,           //Yr_Protection_Achieved_Score.High
                   //DNAPL_Tc_99_not_Removed_Occurs_Y_N.No
                   //Short_Circuit_Occurs_Y_N.Yes
ST5_1+0.25+1,              //Yr_Protection_Achieved_Score.Low
ST5_2+0.25+1,              //Yr_Protection_Achieved_Score.Nominal
ST5_3+0.25+1,              //Yr_Protection_Achieved_Score.High
                   //Short_Circuit_Occurs_Y_N.No
ST5_1+0.25,                //Yr_Protection_Achieved_Score.Low
ST5_2+0.25,                //Yr_Protection_Achieved_Score.Nominal
ST5_3+0.25,                //Yr_Protection_Achieved_Score.High
              //Building_Breakouts.No
              //Surface_Breakouts.Yes
              //DNAPL_Tc_99_not_Removed_Occurs_Y_N.Yes
                   //Short_Circuit_Occurs_Y_N.Yes
ST5_1+0.25+1.33+1,         //Yr_Protection_Achieved_Score.Low
ST5_2+0.25+1.33+1,         //Yr_Protection_Achieved_Score.Nominal
ST5_3+0.25+1.33+1,         //Yr_Protection_Achieved_Score.High
                   //Short_Circuit_Occurs_Y_N.No
ST5_1+0.25+1.33,           //Yr_Protection_Achieved_Score.Low
ST5_2+0.25+1.33,           //Yr_Protection_Achieved_Score.Nominal
```

```
        ST5_3+0.25+1.33,            //Yr_Protection_Achieved_Score.High
                    //DNAPL_Tc_99_not_Removed_Occurs_Y_N.No
                              //Short_Circuit_Occurs_Y_N.Yes
        ST5_1+0.25+1,               //Yr_Protection_Achieved_Score.Low
        ST5_2+0.25+1,               //Yr_Protection_Achieved_Score.Nominal
        ST5_3+0.25+1,               //Yr_Protection_Achieved_Score.High
                              //Short_Circuit_Occurs_Y_N.No
        ST5_1+0.25,                 //Yr_Protection_Achieved_Score.Low
        ST5_2+0.25,                 //Yr_Protection_Achieved_Score.Nominal
        ST5_3+0.25,                 //Yr_Protection_Achieved_Score.High
                    //Surface_Breakouts.No
                    //DNAPL_Tc_99_not_Removed_Occurs_Y_N.Yes
                              //Short_Circuit_Occurs_Y_N.Yes
        ST5_1+1.33+1,               //Yr_Protection_Achieved_Score.Low
        ST5_2+1.33+1,               //Yr_Protection_Achieved_Score.Nominal
        ST5_3+1.33+1,               //Yr_Protection_Achieved_Score.High
                              //Short_Circuit_Occurs_Y_N.No
        ST5_1+1.33,                 //Yr_Protection_Achieved_Score.Low
        ST5_2+1.33,                 //Yr_Protection_Achieved_Score.Nominal
        ST5_3+1.33,                 //Yr_Protection_Achieved_Score.High
                    //DNAPL_Tc_99_not_Removed_Occurs_Y_N.No
                              //Short_Circuit_Occurs_Y_N.Yes
        ST5_1+1,                    //Yr_Protection_Achieved_Score.Low
        ST5_2+1,                    //Yr_Protection_Achieved_Score.Nominal
        ST5_3+1,                    //Yr_Protection_Achieved_Score.High
                              //Short_Circuit_Occurs_Y_N.No
        ST5_1,                      //Yr_Protection_Achieved_Score.Low
        ST5_2,                      //Yr_Protection_Achieved_Score.Nominal
        ST5_3;                      //Yr_Protection_Achieved_Score.High
value Yr_Protection_Achieved_Value=@if(Yr_Protection_Achieved_Score<=
2010,10,-10/22*(Yr_Protection_Achieved_Score-2010)+10);
value Short_Term_Value=(1/4*Community_Protection_Value+1/4*Worker_
Protection_Value+1/4*(1/2*Surface_Releases_Value+1/2*Subsurface_Injectants_
Value)+1/4*Yr_Protection_Achieved_Value);

// Implementability
excel(Excel_1,"xaxis!IM1_1") value IM1_1;
excel(Excel_1,"xaxis!IM2_1") value IM2_1;
excel(Excel_1,"xaxis!IM3_1") value IM3_1;
excel(Excel_1,"xaxis!IM4_1") value IM4_1;
excel(Excel_1,"xaxis!IM5_1") value IM5_1;
excel(Excel_1,"xaxis!IM6_1") value IM6_1;
excel(Excel_1,"xaxis!IM7_1") value IM7_1;
excel(Excel_1,"xaxis!IM8_1") value IM8_1;
excel(Excel_1,"xaxis!IM1_2") value IM1_2;
```

```
excel(Excel_1,"xaxis!IM2_2") value IM2_2;
excel(Excel_1,"xaxis!IM3_2") value IM3_2;
excel(Excel_1,"xaxis!IM4_2") value IM4_2;
excel(Excel_1,"xaxis!IM5_2") value IM5_2;
excel(Excel_1,"xaxis!IM6_2") value IM6_2;
excel(Excel_1,"xaxis!IM7_2") value IM7_2;
excel(Excel_1,"xaxis!IM8_2") value IM8_2;
excel(Excel_1,"xaxis!IM1_3") value IM1_3;
excel(Excel_1,"xaxis!IM2_3") value IM2_3;
excel(Excel_1,"xaxis!IM3_3") value IM3_3;
excel(Excel_1,"xaxis!IM4_3") value IM4_3;
excel(Excel_1,"xaxis!IM5_3") value IM5_3;
excel(Excel_1,"xaxis!IM6_3") value IM6_3;
excel(Excel_1,"xaxis!IM7_3") value IM7_3;
excel(Excel_1,"xaxis!IM8_3") value IM8_3;
chance Exposure_Risk_Score.{Best,Most_Likely,Worse}={0.185,0.63,0.185},
=
        IM5_1,                          //Exposure_Risk_Score.Best
        IM5_2,                          //Exposure_Risk_Score.Most_Likely
        IM5_3;                          //Exposure_Risk_Score.Worse
value Exposure_Risk_Value=-Exposure_Risk_Score+10;
value Ability_to_Construct_Score=IM1_1;
value N_of_System_Equiv_Score=IM2_1;
value Applications_Score=IM3_1;
value Impact_on_RA_Score|DNAPL_Tc_99_not_Removed_Occurs_Y_N,DNAPL_
Tc_99_not_Removed=
                        //DNAPL_Tc_99_not_Removed_Occurs_Y_N.Yes
        7.5,                    //DNAPL_Tc_99_not_Removed.Low
        10,                     //DNAPL_Tc_99_not_Removed.Nominal
        10,                     //DNAPL_Tc_99_not_Removed.High
                        //DNAPL_Tc_99_not_Removed_Occurs_Y_N.No
        IM4_1,                  //DNAPL_Tc_99_not_Removed.Low
        IM4_1,                  //DNAPL_Tc_99_not_Removed.Nominal
        IM4_1;                  //DNAPL_Tc_99_not_Removed.High
value Effort_Obtain_Approvals_Score=IM6_1;
value Treat_Store__Dispose_Score=IM7_1;
value Contractors__Sub_Score=IM8_1;
value Ability_to_Construct_Value=-10/3*Ability_to_Construct_Score+ 10;
value N_of_System_Equiv__Value=-10/19*(N_of_System_Equiv_Score-1)+10;
value Applications_Value=@if(Applications_Score<1,0,@if(Applications_Score==1,
2.5,@if(Applications_Score==10,10,@if(Applications_Score>1,10.06-12.99*exp
(-0.5417*Applications_Score),"error"))));
value Impact_on_RA_Value=-Impact_on_RA_Score+10;
value Effort_Obtain_Approvals_Value=-2*Effort_Obtain_Approvals_Score+10;
```

```
value Treat_Store__Dispose_Value=@if(Treat_Store__Dispose_Score==1,10,
@if(Treat_Store__Dispose_Score==0,0,"error"));
value Contractors__Sub_Value=@if(Contractors__Sub_Score==0,0,
@if(Contractors__Sub_Score==1,2.5,@if(Contractors__Sub_Score==2,5,
@if(Contractors__Sub_Score==3,10,"error"))));
value Implementability_Value=(1/3*(1/4*(1/2*Ability_to_Construct_Value+1/2*
N_of_System_Equiv__Value)+1/4*Applications_Value+1/4*Impact_on_RA_Value+
1/4*Exposure_Risk_Value)+1/3*Effort_Obtain_Approvals_Value+1/3*(1/2*Treat_
Store__Dispose_Value+1/2*Contractors__Sub_Value));

excel(Excel_1,"xaxis!LT1_1") value LT1_1;
value HM_Remaining_Score=LT1_1;
excel(Excel_1,"xaxis!LT2_1") value LT2_1;
excel(Excel_1,"xaxis!LT3_1") value LT3_1;
excel(Excel_1,"xaxis!LT4_1") value LT4_1;
excel(Excel_1,"xaxis!LT1_2") value LT1_2;
excel(Excel_1,"xaxis!LT2_2") value LT2_2;
excel(Excel_1,"xaxis!LT3_2") value LT3_2;
excel(Excel_1,"xaxis!LT4_2") value LT4_2;
excel(Excel_1,"xaxis!LT1_3") value LT1_3;
excel(Excel_1,"xaxis!LT2_3") value LT2_3;
excel(Excel_1,"xaxis!LT3_3") value LT3_3;
excel(Excel_1,"xaxis!LT4_3") value LT4_3;
value HM_Remaining_Value=@if(HM_Remaining_Score==0, 10 ,
@if(HM_Remaining_Score==1,0,"error"));
value Replacement_Score=LT4_1;
value Replacement_Value=@if(Replacement_Score==1,10,@if(Replacement_
Score==2,7,@if(Replacement_Score==3,1,"error")));
chance N_of_TCE_Left_Score.{Best,Most_Likely,Worse}={0.185,0.63,0.185};
value N_of_TCE_Left_Score|Unrecovered_DNAPL_Occurs_Y_N,DNAPL_
Tc_99_not_Removed_Occurs_Y_N,Short_Circuit_Occurs_Y_N,N_of_TCE_
Left_Score=
            //Unrecovered_DNAPL_Occurs_Y_N.Yes
                  //DNAPL_Tc_99_not_Removed_Occurs_Y_N.Yes
                              //Short_Circuit_Occurs_Y_N.Yes
      LT2_1+Unrecovered_DNAPL+DNAPL_Tc_99_not_Removed+Short_Circuit
*0.1, //N_of_TCE_Left_Score.Best
      LT2_2+Unrecovered_DNAPL+DNAPL_Tc_99_not_Removed+Short_Circuit
*0.1, //N_of_TCE_Left_Score.Most_Likely
      LT2_3+Unrecovered_DNAPL+DNAPL_Tc_99_not_Removed+Short_Circuit
*0.1, // N_of_TCE_Left_Score.Worse
                              //Short_Circuit_Occurs_Y_N.No
      LT2_1+Unrecovered_DNAPL+DNAPL_Tc_99_not_Removed,
      //N_of_TCE_Left_Score.Best
```

```
        LT2_2+Unrecovered_DNAPL+DNAPL_Tc_99_not_Removed,
        //N_of_TCE_Left_Score.Most_Likely
        LT2_3+Unrecovered_DNAPL+DNAPL_Tc_99_not_Removed,
        //N_of_TCE_Left_Score.Worse
                    //DNAPL_Tc_99_not_Removed_Occurs_Y_N.No
                              //Short_Circuit_Occurs_Y_N.Yes
        LT2_1+Unrecovered_DNAPL+Short_Circuit*0.1,
        //N_of_TCE_Left_Score.Best
        LT2_2+Unrecovered_DNAPL+Short_Circuit*0.1,
        //N_of_TCE_Left_Score.Most_Likely
        LT2_3+Unrecovered_DNAPL+Short_Circuit*0.1,
        //N_of_TCE_Left_Score.Worse
                              //Short_Circuit_Occurs_Y_N.No
        LT2_1+Unrecovered_DNAPL,     //N_of_TCE_Left_Score.Best
        LT2_2+Unrecovered_DNAPL,     //N_of_TCE_Left_Score.Most_Likely
        LT2_3+Unrecovered_DNAPL,     //N_of_TCE_Left_Score.Worse
              //Unrecovered_DNAPL_Occurs_Y_N.No
                    //DNAPL_Tc_99_not_Removed_Occurs_Y_N.Yes
                              //Short_Circuit_Occurs_Y_N.Yes
        LT2_1+DNAPL_Tc_99_not_Removed+Short_Circuit*0.1,
        //N_of_TCE_Left_Score.Best
        LT2_2+DNAPL_Tc_99_not_Removed+Short_Circuit*0.1,
        //N_of_TCE_Left_Score.Most_Likely
        LT2_3+DNAPL_Tc_99_not_Removed+Short_Circuit*0.1,
        //N_of_TCE_Left_Score.Worse
                              //Short_Circuit_Occurs_Y_N.No
        LT2_1+DNAPL_Tc_99_not_Removed,     //N_of_TCE_Left_Score.Best
        LT2_2+DNAPL_Tc_99_not_Removed, //N_of_TCE_Left_Score.Most_Likely
        LT2_3+DNAPL_Tc_99_not_Removed,     //N_of_TCE_Left_Score.Worse
                    //DNAPL_Tc_99_not_Removed_Occurs_Y_N.No
                         //Short_Circuit_Occurs_Y_N.Yes
        LT2_1+Short_Circuit*0.1,   //N_of_TCE_Left_Score.Best
        LT2_2+Short_Circuit*0.1,   //N_of_TCE_Left_Score.Most_Likely
        LT2_3+Short_Circuit*0.1,   //N_of_TCE_Left_Score.Worse
                         //Short_Circuit_Occurs_Y_N.No
        LT2_1,                     //N_of_TCE_Left_Score.Best
        LT2_2,                     //N_of_TCE_Left_Score.Most_Likely
        LT2_3;                     //N_of_TCE_Left_Score.Worse
chance Tc_99_Left_Score.{Best,Most_Likely,Worse}={0.185,0.63,0.185};
value Tc_99_Left_Score|DNAPL_Tc_99_not_Removed_Occurs_Y_N,Tc_99_
Left_Score=
              // DNAPL_Tc_99_not_Removed_Occurs_Y_N.Yes
        LT3_1+43922*DNAPL_Tc_99_not_Removed,     //Tc_99_Left_Score.Best
        LT3_2+43922*DNAPL_Tc_99_not_Removed,
                                        //Tc_99_Left_Score.Most_Likely
```

```
        LT3_3+43922*DNAPL_Tc_99_not_Removed,
                                                        //Tc_99_Left_Score.Worse
            // DNAPL_Tc_99_not_Removed_Occurs_Y_N.No
        LT3_1,                                          //Tc_99_Left_Score.Best
        LT3_2,                                          //Tc_99_Left_Score.Most_Likely
        LT3_3;                                          //Tc_99_Left_Score.Worse
value N_of_TCE_Left_Value=@if(N_of_TCE_Left_Score<=5,10,
@if(N_of_TCE_Left_Score>=70,0,10.77-0.1538*N_of_TCE_Left_Score));
value Tc_99_Left_Value=@if(Tc_99_Left_Score<=900,10,@if(Tc_99_Left_
Score>=43922,0,-10/43022*Tc_99_Left_Score-900*(-10/43022)+10));
value Long_Term_Value=(1/2*(1/10*HM_Remaining_Value+7/10*N_of_
TCE_Left_Value+2/10*Tc_99_Left_Value)+1/2*Replacement_Value);

// NPV with VOLUME
excel(Excel_1,"xaxis!NPV1_1") value NPV1_1;
excel(Excel_1,"xaxis!NPV1_2") value NPV1_2;
excel(Excel_1,"xaxis!NPV1_3") value NPV1_3;
excel(Excel_1,"xaxis!NPV1_4") value NPV1_4;
excel(Excel_1,"xaxis!NPV1_5") value NPV1_5;
excel(Excel_1,"xaxis!NPV1_6") value NPV1_6;
excel(Excel_1,"xaxis!NPV1_7") value NPV1_7;
excel(Excel_1,"xaxis!NPV1_8") value NPV1_8;
excel(Excel_1,"xaxis!NPV1_9") value NPV1_9;
excel(Excel_1,"xaxis!NPV1_10") value NPV1_10;
excel(Excel_1,"xaxis!NPV1_11") value NPV1_11;
excel(Excel_1,"xaxis!NPV1_12") value NPV1_12;
excel(Excel_1,"xaxis!NPV1_13") value NPV1_13;
excel(Excel_1,"xaxis!NPV1_14") value NPV1_14;
excel(Excel_1,"xaxis!NPV1_15") value NPV1_15;
excel(Excel_1,"xaxis!NPV1_16") value NPV1_16;
excel(Excel_1,"xaxis!NPV1_17") value NPV1_17;
excel(Excel_1,"xaxis!NPV1_18") value NPV1_18;
chance Characterization_change_of_Plume__width_.{Low,Nominal,High}=
uniform(0,0.1);
chance Outside_P_T.{Low,Nominal,High}=uniform(0,0.16);
chance Volume.{N100K,N50K,N200K,N400K,N500K}=
{0.290556,0.431374,0.236337,0.035082};
chance Plume_Outside_RA_Y_N.{Yes,No}|DNAPL_Tc_99_not_Removed_
Occurs_Y_N=
        {DNAPL_Tc_99_not_Removed*Characterization_change_of_Plume__width
_*Outside_P_T},       // DNAPL_Tc_99_not_Removed_Occurs_Y_N.Yes {0,1};
                      // DNAPL_Tc_99_not_Removed_Occurs_Y_N.No
chance Cost_Score.{Best,Most_Likely,Worse}={0.185,0.63,0.185};
```

```
value Cost_Score|DNAPL_Tc_99_not_Removed_Occurs_Y_N,Plume_
Outside_RA_Y_N,Volume,Surface_Breakouts,Building_Breakouts,Impact_on_Utiliti
es,Cost_Score=
                              //DNAPL_Tc_99_not_Removed_Occurs_Y_N.Yes
                                   //Plume_Outside_RA_Y_N.Yes
                                   //Volume.N100K
                                   //Surface_Breakouts.Yes
                                   //Building_Breakouts.Yes
                                   //Impact_on_Utilities.Yes
    NPV1_1*2*1.1+ 500000,               //Cost_Score.Best
    NPV1_2*2*1.1 + 500000,              //Cost_Score.Most_Likely
    NPV1_3*2*1.1+ 500000,               //Cost_Score.Worse
                                   //Impact_on_Utilities.No
    NPV1_1*2*1.1+ 500000,               //Cost_Score.Best
    NPV1_2*2*1.1 + 500000,              //Cost_Score.Most_Likely
    NPV1_3*2*1.1+ 500000,               //Cost_Score.Worse
                                   //Building_Breakouts.No
                                   //Impact_on_Utilities.Yes
    NPV1_1*2*1.1+ 500000,               //Cost_Score.Best
    NPV1_2*2*1.1 + 500000,              //Cost_Score.Most_Likely
    NPV1_3*2*1.1+ 500000,               //Cost_Score.Worse
                                   //Impact_on_Utilities.No
    NPV1_1*2*1.1+ 500000,               //Cost_Score.Best
    NPV1_2*2*1.1 + 500000,              //Cost_Score.Most_Likely
    NPV1_3*2*1.1+ 500000,               //Cost_Score.Worse
                                   //Surface_Breakouts.No
                                   //Building_Breakouts.Yes
                                   //Impact_on_Utilities.Yes
    NPV1_1*2*1.1+ 500000,               //Cost_Score.Best
    NPV1_2*2*1.1 + 500000,              //Cost_Score.Most_Likely
    NPV1_3*2*1.1+ 500000,               //Cost_Score.Worse
                                   //Impact_on_Utilities.No
    NPV1_1*2*1.1+ 500000,               //Cost_Score.Best
    NPV1_2*2*1.1 + 500000,              //Cost_Score.Most_Likely
    NPV1_3*2*1.1+ 500000,               //Cost_Score.Worse
                                   //Building_Breakouts.No
                                   //Impact_on_Utilities.Yes
    NPV1_1*2*1.1+ 500000,               //Cost_Score.Best
    NPV1_2*2*1.1 + 500000,              //Cost_Score.Most_Likely
    NPV1_3*2*1.1+ 500000,               //Cost_Score.Worse
                                   //Impact_on_Utilities.No
    NPV1_1*2+ 500000,                   //Cost_Score.Best
    NPV1_2*2 + 500000,                  //Cost_Score.Most_Likely
    NPV1_3*2+ 500000,                   //Cost_Score.Worse
                                   //Volume.N50K
```

```
                                  //Surface_Breakouts.Yes
                                  //Building_Breakouts.Yes
                                  //Impact_on_Utilities.Yes
NPV1_4*2*1.1+ 500000,                 //Cost_Score.Best
NPV1_5*2*1.1 + 500000,                //Cost_Score.Most_Likely
NPV1_6*2*1.1+ 500000,                 //Cost_Score.Worse
                                  //Impact_on_Utilities.No
NPV1_4*2*1.1+ 500000,                 //Cost_Score.Best
NPV1_5*2*1.1 + 500000,                //Cost_Score.Most_Likely
NPV1_6*2*1.1+ 500000,                 //Cost_Score.Worse
                                  //Building_Breakouts.No
                                  //Impact_on_Utilities.Yes
NPV1_4*2*1.1+ 500000,                 //Cost_Score.Best
NPV1_5*2*1.1 + 500000,                //Cost_Score.Most_Likely
NPV1_6*2*1.1+ 500000,                 //Cost_Score.Worse
                                  //Impact_on_Utilities.No
NPV1_4*2*1.1+ 500000,                 //Cost_Score.Best
NPV1_5*2*1.1 + 500000,                //Cost_Score.Most_Likely
NPV1_6*2*1.1+ 500000,                 //Cost_Score.Worse
                                  //Surface_Breakouts.No
                                  //Building_Breakouts.Yes
                                  //Impact_on_Utilities.Yes
NPV1_4*2*1.1+ 500000,                 //Cost_Score.Best
NPV1_5*2 *1.1+ 500000,                //Cost_Score.Most_Likely
NPV1_6*2*1.1+ 500000,                 //Cost_Score.Worse
                                  //Impact_on_Utilities.No
NPV1_4*2*1.1+ 500000,                 //Cost_Score.Best
NPV1_5*2 *1.1+ 500000,                //Cost_Score.Most_Likely
NPV1_6*2*1.1+ 500000,                 //Cost_Score.Worse
                                  //Building_Breakouts.No
                                  //Impact_on_Utilities.Yes
NPV1_4*2*1.1+ 500000,                 //Cost_Score.Best
NPV1_5*2 *1.1+ 500000,                //Cost_Score.Most_Likely
NPV1_6*2*1.1+ 500000,                 //Cost_Score.Worse
                                  //Impact_on_Utilities.No
NPV1_4*2+ 500000,                     //Cost_Score.Best
NPV1_5*2 + 500000,                    //Cost_Score.Most_Likely
NPV1_6*2+ 500000,                     //Cost_Score.Worse
                                  //Volume.N200K
                                  //Surface_Breakouts.Yes
                                  //Building_Breakouts.Yes
                                  //Impact_on_Utilities.Yes
NPV1_7*2*1.1+ 500000,                 //Cost_Score.Best
NPV1_8*2 *1.1+ 500000,                //Cost_Score.Most_Likely
NPV1_9*2*1.1+ 500000,                 //Cost_Score.Worse
```

```
                                //Impact_on_Utilities.No
NPV1_7*2*1.1+ 500000,               //Cost_Score.Best
NPV1_8*2 *1.1+ 500000,              //Cost_Score.Most_Likely
NPV1_9*2*1.1+ 500000,               //Cost_Score.Worse
                                //Building_Breakouts.No
                                //Impact_on_Utilities.Yes
NPV1_7*2*1.1+ 500000,               //Cost_Score.Best
NPV1_8*2 *1.1+ 500000,              //Cost_Score.Most_Likely
NPV1_9*2*1.1+ 500000,               //Cost_Score.Worse
                                //Impact_on_Utilities.No
NPV1_7*2*1.1+ 500000,               //Cost_Score.Best
NPV1_8*2 *1.1+ 500000,              //Cost_Score.Most_Likely
NPV1_9*2*1.1+ 500000,               //Cost_Score.Worse
                                //Surface_Breakouts.No
                                //Building_Breakouts.Yes
                                //Impact_on_Utilities.Yes
NPV1_7*2*1.1+ 500000,               //Cost_Score.Best
NPV1_8*2 *1.1+ 500000,              //Cost_Score.Most_Likely
NPV1_9*2*1.1+ 500000,               //Cost_Score.Worse
                                //Impact_on_Utilities.No
NPV1_7*2*1.1+ 500000,               //Cost_Score.Best
NPV1_8*2 *1.1+ 500000,              //Cost_Score.Most_Likely
NPV1_9*2*1.1+ 500000,               //Cost_Score.Worse
                                //Building_Breakouts.No
                                //Impact_on_Utilities.Yes
NPV1_7*2*1.1+ 500000,               //Cost_Score.Best
NPV1_8*2*1.1 + 500000,              //Cost_Score.Most_Likely
NPV1_9*2*1.1+ 500000,               //Cost_Score.Worse
                                //Impact_on_Utilities.No
NPV1_7*2+ 500000,                   //Cost_Score.Best
NPV1_8*2 + 500000,                  //Cost_Score.Most_Likely
NPV1_9*2+ 500000,                   //Cost_Score.Worse
                                //Volume.N400K
                                //Surface_Breakouts.Yes
                                //Building_Breakouts.Yes
                                //Impact_on_Utilities.Yes
NPV1_13*2*1.1+ 500000,              //Cost_Score.Best
NPV1_14*2*1.1 + 500000,             //Cost_Score.Most_Likely
NPV1_15*2*1.1+ 500000,              //Cost_Score.Worse
                                //Impact_on_Utilities.No
NPV1_13*2*1.1+ 500000,              //Cost_Score.Best
NPV1_14*2*1.1 + 500000,             //Cost_Score.Most_Likely
NPV1_15*2*1.1+ 500000,              //Cost_Score.Worse
                                //Building_Breakouts.No
                                //Impact_on_Utilities.Yes
```

```
NPV1_13*2*1.1+ 500000,          //Cost_Score.Best
NPV1_14*2*1.1 + 500000,         //Cost_Score.Most_Likely
NPV1_15*2*1.1+ 500000,          //Cost_Score.Worse
                              //Impact_on_Utilities.No
NPV1_13*2*1.1+ 500000,          //Cost_Score.Best
NPV1_14*2*1.1 + 500000,         //Cost_Score.Most_Likely
NPV1_15*2*1.1+ 500000,          //Cost_Score.Worse
                              //Surface_Breakouts.No
                              //Building_Breakouts.Yes
                              //Impact_on_Utilities.Yes
NPV1_13*2*1.1+ 500000,          //Cost_Score.Best
NPV1_14*2 *1.1+ 500000,         //Cost_Score.Most_Likely
NPV1_15*2*1.1+ 500000,          //Cost_Score.Worse
                              //Impact_on_Utilities.No
NPV1_13*2*1.1+ 500000,          //Cost_Score.Best
NPV1_14*2 *1.1+ 500000,         //Cost_Score.Most_Likely
NPV1_15*2*1.1+ 500000,          //Cost_Score.Worse
                              //Building_Breakouts.No
                              //Impact_on_Utilities.Yes
NPV1_13*2*1.1+ 500000,          //Cost_Score.Best
NPV1_14*2*1.1 + 500000,         //Cost_Score.Most_Likely
NPV1_15*2*1.1+ 500000,          //Cost_Score.Worse
                              //Impact_on_Utilities.No
NPV1_13*2+ 500000,              //Cost_Score.Best
NPV1_14*2 + 500000,             //Cost_Score.Most_Likely
NPV1_15*2+ 500000,              //Cost_Score.Worse
                              //Volume.N500K
                              //Surface_Breakouts.Yes
                              //Building_Breakouts.Yes
                              //Impact_on_Utilities.Yes
NPV1_16*2*1.1+ 500000,          //Cost_Score.Best
NPV1_17*2 *1.1+ 500000,         //Cost_Score.Most_Likely
NPV1_18*2*1.1+ 500000,          //Cost_Score.Worse
                              //Impact_on_Utilities.No
NPV1_16*2*1.1+ 500000,          //Cost_Score.Best
NPV1_17*2 *1.1+ 500000,         //Cost_Score.Most_Likely
NPV1_18*2*1.1+ 500000,          //Cost_Score.Worse
                              //Building_Breakouts.No
                              //Impact_on_Utilities.Yes
NPV1_16*2*1.1+ 500000,          //Cost_Score.Best
NPV1_17*2 *1.1+ 500000,         //Cost_Score.Most_Likely
NPV1_18*2*1.1+ 500000,          //Cost_Score.Worse
                              //Impact_on_Utilities.No
NPV1_16*2*1.1+ 500000,          //Cost_Score.Best
NPV1_17*2 *1.1+ 500000,         //Cost_Score.Most_Likely
```

```
NPV1_18*2*1.1+ 500000,          //Cost_Score.Worse
                            //Surface_Breakouts.No
                            //Building_Breakouts.Yes
                            //Impact_on_Utilities.Yes
NPV1_16*2*1.1+ 500000,          //Cost_Score.Best
NPV1_17*2*1.1 + 500000,         //Cost_Score.Most_Likely
NPV1_18*2*1.1+ 500000,          //Cost_Score.Worse
                            //Impact_on_Utilities.No
NPV1_16*2*1.1+ 500000,          //Cost_Score.Best
NPV1_17*2*1.1 + 500000,         //Cost_Score.Most_Likely
NPV1_18*2*1.1+ 500000,          //Cost_Score.Worse
                            //Building_Breakouts.No
                            //Impact_on_Utilities.Yes
NPV1_16*2*1.1+ 500000,          //Cost_Score.Best
NPV1_17*2*1.1 + 500000,         //Cost_Score.Most_Likely
NPV1_18*2*1.1+ 500000,          //Cost_Score.Worse
                            //Impact_on_Utilities.No
NPV1_16*2+ 500000,              //Cost_Score.Best
NPV1_17*2 + 500000,             //Cost_Score.Most_Likely
NPV1_18*2+500000,               //Cost_Score.Worse
                            //Plume_Outside_RA_Y_N.No
                            //Volume.N100K
                            //Surface_Breakouts.Yes
                            //Building_Breakouts.Yes
                            //Impact_on_Utilities.Yes
NPV1_1*2*1.1,                   //Cost_Score.Best
NPV1_2*2*1.1,                   //Cost_Score.Most_Likely
NPV1_3*2*1.1,                   //Cost_Score.Worse
                            //Impact_on_Utilities.No
NPV1_1*2*1.1,                   //Cost_Score.Best
NPV1_2*2*1.1,                   //Cost_Score.Most_Likely
NPV1_3*2*1.1,                   //Cost_Score.Worse
                            //Building_Breakouts.No
                            //Impact_on_Utilities.Yes
NPV1_1*2*1.1,                   //Cost_Score.Best
NPV1_2*2*1.1,                   //Cost_Score.Most_Likely
NPV1_3*2*1.1,                   //Cost_Score.Worse
                            //Impact_on_Utilities.No
NPV1_1*2*1.1,                   //Cost_Score.Best
NPV1_2*2*1.1,                   //Cost_Score.Most_Likely
NPV1_3*2*1.1,                   //Cost_Score.Worse
                            //Surface_Breakouts.No
                            //Building_Breakouts.Yes
                            //Impact_on_Utilities.Yes
NPV1_1*2*1.1,                   //Cost_Score.Best
```

```
NPV1_2*2*1.1,            //Cost_Score.Most_Likely
NPV1_3*2*1.1,            //Cost_Score.Worse
                     //Impact_on_Utilities.No
NPV1_1*2*1.1,            //Cost_Score.Best
NPV1_2*2*1.1,            //Cost_Score.Most_Likely
NPV1_3*2*1.1,            //Cost_Score.Worse
                     //Building_Breakouts.No
                     //Impact_on_Utilities.Yes
NPV1_1*2*1.1,            //Cost_Score.Best
NPV1_2*2*1.1,            //Cost_Score.Most_Likely
NPV1_3*2*1.1,            //Cost_Score.Worse
                     //Impact_on_Utilities.No
NPV1_1*2,                //Cost_Score.Best
NPV1_2*2,                //Cost_Score.Most_Likely
NPV1_3*2,                //Cost_Score.Worse
                     //Volume.N50K
                     //Surface_Breakouts.Yes
                     //Building_Breakouts.Yes
                     //Impact_on_Utilities.Yes
NPV1_4*2*1.1,            //Cost_Score.Best
NPV1_5*2*1.1,            //Cost_Score.Most_Likely
NPV1_6*2*1.1,            //Cost_Score.Worse
                     //Impact_on_Utilities.No
NPV1_4*2*1.1,            //Cost_Score.Best
NPV1_5*2*1.1,            //Cost_Score.Most_Likely
NPV1_6*2*1.1,            //Cost_Score.Worse
                     //Building_Breakouts.No
                     //Impact_on_Utilities.Yes
NPV1_4*2*1.1,            //Cost_Score.Best
NPV1_5*2*1.1,            //Cost_Score.Most_Likely
NPV1_6*2*1.1,            //Cost_Score.Worse
                     //Impact_on_Utilities.No
NPV1_4*2*1.1,            //Cost_Score.Best
NPV1_5*2*1.1,            //Cost_Score.Most_Likely
NPV1_6*2*1.1,            //Cost_Score.Worse
                     //Surface_Breakouts.No
                     //Building_Breakouts.Yes
                     //Impact_on_Utilities.Yes
NPV1_4*2*1.1,            //Cost_Score.Best
NPV1_5*2*1.1,            //Cost_Score.Most_Likely
NPV1_6*2*1.1,            //Cost_Score.Worse
                     //Impact_on_Utilities.No
NPV1_4*2*1.1,            //Cost_Score.Best
NPV1_5*2*1.1,            //Cost_Score.Most_Likely
NPV1_6*2*1.1,            //Cost_Score.Worse
```

```
                                   //Building_Breakouts.No
                                   //Impact_on_Utilities.Yes
NPV1_4*2*1.1,                           //Cost_Score.Best
NPV1_5*2*1.1,                           //Cost_Score.Most_Likely
NPV1_6*2*1.1,                           //Cost_Score.Worse
                                   //Impact_on_Utilities.No
NPV1_4*2,                               //Cost_Score.Best
NPV1_5*2,                               //Cost_Score.Most_Likely
NPV1_6*2,                               //Cost_Score.Worse
                                   //Volume.N200K
                                   //Surface_Breakouts.Yes
                                   //Building_Breakouts.Yes
                                   //Impact_on_Utilities.Yes
NPV1_7*2*1.1,                           //Cost_Score.Best
NPV1_8*2*1.1,                           //Cost_Score.Most_Likely
NPV1_9*2*1.1,                           //Cost_Score.Worse
                                   //Impact_on_Utilities.No
NPV1_7*2*1.1,                           //Cost_Score.Best
NPV1_8*2*1.1,                           //Cost_Score.Most_Likely
NPV1_9*2*1.1,                           //Cost_Score.Worse
                                   //Building_Breakouts.No
                                   //Impact_on_Utilities.Yes
NPV1_7*2*1.1,                           //Cost_Score.Best
NPV1_8*2*1.1,                           //Cost_Score.Most_Likely
NPV1_9*2*1.1,                           //Cost_Score.Worse
                                   //Impact_on_Utilities.No
NPV1_7*2*1.1,                           //Cost_Score.Best
NPV1_8*2*1.1,                           //Cost_Score.Most_Likely
NPV1_9*2*1.1,                           //Cost_Score.Worse
                                   //Surface_Breakouts.No
                                   //Building_Breakouts.Yes
                                   //Impact_on_Utilities.Yes
NPV1_7*2*1.1,                           //Cost_Score.Best
NPV1_8*2*1.1,                           //Cost_Score.Most_Likely
NPV1_9*2*1.1,                           //Cost_Score.Worse
                                   //Impact_on_Utilities.No
NPV1_7*2*1.1,                           //Cost_Score.Best
NPV1_8*2*1.1,                           //Cost_Score.Most_Likely
NPV1_9*2*1.1,                           //Cost_Score.Worse
                                   //Building_Breakouts.No
                                   //Impact_on_Utilities.Yes
NPV1_7*2*1.1,                           //Cost_Score.Best
NPV1_8*2*1.1,                           //Cost_Score.Most_Likely
NPV1_9*2*1.1,                           //Cost_Score.Worse
                                   //Impact_on_Utilities.No
```

```
NPV1_7*2,                   //Cost_Score.Best
NPV1_8*2,                   //Cost_Score.Most_Likely
NPV1_9*2,                   //Cost_Score.Worse
                       //Volume.N400K
                       //Surface_Breakouts.Yes
                       //Building_Breakouts.Yes
                       //Impact_on_Utilities.Yes
NPV1_13*2*1.1,              //Cost_Score.Best
NPV1_14*2*1.1,              //Cost_Score.Most_Likely
NPV1_15*2*1.1,              //Cost_Score.Worse
                       //Impact_on_Utilities.No
NPV1_13*2*1.1,              //Cost_Score.Best
NPV1_14*2*1.1,              //Cost_Score.Most_Likely
NPV1_15*2*1.1,              //Cost_Score.Worse
                       //Building_Breakouts.No
                       //Impact_on_Utilities.Yes
NPV1_13*2*1.1,              //Cost_Score.Best
NPV1_14*2*1.1,              //Cost_Score.Most_Likely
NPV1_15*2*1.1,              //Cost_Score.Worse
                       //Impact_on_Utilities.No
NPV1_13*2*1.1,              //Cost_Score.Best
NPV1_14*2*1.1,              //Cost_Score.Most_Likely
NPV1_15*2*1.1,              //Cost_Score.Worse
                       //Surface_Breakouts.No
                       //Building_Breakouts.Yes
                       //Impact_on_Utilities.Yes
NPV1_13*2*1.1,              //Cost_Score.Best
NPV1_14*2*1.1,              //Cost_Score.Most_Likely
NPV1_15*2*1.1,              //Cost_Score.Worse
                       //Impact_on_Utilities.No
NPV1_13*2*1.1,              //Cost_Score.Best
NPV1_14*2*1.1,              //Cost_Score.Most_Likely
NPV1_15*2*1.1,              //Cost_Score.Worse
                       //Building_Breakouts.No
                       //Impact_on_Utilities.Yes
NPV1_13*2*1.1,              //Cost_Score.Best
NPV1_14*2*1.1,              //Cost_Score.Most_Likely
NPV1_15*2*1.1,              //Cost_Score.Worse
                       //Impact_on_Utilities.No
NPV1_13*2,                  //Cost_Score.Best
NPV1_14*2,                  //Cost_Score.Most_Likely
NPV1_15*2,                  //Cost_Score.Worse
                       //Volume.N500K
                       //Surface_Breakouts.Yes
                       //Building_Breakouts.Yes
```

```
                    //Impact_on_Utilities.Yes
NPV1_16*2*1.1,          //Cost_Score.Best
NPV1_17*2*1.1,          //Cost_Score.Most_Likely
NPV1_18*2*1.1,          //Cost_Score.Worse
                    //Impact_on_Utilities.No
NPV1_16*2*1.1,          //Cost_Score.Best
NPV1_17*2*1.1,          //Cost_Score.Most_Likely
NPV1_18*2*1.1,          //Cost_Score.Worse
                    //Building_Breakouts.No
                    //Impact_on_Utilities.Yes
NPV1_16*2*1.1,          //Cost_Score.Best
NPV1_17*2*1.1,          //Cost_Score.Most_Likely
NPV1_18*2*1.1,          //Cost_Score.Worse
                    //Impact_on_Utilities.No
NPV1_16*2*1.1,          //Cost_Score.Best
NPV1_17*2*1.1,          //Cost_Score.Most_Likely
NPV1_18*2*1.1,          //Cost_Score.Worse
                    //Surface_Breakouts.No
                    //Building_Breakouts.Yes
                    //Impact_on_Utilities.Yes
NPV1_16*2*1.1,          //Cost_Score.Best
NPV1_17*2*1.1,          //Cost_Score.Most_Likely
NPV1_18*2*1.1,          //Cost_Score.Worse
                    //Impact_on_Utilities.No
NPV1_16*2*1.1,          //Cost_Score.Best
NPV1_17*2*1.1,          //Cost_Score.Most_Likely
NPV1_18*2*1.1,          //Cost_Score.Worse
                    //Building_Breakouts.No
                    //Impact_on_Utilities.Yes
NPV1_16*2*1.1,          //Cost_Score.Best
NPV1_17*2*1.1,          //Cost_Score.Most_Likely
NPV1_18*2*1.1,          //Cost_Score.Worse
                    //Impact_on_Utilities.No
NPV1_16*2,              //Cost_Score.Best
NPV1_17*2,              //Cost_Score.Most_Likely
NPV1_18*2,              //Cost_Score.Worse
                //DNAPL_Tc_99_not_Removed_Occurs_Y_N.No
                    //Plume_Outside_RA_Y_N.Yes
                    //Volume.N100K
                    //Surface_Breakouts.Yes
                    //Building_Breakouts.Yes
                    //Impact_on_Utilities.Yes
NPV1_1*1.1+500000,      //Cost_Score.Best
NPV1_2*1.1+500000,      //Cost_Score.Most_Likely
NPV1_3*1.1+500000,      //Cost_Score.Worse
```

```
                                  //Impact_on_Utilities.No
NPV1_1*1.1+500000,                        //Cost_Score.Best
NPV1_2*1.1+500000,                        //Cost_Score.Most_Likely
NPV1_3*1.1+500000,                        //Cost_Score.Worse
                                  //Building_Breakouts.No
                                  //Impact_on_Utilities.Yes
NPV1_1*1.1+500000,                        //Cost_Score.Best
NPV1_2*1.1+500000,                        //Cost_Score.Most_Likely
NPV1_3*1.1+500000,                        //Cost_Score.Worse
                                  //Impact_on_Utilities.No
NPV1_1*1.1+500000,                        //Cost_Score.Best
NPV1_2*1.1+500000,                        //Cost_Score.Most_Likely
NPV1_3*1.1+500000,                        //Cost_Score.Worse
                                  //Surface_Breakouts.No
                                  //Building_Breakouts.Yes
                                  //Impact_on_Utilities.Yes
NPV1_1*1.1+500000,                        //Cost_Score.Best
NPV1_2*1.1+500000,                        //Cost_Score.Most_Likely
NPV1_3*1.1+500000,                        //Cost_Score.Worse
                                  //Impact_on_Utilities.No
NPV1_1*1.1+500000,                        //Cost_Score.Best
NPV1_2*1.1+500000,                        //Cost_Score.Most_Likely
NPV1_3*1.1+500000,                        //Cost_Score.Worse
                                  //Building_Breakouts.No
                                  //Impact_on_Utilities.Yes
NPV1_1*1.1+500000,                        //Cost_Score.Best
NPV1_2*1.1+500000,                        //Cost_Score.Most_Likely
NPV1_3*1.1+500000,                        //Cost_Score.Worse
                                  //Impact_on_Utilities.No
NPV1_1+500000,                            //Cost_Score.Best
NPV1_2+500000,                            //Cost_Score.Most_Likely
NPV1_3+500000,                            //Cost_Score.Worse
                                  //Volume.N50K
                                  //Surface_Breakouts.Yes
                                  //Building_Breakouts.Yes
                                  //Impact_on_Utilities.Yes
NPV1_4*1.1+500000,                        //Cost_Score.Best
NPV1_5*1.1+500000,                        //Cost_Score.Most_Likely
NPV1_6*1.1+500000,                        //Cost_Score.Worse
                                  //Impact_on_Utilities.No
NPV1_4*1.1+500000,                        //Cost_Score.Best
NPV1_5*1.1+500000,                        //Cost_Score.Most_Likely
NPV1_6*1.1+500000,                        //Cost_Score.Worse
                                  //Building_Breakouts.No
                                  //Impact_on_Utilities.Yes
```

```
NPV1_4*1.1+500000,          //Cost_Score.Best
NPV1_5*1.1+500000,          //Cost_Score.Most_Likely
NPV1_6*1.1+500000,          //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_4*1.1+500000,          //Cost_Score.Best
NPV1_5*1.1+500000,          //Cost_Score.Most_Likely
NPV1_6*1.1+500000,          //Cost_Score.Worse
                        //Surface_Breakouts.No
                        //Building_Breakouts.Yes
                        //Impact_on_Utilities.Yes
NPV1_4*1.1+500000,          //Cost_Score.Best
NPV1_5*1.1+500000,          //Cost_Score.Most_Likely
NPV1_6*1.1+500000,          //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_4*1.1+500000,          //Cost_Score.Best
NPV1_5*1.1+500000,          //Cost_Score.Most_Likely
NPV1_6*1.1+500000,          //Cost_Score.Worse
                        //Building_Breakouts.No
                        //Impact_on_Utilities.Yes
NPV1_4*1.1+500000,          //Cost_Score.Best
NPV1_5*1.1+500000,          //Cost_Score.Most_Likely
NPV1_6*1.1+500000,          //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_4+500000,              //Cost_Score.Best
NPV1_5+500000,              //Cost_Score.Most_Likely
NPV1_6+500000,              //Cost_Score.Worse
                        //Volume.N200K
                        //Surface_Breakouts.Yes
                        //Building_Breakouts.Yes
                        //Impact_on_Utilities.Yes
NPV1_7*1.1+500000,          //Cost_Score.Best
NPV1_8*1.1+500000,          //Cost_Score.Most_Likely
NPV1_9*1.1+500000,          //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_7*1.1+500000,          //Cost_Score.Best
NPV1_8*1.1+500000,          //Cost_Score.Most_Likely
NPV1_9*1.1+500000,          //Cost_Score.Worse
                        //Building_Breakouts.No
                        //Impact_on_Utilities.Yes
NPV1_7*1.1+500000,          //Cost_Score.Best
NPV1_8*1.1+500000,          //Cost_Score.Most_Likely
NPV1_9*1.1+500000,          //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_7*1.1+500000,          //Cost_Score.Best
NPV1_8*1.1+500000,          //Cost_Score.Most_Likely
```

```
NPV1_9*1.1+500000,          //Cost_Score.Worse
                        //Surface_Breakouts.No
                        //Building_Breakouts.Yes
                        //Impact_on_Utilities.Yes
NPV1_7*1.1+500000,          //Cost_Score.Best
NPV1_8*1.1+500000,          //Cost_Score.Most_Likely
NPV1_9*1.1+500000,          //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_7*1.1+500000,          //Cost_Score.Best
NPV1_8*1.1+500000,          //Cost_Score.Most_Likely
NPV1_9*1.1+500000,          //Cost_Score.Worse
                        //Building_Breakouts.No
                        //Impact_on_Utilities.Yes
NPV1_7*1.1+500000,          //Cost_Score.Best
NPV1_8*1.1+500000,          //Cost_Score.Most_Likely
NPV1_9*1.1+500000,          //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_7+500000,              //Cost_Score.Best
NPV1_8+500000,              //Cost_Score.Most_Likely
NPV1_9+500000,              //Cost_Score.Worse
                        //Volume.N400K
                        //Surface_Breakouts.Yes
                        //Building_Breakouts.Yes
                        //Impact_on_Utilities.Yes
NPV1_13*1.1+500000,         //Cost_Score.Best
NPV1_14*1.1+500000,         //Cost_Score.Most_Likely
NPV1_15*1.1+500000,         //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_13*1.1+500000,         //Cost_Score.Best
NPV1_14*1.1+500000,         //Cost_Score.Most_Likely
NPV1_15*1.1+500000,         //Cost_Score.Worse
                        //Building_Breakouts.No
                        //Impact_on_Utilities.Yes
NPV1_13*1.1+500000,         //Cost_Score.Best
NPV1_14*1.1+500000,         //Cost_Score.Most_Likely
NPV1_15*1.1+500000,         //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_13*1.1+500000,         //Cost_Score.Best
NPV1_14*1.1+500000,         //Cost_Score.Most_Likely
NPV1_15*1.1+500000,         //Cost_Score.Worse
                        //Surface_Breakouts.No
                        //Building_Breakouts.Yes
                        //Impact_on_Utilities.Yes
NPV1_13*1.1+500000,         //Cost_Score.Best
NPV1_14*1.1+500000,         //Cost_Score.Most_Likely
```

```
NPV1_15*1.1+500000,          //Cost_Score.Worse
                         //Impact_on_Utilities.No
NPV1_13*1.1+500000,          //Cost_Score.Best
NPV1_14*1.1+500000,          //Cost_Score.Most_Likely
NPV1_15*1.1+500000,          //Cost_Score.Worse
                         //Building_Breakouts.No
                         //Impact_on_Utilities.Yes
NPV1_13*1.1+500000,          //Cost_Score.Best
NPV1_14*1.1+500000,          //Cost_Score.Most_Likely
NPV1_15*1.1+500000,          //Cost_Score.Worse
                         //Impact_on_Utilities.No
NPV1_13+500000,              //Cost_Score.Best
NPV1_14+500000,              //Cost_Score.Most_Likely
NPV1_15+500000,              //Cost_Score.Worse
                         //Volume.N500K
                         //Surface_Breakouts.Yes
                         //Building_Breakouts.Yes
                         //Impact_on_Utilities.Yes
NPV1_16*1.1+500000,          //Cost_Score.Best
NPV1_17*1.1+500000,          //Cost_Score.Most_Likely
NPV1_18*1.1+500000,          //Cost_Score.Worse
                         //Impact_on_Utilities.No
NPV1_16*1.1+500000,          //Cost_Score.Best
NPV1_17*1.1+500000,          //Cost_Score.Most_Likely
NPV1_18*1.1+500000,          //Cost_Score.Worse
                         //Building_Breakouts.No
                         //Impact_on_Utilities.Yes
NPV1_16*1.1+500000,          //Cost_Score.Best
NPV1_17*1.1+500000,          //Cost_Score.Most_Likely
NPV1_18*1.1+500000,          //Cost_Score.Worse
                         //Impact_on_Utilities.No
NPV1_16*1.1+500000,          //Cost_Score.Best
NPV1_17*1.1+500000,          //Cost_Score.Most_Likely
NPV1_18*1.1+500000,          //Cost_Score.Worse
                         //Surface_Breakouts.No
                         //Building_Breakouts.Yes
                         //Impact_on_Utilities.Yes
NPV1_16*1.1+500000,          //Cost_Score.Best
NPV1_17*1.1+500000,          //Cost_Score.Most_Likely
NPV1_18*1.1+500000,          //Cost_Score.Worse
                         //Impact_on_Utilities.No
NPV1_16*1.1+500000,          //Cost_Score.Best
NPV1_17*1.1+500000,          //Cost_Score.Most_Likely
NPV1_18*1.1+500000,          //Cost_Score.Worse
                         //Building_Breakouts.No
```

```
                        //Impact_on_Utilities.Yes
NPV1_16*1.1+500000,         //Cost_Score.Best
NPV1_17*1.1+500000,         //Cost_Score.Most_Likely
NPV1_18*1.1+500000,         //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_16+500000,             //Cost_Score.Best
NPV1_17+500000,             //Cost_Score.Most_Likely
NPV1_18+500000,             //Cost_Score.Worse
                        //Plume_Outside_RA_Y_N.No
                        //Volume.N100K
                        //Surface_Breakouts.Yes
                        //Building_Breakouts.Yes
                        //Impact_on_Utilities.Yes
NPV1_1*1.1,                 //Cost_Score.Best
NPV1_2*1.1,                 //Cost_Score.Most_Likely
NPV1_3*1.1,                 //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_1*1.1,                 //Cost_Score.Best
NPV1_2*1.1,                 //Cost_Score.Most_Likely
NPV1_3*1.1,                 //Cost_Score.Worse
                        //Building_Breakouts.No
                        //Impact_on_Utilities.Yes
NPV1_1*1.1,                 //Cost_Score.Best
NPV1_2*1.1,                 //Cost_Score.Most_Likely
NPV1_3*1.1,                 //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_1*1.1,                 //Cost_Score.Best
NPV1_2*1.1,                 //Cost_Score.Most_Likely
NPV1_3*1.1,                 //Cost_Score.Worse
                        //Surface_Breakouts.No
                        //Building_Breakouts.Yes
                        //Impact_on_Utilities.Yes
NPV1_1*1.1,                 //Cost_Score.Best
NPV1_2*1.1,                 //Cost_Score.Most_Likely
NPV1_3*1.1,                 //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_1*1.1,                 //Cost_Score.Best
NPV1_2*1.1,                 //Cost_Score.Most_Likely
NPV1_3*1.1,                 //Cost_Score.Worse
                        //Building_Breakouts.No
                        //Impact_on_Utilities.Yes
NPV1_1*1.1,                 //Cost_Score.Best
NPV1_2*1.1,                 //Cost_Score.Most_Likely
NPV1_3*1.1,                 //Cost_Score.Worse
                        //Impact_on_Utilities.No
```

```
NPV1_1,                    //Cost_Score.Best
NPV1_2,                    //Cost_Score.Most_Likely
NPV1_3,                    //Cost_Score.Worse
                   //Volume.N50K
                   //Surface_Breakouts.Yes
                   //Building_Breakouts.Yes
                   //Impact_on_Utilities.Yes
NPV1_4*1.1,                //Cost_Score.Best
NPV1_5*1.1,                //Cost_Score.Most_Likely
NPV1_6*1.1,                //Cost_Score.Worse
                   //Impact_on_Utilities.No
NPV1_4*1.1,                //Cost_Score.Best
NPV1_5*1.1,                //Cost_Score.Most_Likely
NPV1_6*1.1,                //Cost_Score.Worse
                   //Building_Breakouts.No
                   //Impact_on_Utilities.Yes
NPV1_4*1.1,                //Cost_Score.Best
NPV1_5*1.1,                //Cost_Score.Most_Likely
NPV1_6*1.1,                //Cost_Score.Worse
                   //Impact_on_Utilities.No
NPV1_4*1.1,                //Cost_Score.Best
NPV1_5*1.1,                //Cost_Score.Most_Likely
NPV1_6*1.1,                //Cost_Score.Worse
                   //Surface_Breakouts.No
                   //Building_Breakouts.Yes
                   //Impact_on_Utilities.Yes
NPV1_4*1.1,                //Cost_Score.Best
NPV1_5*1.1,                //Cost_Score.Most_Likely
NPV1_6*1.1,                //Cost_Score.Worse
                   //Impact_on_Utilities.No
NPV1_4*1.1,                //Cost_Score.Best
NPV1_5*1.1,                //Cost_Score.Most_Likely
NPV1_6*1.1,                //Cost_Score.Worse
                   //Building_Breakouts.No
                   //Impact_on_Utilities.Yes
NPV1_4*1.1,                //Cost_Score.Best
NPV1_5*1.1,                //Cost_Score.Most_Likely
NPV1_6*1.1,                //Cost_Score.Worse
                   //Impact_on_Utilities.No
NPV1_4,                    //Cost_Score.Best
NPV1_5,                    //Cost_Score.Most_Likely
NPV1_6,                    //Cost_Score.Worse
                   //Volume.N200K
                   //Surface_Breakouts.Yes
                   //Building_Breakouts.Yes
```

```
                        //Impact_on_Utilities.Yes
NPV1_7*1.1,                 //Cost_Score.Best
NPV1_8*1.1,                 //Cost_Score.Most_Likely
NPV1_9*1.1,                 //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_7*1.1,                 //Cost_Score.Best
NPV1_8*1.1,                 //Cost_Score.Most_Likely
NPV1_9*1.1,                 //Cost_Score.Worse
                        //Building_Breakouts.No
                        //Impact_on_Utilities.Yes
NPV1_7*1.1,                 //Cost_Score.Best
NPV1_8*1.1,                 //Cost_Score.Most_Likely
NPV1_9*1.1,                 //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_7*1.1,                 //Cost_Score.Best
NPV1_8*1.1,                 //Cost_Score.Most_Likely
NPV1_9*1.1,                 //Cost_Score.Worse
                        //Surface_Breakouts.No
                        //Building_Breakouts.Yes
                        //Impact_on_Utilities.Yes
NPV1_7*1.1,                 //Cost_Score.Best
NPV1_8*1.1,                 //Cost_Score.Most_Likely
NPV1_9*1.1,                 //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_7*1.1,                 //Cost_Score.Best
NPV1_8*1.1,                 //Cost_Score.Most_Likely
NPV1_9*1.1,                 //Cost_Score.Worse
                        //Building_Breakouts.No
                        //Impact_on_Utilities.Yes
NPV1_7*1.1,                 //Cost_Score.Best
NPV1_8*1.1,                 //Cost_Score.Most_Likely
NPV1_9*1.1,                 //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_7,                     //Cost_Score.Best
NPV1_8,                     //Cost_Score.Most_Likely
NPV1_9,                     //Cost_Score.Worse
                        //Volume.N400K
                        //Surface_Breakouts.Yes
                        //Building_Breakouts.Yes
                        //Impact_on_Utilities.Yes
NPV1_13*1.1,                //Cost_Score.Best
NPV1_14*1.1,                //Cost_Score.Most_Likely
NPV1_15*1.1,                //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_13*1.1,                //Cost_Score.Best
```

```
NPV1_14*1.1,                //Cost_Score.Most_Likely
NPV1_15*1.1,                //Cost_Score.Worse
                        //Building_Breakouts.No
                        //Impact_on_Utilities.Yes
NPV1_13*1.1,                //Cost_Score.Best
NPV1_14*1.1,                //Cost_Score.Most_Likely
NPV1_15*1.1,                //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_13*1.1,                //Cost_Score.Best
NPV1_14*1.1,                //Cost_Score.Most_Likely
NPV1_15*1.1,                //Cost_Score.Worse
                        //Surface_Breakouts.No
                        //Building_Breakouts.Yes
                        //Impact_on_Utilities.Yes
NPV1_13*1.1,                //Cost_Score.Best
NPV1_14*1.1,                //Cost_Score.Most_Likely
NPV1_15*1.1,                //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_13*1.1,                //Cost_Score.Best
NPV1_14*1.1,                //Cost_Score.Most_Likely
NPV1_15*1.1,                //Cost_Score.Worse
                        //Building_Breakouts.No
                        //Impact_on_Utilities.Yes
NPV1_13*1.1,                //Cost_Score.Best
NPV1_14*1.1,                //Cost_Score.Most_Likely
NPV1_15*1.1,                //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_13,                    //Cost_Score.Best
NPV1_14,                    //Cost_Score.Most_Likely
NPV1_15,                    //Cost_Score.Worse
                        //Volume.N500K
                        //Surface_Breakouts.Yes
                        //Building_Breakouts.Yes
                        //Impact_on_Utilities.Yes
NPV1_16*1.1,                //Cost_Score.Best
NPV1_17*1.1,                //Cost_Score.Most_Likely
NPV1_18*1.1,                //Cost_Score.Worse
                        //Impact_on_Utilities.No
NPV1_16*1.1,                //Cost_Score.Best
NPV1_17*1.1,                //Cost_Score.Most_Likely
NPV1_18*1.1,                //Cost_Score.Worse
                        //Building_Breakouts.No
                        //Impact_on_Utilities.Yes
NPV1_16*1.1,                //Cost_Score.Best
NPV1_17*1.1,                //Cost_Score.Most_Likely
```

```
        NPV1_18*1.1,                    //Cost_Score.Worse
                                //Impact_on_Utilities.No
        NPV1_16*1.1,                    //Cost_Score.Best
        NPV1_17*1.1,                    //Cost_Score.Most_Likely
        NPV1_18*1.1,                    //Cost_Score.Worse
                                //Surface_Breakouts.No
                                //Building_Breakouts.Yes
                                //Impact_on_Utilities.Yes
        NPV1_16*1.1,                    //Cost_Score.Best
        NPV1_17*1.1,                    //Cost_Score.Most_Likely
        NPV1_18*1.1,                    //Cost_Score.Worse
                                //Impact_on_Utilities.No
        NPV1_16*1.1,                    //Cost_Score.Best
        NPV1_17*1.1,                    //Cost_Score.Most_Likely
        NPV1_18*1.1,                    //Cost_Score.Worse
                                //Building_Breakouts.No
                                        //Impact_on_Utilities.Yes
        NPV1_16*1.1,                            //Cost_Score.Best
        NPV1_17*1.1,                            //Cost_Score.Most_Likely
        NPV1_18*1.1,                            //Cost_Score.Worse
                                        //Impact_on_Utilities.No
        NPV1_16,                                //Cost_Score.Best
        NPV1_17,                                //Cost_Score.Most_Likely
        NPV1_18;                                // Cost_Score.Worse
value Cost_Value|Cost_Score=
        @if(Cost_Score<1229000,10,@if(Cost_Score>38189000,0,-10/(38189000-
1229000)*(Cost_Score-1229000)+10)),     // Cost_Score.Best
        @if(Cost_Score<1229000,10,@if(Cost_Score>38189000,0,-10/(38189000-
1229000)*(Cost_Score-1229000)+10)),     // Cost_Score.Most_Likely
        @if(Cost_Score<1229000,10,@if(Cost_Score>38189000,0,-10/(38189000-
1229000)*(Cost_Score-1229000)+10));     // Cost_Score.Worse
value NPV_Value=Cost_Value*1;

// TOTAL
value Implementability_Weight=1/6;
value Short_Term_Weight=1/6;
value Long_Term_Weight=1/4;
value TMV_Weight=1/4;
value NPV_Weight=1/6;
value Total_Value=Implementability_Weight*Implementability_Value+Long_Term_
Weight*Long_Term_Value+NPV_Weight*NPV_Value+Short_Term_Weight*Short
_Term_Value+TMV_Weight*TMV_Value;

sequence:
// All
```

```
gamble on DNAPL_Tc_99_not_Removed then
gamble on DNAPL_Tc_99_not_Removed_Occurs_Y_N then
gamble on Short_Circuit_Occurs_Y_N then
gamble on Short_Circuit then
gamble on Surface_Breakouts_Occurs_Y_N then
gamble on Building_Breakouts_Occurs_Y_N then
gamble on Impact_on_Utilities_Occurs_Y_N then
gamble on Surface_Breakouts then
gamble on Building_Breakouts then
gamble on Impact_on_Utilities then
gamble on Unrecovered_DNAPL then
gamble on Unrecovered_DNAPL_Occurs_Y_N then
// NPV VOLUME
gamble on Characterization_change_of_Plume__width_ then
gamble on Outside_P_T then
gamble on Plume_Outside_RA_Y_N then
gamble on Volume then
gamble on Cost_Score then
// Implementability
gamble on Exposure_Risk_Score then
// Short Term
gamble on Yr_Protection_Achieved_Score then
// Long Term
gamble on Tc_99_Left_Score then
gamble on N_of_TCE_Left_Score then
// TMV
gamble on N_Tc_99_Destroyed__etc_Score then
gamble on N_Tc_99_Irrev_Treated_Score then
gamble on N_TCE_Destroyed__etc_Score then
gamble on N_TCE_Irrev_Treated_Score then

get Total_Value
```

Appendix H: Technological Risks' Effect

This appendix presents the impact the technological risks have on the CERCLA evaluation measures. Not all the evaluation measures are affected by these undesirable events. On the last page of this appendix is a matrix which indicates which evaluation measures are affected by which technological risk. All the numbers reflect the change in score if the technological risks occur.

Table H-1 % TCE Left in the Subsurface

Long Term % TCE Left in Subsurface		**Lowest**	**Most Likely**	**Highest**
	Original Score:	5%	10%	30%
	Probability:	0.185	0.63	0.185
Unrecovered DNAPL*				
Probability	Percentage			
0.185	0.351%	5.351%	10.351%	30.351%
0.63	1.26%	6.26%	11.26%	31.26%
0.185	2.99%	7.99%	12.99%	32.99%
DNAPL not Removed*				
Probability	Percentage			
0.278	1.13%	6.13%	11.13%	31.13%
0.444	5%	10%	15%	35%
0.278	8.87%	13.87%	18.87%	38.87%
Short Circuits*				
Probability	Percentage			
0.278	1.13%	6.13%	11.13%	31.13%
0.444	5%	10%	15%	35%
0.278	8.87%	13.87%	18.87%	38.87%

*Additive

Table H-2 Activity Tc-99 Left in Subsurface

Long Term Activity Tc –99 Left in Subsurface		Lowest	Most Likely	Highest
	Original Score:	0	50	5000
	Probability:	0.185	0.63	0.185
DNAPL not Removed*				
Probability	Percentage			
0.278	1.13%*43,922	496.32	546.32	5496.32
0.444	5%*43,922	2196.1	2246.1	7196.1
0.278	8.87%*43,922	3895.88	3945.88	8895.88

*Additive

Table H-3 % TCE Destroyed, etc

TMV % TCE Destroyed, etc.		Highest	Most Likely	Lowest
	Original Score:	95%	90%	70%
	Probability:	0.185	0.63	0.185
Unrecovered DNAPL*				
Probability	Percentage			
0.185	0.351%	94.649	89.649%	69.649%
0.63	1.26%	93.74%	88.74%	68.74%
0.185	2.99%	92.01%	87.01%	67.01%
DNAPL not Removed*				
Probability	Percentage			
0.278	1.13%	93.87%	88.87%	68.87%
0.444	5%	90%	85%	65%
0.278	8.87%	86.13%	81.13%	61.13%
Short Circuits*				
Probability	Percentage			
0.278	1.13%	93.87%	88.87%	68.87%
0.444	5%	90%	85%	65%
0.278	8.87%	86.13%	81.13%	61.13%

*Additive

Table H-4 % Tc-99 Destroyed, etc

TMV % Tc-99 Destroyed, etc.		Highest	Most Likely	Lowest
	Original Score:	100%	100%	90%
	Probability:	0.185	0.63	0.185
DNAPL not Removed*				
Probability	Percentage			
0.278	1.13%	98.87%	98.87%	88.87%
0.444	5%	95%	95%	85%
0.278	8.87%	91.13%	91.13%	81.13%

*Additive

Table H-5 Reduction of TCE Volume

TMV Reduction of TCE Volume	No Uncertainty
Original Score:	No Change
Unrecovered DNAPL	
Event Occurs:	Increase
DNAPL not Removed	
Event Occurs:	Increase

Table H-6 Reduction of Tc-99 Volume

TMV Reduction of Tc-99 Volume	No Uncertainty
Original Score:	No Change
DNAPL not Removed	
Event Occurs:	Increase

Table H-7 % TCE Irrev. Treated

TMV % TCE Irrev. Treated		Highest	Most Likely	Lowest
	Original Score:	95%	90%	70%
	Probability:	0.185	0.63	0.185
Unrecovered DNAPL*				
Probability	Percentage			
0.185	0.351%	94.649	89.649%	69.649%
0.63	1.26%	93.74%	88.74%	68.74%
0.185	2.99%	92.01%	87.01%	67.01%
DNAPL not Removed*				
Probability	Percentage			
0.278	1.13%	93.87%	88.87%	68.87%
0.444	5%	90%	85%	65%
0.278	8.87%	86.13%	81.13%	61.13%
Short Circuits*				
Probability	Percentage			
0.278	1.13%	93.87%	88.87%	68.87%
0.444	5%	90%	85%	65%
0.278	8.87%	86.13%	81.13%	61.13%

*Additive

Table H-8 % Tc-99 Irrev. Treated

TMV % Tc-99 Irrev. Treated		Highest	Most Likely	Lowest
	Original Score:	100%	100%	90%
	Probability:	0.185	0.63	0.185
DNAPL not Removed*				
Probability	Percentage			
0.278	1.13%	98.87%	98.87%	88.87%
0.444	5%	95%	95%	85%
0.278	8.87%	91.13%	91.13%	81.13%

*Additive

Table H-9 Community Protection

Short Term Community Protection	No Uncertainty
Original Score:	Treated
Steam Breakouts	
Event Occurs:	Untreated

Table H-10 Surface Releases

Short Term Surface Releases	No Uncertainty
Original Score:	Controlled Air & Water
Steam Breakouts	
Event Occurs:	Uncontrolled Air

Table H-11 Yr Until Protection Achieved

Short Term Yr Until Protection Achieved	Lowest	Most Likely	Highest
Original Score:	2003.33	2003.33	2006.33
Probability:	0.185	0.63	0.185
DNAPL not Removed			
Event Occurs:	An additional 1.33 years		
Steam Breakouts			
Event Occurs	An additional 0.25 years		
Short Circuits			
Event Occurs:	An additional year		

Table H-12 Impact on Future RAs

Implementability Impact on Future RAs		No Uncertainty
Original Score:		Minor Positive
DNAPL not Removed		
Probability	Percentage	
0.278	1.13%	Minor Negative
0.444	5%	Major Negative
0.278	8.87%	Major Negative

Table H-13 NPV

NPV		Lowest	Most Likely	Highest
Original Score:		Depends upon volume (Appendix F)		
Probability:		0.185	0.63	0.185
Unrecovered DNAPL				
Event Occurs:		An additional $500,000		
DNAPL not Removed				
Event Occurs:		NPV*2		
Plume Outside the RA				
Event Occurs:		An additional $500,000		
Steam Breakouts				
Event Occurs:		NPV*1.1		
Short Circuit				
Probability	Percentage			
0.278	1.13%	An additional $2,000		
0.444	5%	An additional $60,000		
0.278	8.87%	An additional $80,000		

Technological Risks, Evaluation Measures Matrix

EVENT MATRIX																												
	Long-Term				Toxicity, Mobility, or Volume										Short-Term					Implementability								Cost
Events	HM Remaining in the Subsurface	% TCE Left in the Subsurface	Activity of Tc-99 Left in Ground Water	Replacement of Technical Components after Remedial Action	PCOCs Addressed in the Treatments	%TCE Destroyed, Treated, or Recycled	%Tc-99 Destroyed, Treated, or Recycled	Reduction of Toxicity Through In-Situ Degradation	TCE Mobility Reduced	Tc-99 Mobility Reduced	Reduction in Volume of TCE Contaminated Zone	Reduction in Volume of Tc-99 Contaminated Zone	%TCE Irreversible Treated/Removed from the Subsurface	%Tc-99 Irreversibly Treated/Removed from the Subsurface	Community Protection	Worker Protection	Surface Releases	Subsurface Injectants of Foreign Materials	Year Until Protection is Achieved	Ability to Construct	# of System Equivalents for the Treatment Train	# of Successful Applications	Effect/Impact on Future Remedial Action	Risk of Exposure from Unmonitored Pathways	Effort Obtain Approvals	Treatment/Storage/Disposal Options for TCE and Tc-99	Minimum # of Contractors/Subcontractors	Net Present Cost
DUS & 2P																												
1. Unrecovered DNAPL (RGA Only, McNairy)		X				X					X		X															X
2. DNAPL not Removed, Tc-99 not Removed		X	X			X	X				X	X	X	X					X				X					X
3. DNAPL outside Remediation Area (Event 2 Dependent)																												X
4. Steam Breakouts (UCRS only)															X		X		X									X
5. Short Circuit (UCRS only)		X				X							X						X									X

Appendix I: Risk Profiles for Balancing Criteria

The follow risk profiles belong to the Long Term, TMV, Implementability balancing criteria. There are two risk profiles in each figure presented. The first risk profile is the balancing criteria excluding the technological risks. The second risk profile includes the technological risks. For all three balancing criteria there was no significant different between these two risk profiles. The risk profiles for the other two balancing criteria are presented in Chapter 4.

Long Term

The risk profile for the Long Term criteria that excludes the technological risks has an expected value of 9.56. Including these risks changes the expected value to 9.556.

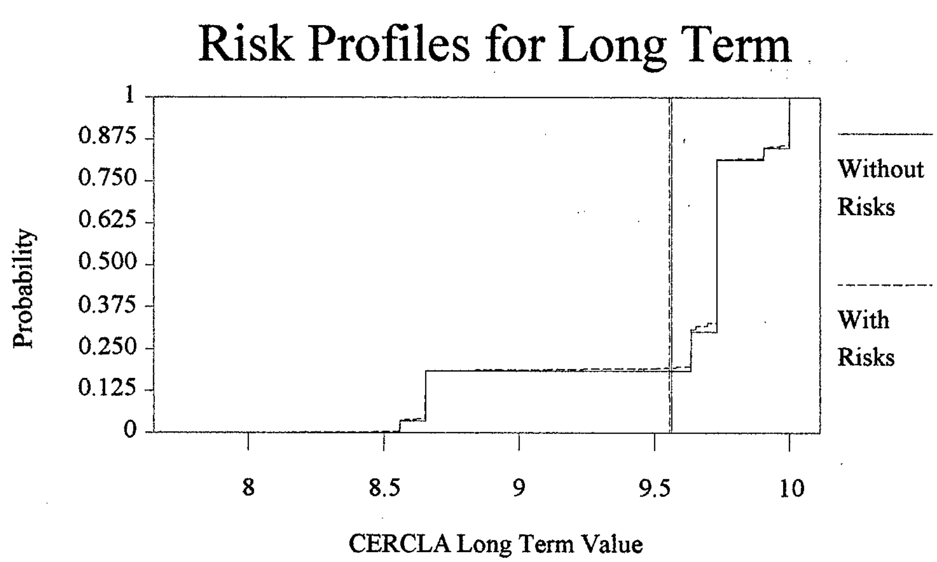

Figure I-1 Long Term Risk Profiles

TMV

The expected value of TMV without risks is 7.57 and the expected value of TMV with risks is 7.54.

Risk Profile for TMV

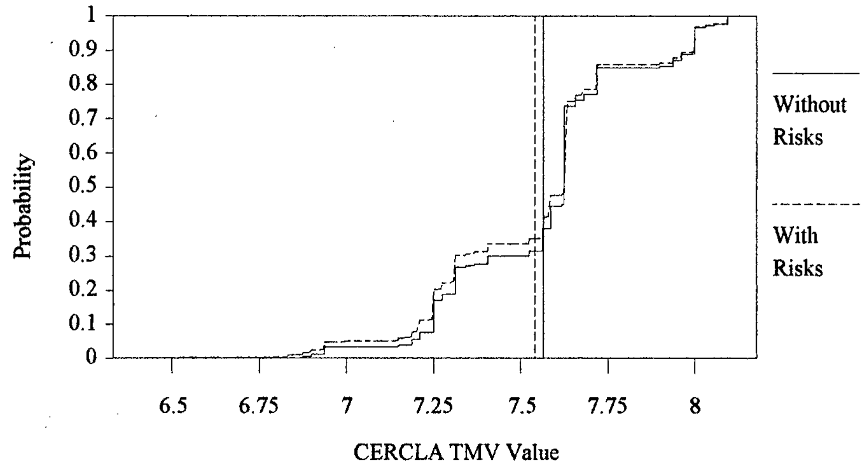

Figure I-2 TMV Risk Profiles

Implementability

The expected value for implementability without the technological risks is 5.15 and with these risks it is 5.12.

Risk Profile for Implementability

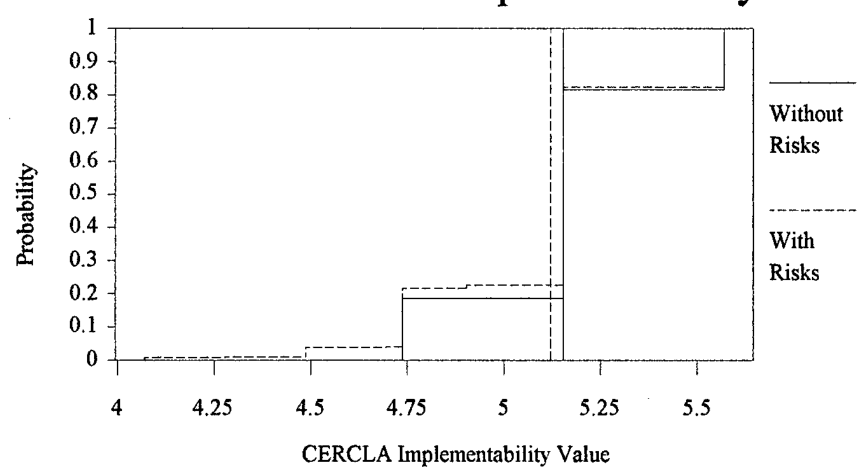

Figure I-3 Implementability Risk Profiles

Appendix J: Distributed Sampling Simulation

This research uses full enumeration and simulation to evaluate the models. Most of the models use the full enumeration method, which evaluates every path in the model. However, full enumeration is time consuming for big models. The simulation method provides a faster analysis.

The accuracy of a simulation analysis depends upon the number of samples used. There are two sample parameters, initial number of samples and restart number of samples. The initial number of samples specifies the number of paths evaluated. The restart number of samples is the minimum number of samples for each decision node. The simulation is restarted at each decision node. The number of samples used at each decision node is the maximum of the restart sample parameter and the remaining number of samples. Since there were no decision nodes in the models used for this research the restart parameter does not apply. The number of samples used for all simulation models was 10,000.

DPL offers three types of simulation, Monte Carlo, Modified Monte Carlo, and Distributed Sampling [ADA, 1995: 427-435]. Of these three methods, the Distributed Sampling provides the most accuracy.

The Distributed Sampling technique is an extension of the Monte Carlo simulation. The Monte Carlo simulation uses random numbers to select a branch for each uncertainty node in the model. The number of samples selected determines the number of times the simulation runs through a model. The negative side to the Monte Carlo method is that some of the branches might not get evaluated.

To overcome this drawback, the Modified Monte Carlo uses a technique called stratified sampling. This technique assigns the number of samples to each branch by multiplying the total number of samples by the branch probability. Any samples not allocated to a branch are distributed randomly among the branches.

The Distributed Sampling incorporates the Modified Monte Carlo method. However, the Distributed Sampling method uses full enumeration until the number of samples remaining are less than or equal to three times the number of branches from a node at which point the Modified Monte Carlo simulation is used.

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13. ABSTRACT *(Maximum 200 words)*

The Department of Energy is responsible for selecting a remediation technology to cleanup the Waste Area Group (WAG) 6 site at the Paducah Gaseous Diffusion Plant (PGDP) in Kentucky. WAG 6 is contaminated with an uncertain amount of trichloroethylene (TCE) and technetium-99 (Tc-99). Selecting a remediation technology involves a certain degree of risk because many of these technologies are new or proven only for a specific type of contaminant or a particular set of site conditions. Differences between contaminant type and site conditions are enough to make the performance of a remediation technology uncertain. This research identifies the technological risks of two remediation technologies: Dynamic Underground Stripping (DUS) and In Situ Chemical Oxidation (ISCO). Risk is defined as the likelihood of undesirable events occurring during the implementation of a technology at WAG 6. These risks were divided up into two categories: acceptable risks and unacceptable risks. For unacceptable risks, technological "fixes" were developed to reduce the probability of occurrence. Further investigations into DUS's technological risks determine the effects these risks have on CERCLA's five balancing criteria. Incorporating the technological risks and their effects into a decision analysis model produces a risk profile for DUS. The results of this research provided the decision makers at WAG 6 with insights into the performance risks for Dynamic Underground Stripping and In-Situ Chemical Oxidation.

14. SUBJECT TERMS

Decision Analysis, Risk Analysis, Event Trees, Dynamic Underground Stripping, In-Situ Chemical Oxidation, Trichloroethylene (TCE), Value Focus Thinking, Technology Development

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