AN ANALYSIS OF INSTITUTIONAL RESPONSIBILITIES FOR THE LONG-TERM MANAGEMENT OF CONTAMINANT ISOLATION FACILITIES

By

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To Mom and Dad for a lifetime of encouragement and support

and

As inspiration to Colton, Samantha and future generations.

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ARCO	Atlantic Richfield Company
ASTM	American Society for Testing and Materials
ASTSWMO	Association of State and Territorial Solid Waste Management Officials
AUES	American University Experiment Station
AUL	Activity and Use Limitation
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CIF	Contaminant Isolation Facility
COC	Contaminants of Concern
CRESP	Consortium for Risk Evaluation with Stakeholder Participation
CFR	Code of Federal Regulations
DOE	Department of Energy
DOE-GJO	DOE Grand Junction Project Office
EDA	Emergency Declaration Area
ELI	Environmental Law Institute
FEMA	Federal Emergency Management Agency
FTA	Fault Tree Analysis
FUDS	Formally Used Defense Sites
INEEL	Idaho National Engineering and Environmental Laboratory
LLW	Low-Level Waste
LM	DOE Office of Legacy Management
LTSM	Long-Term Surveillance and Maintenance Program
LUC	Land Use Control
M&O	Management and Operating
NPL	National Priority List
NRC	National Research Council
OU	Operable Unit
PRP	Potentially Responsible Parties
QA	Quality Assurance
QC	Quality Control

RCRA	Resources Conservation and Recovery Act
RI/FS	Remedial Investigation and Feasibility Study
RMA	Rocky Mountain Arsenal
RMANWRA	Rocky Mountain Arsenal National Wildlife Refuge Act
ROD	Record of Decision
RRM	Residual Radioactive Material
SARA	Superfund Amendments and Reauthorization Act
UECA	Uniform Environmental Covenant Act
UMTRCA	Uranium Mill Tailings Radiation Control Act
UMTRA	Uranium Mill Tailings Remedial Action
USACE	U.S. Army Corps of Engineers
USDOD	U.S. Department of Defense
USDOE	U.S. Department of Energy
USDOI	U.S. Department of Interior
USDOJ	U.S. Department of Justice
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGAO	U.S. Government Accounting Office
USNRC	U.S. Nuclear Regulatory Commission

CHAPTER I

INTRODUCTION

While scientific, engineering and social advancements have significantly raised the standard of living for much of the world's population, these advances have also produced certain by-products, such as hazardous and radioactive waste. These materials are the unwanted result of energy production, mineral extraction and national defense programs, as well as industrial and manufacturing operations. In many circumstances, treatment processes do not exist that can destroy these materials. Because of these limitations, such materials are routinely disposed of in shallow burial grounds throughout the world. These disposal practices have restricted and limited the use of private and public property, have increased the risk to human health and the environment and have resulted in damage to the ecosystem by contaminating considerable volumes of soil and groundwater.

Current Strategies for Contaminant Isolation

Society is realizing that it cannot restore many of these environmentally contaminated sites to pristine conditions (NRC, 2000). Additionally, many of today's waste management techniques do not eliminate the waste contaminants, but rather only concentrate or attempt to contain the contaminants of concern (Suter et al., 1993; Rumer and Mitchell, 1995; NRC, 1997; Applegate and Dycus, 1998; USEPA, 1998; Russell, 2000). As such, risks to human health and the environment often remain at many sites even after regulatory-approved environmental remediation operations are complete. These risks are associated with the residual wastes left in-place or disposed of on-site, as well as residual contamination of soils, facilities, surface water and groundwater.

The primary strategy for managing these risks involves the emplacement of contaminated materials into near-surface contaminant isolation facilities and subsequent long-term monitoring of the facility and surrounding groundwater. The best available technology is most often used in the design, construction and monitoring of isolation facilities. The intent of these facilities is to maintain the long-term isolation of the identified contaminants (radioactive, organic, inorganic, etc.) as well as to mitigate their associated hazards (gamma radiation, radon emanation, contaminant migration, fire and explosion potential, etc.).

Applicable Regulations

The United States is addressing waste-related problems by enforcing a variety of environmental regulations. Two primary regulations applicable to the remediation of abandoned radioactive and hazardous waste sites are the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980 and the Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978. CERCLA, commonly known as Superfund, establishes the framework for the federal response to the release of hazardous substances that endanger public health or the environment (CERCLA 1994). UMTRCA defines the remediation requirements for abandoned sites that processed uranium and related ores for the federal government (UMTRCA 1978).

Additional related regulations include the Resources Conservation and Recovery

Act (RCRA) of 1976 (RCRA 1976), the Small Business Liability Relief and Brownfields Revitalization Act (Brownfields) of 2002 (USEPA, 2002d) and the U.S. Nuclear Regulatory Commission's (USNRC) Consolidated Nuclear Material Safety and Safeguards Guidance of 2002 (USNRC, 2002). RCRA establishes requirements for managing hazardous, industrial and household wastes from generation through disposal to minimize future pollution that could result from solid waste landfills. The Brownfields Program focuses on abandoned, idle or under-utilized industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination. The USNRC program provides decommissioning guidance to nuclear facility licensees. Of particular interest is the USNRC's requirements for License Termination (USNRC, 2003b) as well as the USNRC Long Term Control Possession Only License (USNRC, 2004).

Despite such regulatory constructs, waste isolation strategies often fail and environmental problems persist. This is partly the result of the long-lived nature of some contaminants, as well as technical, economic, social and political limitations.

Problem Statement

Society's experience with modern waste isolation techniques is beginning to show that contaminant isolation facilities and associated management techniques do not always perform as expected (USGAO, 1990). The reality is that actual performance can deviate from planned performance. If not rectified by the site stewards, these performance deviations can negatively affect facility performance to the point that the system fails, resulting in negative consequences such as exposure of human receptors to the residual contaminants.

Figure 1 illustrates the prevailing concept used for the management of residual contaminants. Remedial operations often consolidate contaminated materials on-site and contain these residual contaminants in an isolation facility. The management objective of such a facility is to maintain isolation of the contaminants for hundreds of years, although in most situations it will be required for perpetuity. In a few limited situations, assuming the contaminants decay, the associated site risk could reduce to acceptable levels and the site could potentially be released for unrestricted use.

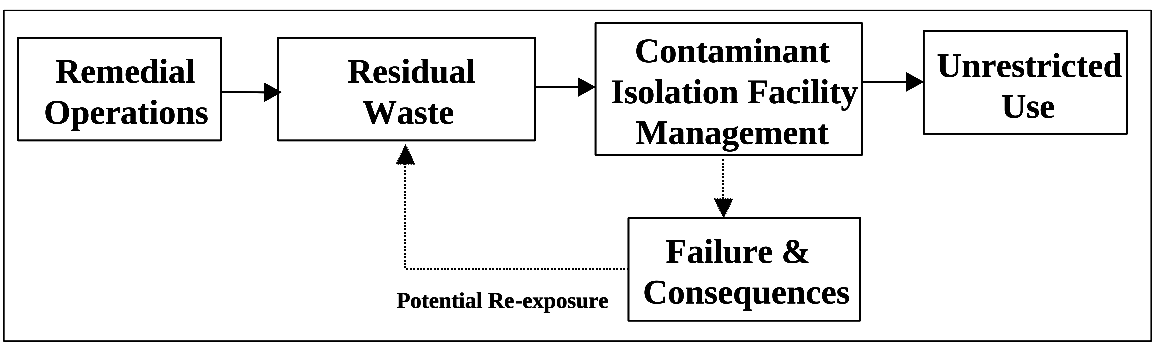

Figure 1. Conceptual model for residual contaminant isolation management.

The management of the contaminant isolation facility can be seen as the critical step within this process. This management step generally includes two key components – maintaining engineered barriers and maintaining institutional controls. Engineered barriers are physical modifications to the natural setting, including the site, facility and/or the residual materials themselves. They are used to reduce or eliminate the potential for exposure to contaminants of concern (COCs). Conversely, institutional controls are processes, instruments and mechanisms designed to influence human behavior and activity. They are used to limit the activities performed on one's land.

The relevant science, state-of-the-art practice and regulatory structure of the time govern the implementation details of the management process. As society gains additional knowledge, regulations are subsequently modified and operational requirements to reduce long-term risks are enhanced. Enhancements tend to focus on either improving the reliability of engineered components or clarifying the administration of the institutional controls.

Engineered structures are designed to perform within expected ranges. Simulation models are often used to predict potential long-term material performance and possible contaminant migration. Engineering advancements have led to improved construction materials, advanced facility designs and new performance models, which improve the system reliability by reducing the performance uncertainties.

Advancements in the area of institutional controls appear to be less developed. Growing attention in the social sciences literature, with regard to the institutional management of residual waste, acknowledges the need to further explore the types of institutional controls that can and are being used as well as identifying their potential effectiveness (Pendergrass, 1996; English et al., 1997; Breggin et al., 1998; Edwards, 2003a; USGAO, 2005).

As noted by the National Academy of Science, society should plan for fallibility with regard to long-term contaminant isolation (NRC, 2000). The research presented in this dissertation builds on this recommendation.

Specifically, the central focus of this research is the evaluation of the effectiveness of institutional controls and the associated functions required to complement the engineered barriers. Although these isolation facilities are intended to successfully perform in perpetuity, this research is focused on evaluating their effectiveness during the first 100 years.

It is important to note that the described research focuses on near-surface residual contaminant isolation facilities only. Other types of contaminant isolation facilities (geologic repositories, aquitards, etc.) are not addressed.

Research Hypothesis

Current near-surface (i.e., within the top 10 meters of the earth's surface) contaminant isolation approaches will ultimately fail without continued human intervention, given the longevity of the contaminants (i.e., half-lives rates greater than 100 years). System failure could be the result of engineered barrier errors, institutional control errors or a combination of both.

Given that the objective of a contaminant isolation facility is to maintain isolation of the known contaminants until such time that they are no longer a risk to humans or the environment, *failure*, in the context of this research, refers to a contaminant isolation facility's inability to achieve its objective of maintaining contaminant isolation. In other words, failure corresponds to an inability to provide contaminant isolation. The consequences associated with such failures will be site-specific, because they depend on the contaminants present, exposure routes and rates, and the receptors involved.

Two simplified scenarios (ingress and egress) illustrate this definition of failure. In one scenario, the potential human receptors, animals or vegetation breach the isolation controls of the contaminant isolation facility and ingress into the contaminated material.

In the second scenario, the contaminated material escapes (egresses) from the contaminant isolation facility and is available for potential exposure. Both of these scenarios could represent acute or chronic occurrences and can result in a range of consequences (i.e., irrelevant through severe) depending on site-specific conditions.

Preventing both of these scenarios from occurring is the primary objective of the contaminant isolation facility management component depicted in Figure 1. This component involves maintaining and monitoring the isolation controls employed at the contaminant isolation facility. Reliability engineering, however, has shown that a variety of errors can occur, which can affect a system's performance (Reason, 1990). In terms of contaminant isolation facility management, *errors* are events in which a planned sequence of activities does not achieve its intended outcome. Errors are potential precursors to contaminant isolation facility failure. They indicate that actions did not go according to the plan or that the plan itself was inadequate to achieve the objective (Reason, 1997).

Research Goal

The goal of this research is to define the institutional responsibilities of a sustainable environmental protection system for the improved management of residual contaminants. Sustainable systems include not only engineered barriers and institutional controls but they may also need to include an expanded set of institutional responsibilities to minimize error precursors. Institutional responsibilities involve a set of management functions that are necessary to maintain the engineered barriers and institutional controls.

To achieve this goal, this research:

- Evaluates existing contaminant isolation facilities, strategies, controls and systems in the form of case studies,
- Determines if and how errors and failures occurred,
- Identifies interactions between the engineered barriers and institutional controls, and
- Develops a framework for evaluating institutional responsibilities to improve the long-term (100-years) management of residual contaminants.

The results of this research can be used to support the planning and implementation of improved and more sustainable long-term management strategies at relevant residual contaminant sites. Furthermore, this research could support the development of new isolation facilities.

Project Relevance

Results of this research are applicable to a variety of organizations that are responsible for the long-term management of residual waste sites. Sites of interest include both federal facilities and non-federal facilities.

Federal Facilities

Federal facilities are those facilities or lands that are owned or leased by the federal government. The management responsibilities for these properties reside in a specific office within the executive branch of the federal government.

The U.S. Government Accounting Office (USGAO) reports that as of fiscal year 2001 the U.S. federal government's environmental liabilities total $307 billion (USGAO, 2003). This is a conservative estimate because it includes only currently known liabilities. Liabilities include excess military bases, closed energy production facilities and legacy waste sites.

Two federal agencies, the U.S. Department of Energy (USDOE) and the U.S. Department of Defense (USDOD), account for 98% of the known environmental liabilities. The USDOE accounts for 78% or $238 billion and the USDOD accounts for 20% or $63 billion (USGAO, 2003). The remaining environmental liabilities are the responsibility of other federal agencies such as the U.S. Nuclear Regulatory Commission (USNRC) and the U.S. Department of Interior (USDOI).

U.S. Department of Energy

The USDOE manages one of the largest environmental remediation efforts in the world. This effort involves the remediation of sites negatively affected by 50 years of nuclear energy research and weapons production. The USDOE has identified 113 known geographic sites located in 30 states and one territory (USDOE, 1997c; USDOE, 1999a). USDOE's cleanup challenges include the remediation of 40 million cubic meters of contaminated soil and buried waste, 1.7 trillion gallons of contaminated groundwater and the deactivation and decommissioning of more than 4000 excess facilities, as well as the long-term care of uranium mine and mill tailings (USDOE, 2001d; USDOE, 2001e).

In 2001, the Idaho National Engineering and Environmental Laboratory (INEEL) completed a baseline assessment of the USDOE cleanup program (INEEL, 2001). This assessment shows that the USDOE cleanup program is planning to "close" sites and shift its resources from active remediation (i.e., facility demolition, waste processing, waste containment) to post-closure management (i.e., long-term stewardship). Long-term stewardship, as defined by the USDOE, includes those activities necessary to protect human health and the environment from hazards and wastes remaining at sites (or portions of sites) once active remediation is complete (USDOE, 2001d).

U.S. Department of Defense

The USDOD has responsibility for all active defense sites, major and minor installations slated for realignment (i.e., sites to be reused for other USDOD missions) or closure sites via the Base Realignment and Closure program (BRAC). In addition, USDOD is accountable for more than 9000 Formally Used Defense Sites (FUDS) that had a historic USDOD role. Similar to the USDOE, a significant percentage of these sites have some form of environmental contamination and many are expected to require post-remediation controls.

Questions continue to arise concerning USDOD environmental management practices. For example, the USGAO has questioned whether the USDOD had adequate justification in determining that more than 4000 FUDS have no remaining hazards and, therefore, required no further cleanup study or cleanup action (USGAO, 2002b).

Other Federal Agencies

Other federal agencies face similar challenges with regard to the long-term isolation of residual hazards. Although these agencies were not the focus of this research, they likely would have similar problems and therefore benefit from these results.

Non-Federal Facilities

State and local governments and private industry are also concerned with residual contaminants, Brownfields sites, contaminated landfills, abandoned mine sites and abandoned hazardous waste sites. These sites include publicly held properties of a state or municipality and privately owned sites, as well as abandoned properties.

The environmental remediation of these non-federal sites is accomplished through collaborative efforts of both the federal (i.e., U.S. Environmental Protection Agency) and the individual state regulators. These efforts are conducted consistent with federal regulations established primarily by the U.S. Environmental Protection Agency.

CERCLA Sites

CERCLA is of primary importance when considering environmental remediation and waste isolation. The U.S. Environmental Protection Agency (USEPA) has managed the Superfund Program for the past 24 years since CERCLA was enacted in 1980. This program has two primary areas of focus: the long-term cleanup of contaminated sites and an emergency response program (USEPA, 2004g).

Superfund is a large, complex program, with approximately $18 billion being expended to date (USEPA, 2004g). The USEPA established the National Priority List (NPL) in 1980 as a way of prioritizing the program’s work. The USEPA has placed approximately 1518 sites on the NPL (although 274 have since been deleted) and approximately 30 new sites are added each year. These sites include both federal facilities and non-federal facilities.

Approximately 900 NPL sites have completed remedial construction. Nearly 70%

of these sites have some form of post-closure institutional controls as part of their environmental remedy (Bellot, 2003a). Following the completion of remedial construction, the USEPA initiates a five-year review process to verify that the remedies are performing as anticipated. The USEPA completed 134 five-year reviews annually from 1999 to 2003 (USEPA, 2004g). The number of reviews completed by the USEPA annually is increasing, as an increased number of sites are being completed.

The emergency response program within Superfund was originally established to enable rapid response and clean up of sites that presented immediate threats to human health and the environment. This program has expanded in recent years to include other emergencies such as train derailments, biological contamination, etc. Approximately 7000 emergency actions have been conducted as part of this program.

Brownfields Sites

The USEPA also manages the Brownfields Program (USEPA, 2004b). Brownfields sites are defined as real property, the expansion, redevelopment or reuse of which could be complicated by the presence or potential presence of a hazardous substance, pollutant or contaminant (USEPA, 2004b). Brownfields sites include sites that a.) meet the definition, b.) are contaminated by a controlled substance, c.) are contaminated by petroleum products, d.) are relatively low risk (i.e., not qualified for inclusion on the NPL) and have no viable responsible party, and/or e.) are mine-scarred lands (USEPA, 2002a; Bromm et al., 2003). More than 400,000 Brownfields sites are believed to be present throughout the United States (USEPA, 2002a; USEPA, 2004b). Following active remediation, however, many of these sites will require continued long-term management because residual contaminants (volatile organic compounds, heavy metals, etc.) will remain on-site at elevated levels that restrict site use. The management of these residual waste sites could benefit from the findings of this research.

Dissertation Structure

The structure of this dissertation is as follows. Chapter I introduces the problem of residual contaminant isolation and presents the objectives of the research project. Chapter II provides a description of current management systems, including both engineered barriers and institutional controls. Chapter III reviews the relevant institutional control literature with a focus on the process of managing residual contaminants. Chapter IV presents the research methodology, including descriptions of the case study approach and fault tree analysis. Chapter V contains individual reports for each of the selected case studies as well as a summary of all cases. The individual reports include the findings and observations obtained from each of the studies. Chapter VI presents a cross-case analysis. This analysis includes the development of fault trees useful in identifying potential error pathways that could lead to system failure. Research conclusions and recommendations are presented in Chapter VII. The dissertation also contains a Glossary of Terms section and individual data collection checklists as appendices and a Bibliography.

CHAPTER II

CONTAMINANT ISOLATION FACILITY

Introduction

A contaminant isolation facility maintains separation of hazardous contaminants (radioactive, organic and inorganic by-products) from potential human receptors. This protection includes the mitigation of associated hazards such as contaminated leachate migration, gamma radiation and radon emanation.

While various contaminant isolation facility design configurations are being used throughout the world (IAEA, 2001), these are most often viewed as “closed systems” having no interaction with the surrounding environment (Jones et al.). As such, to maintain long-term isolation, the contaminant isolation facility must successfully prevent the release of contaminants via the following five mechanisms:

- Infiltration of water (precipitation and surface runoff) into the waste,
- Groundwater intrusion (lateral and vertical flow) into the waste,
- Leachate migration from the waste,
- Human and other biological intrusion into the waste, and
- Release of gases (e.g., radon) from the contaminant isolation facility.

This chapter draws primarily on the experience generated from near-surface (within 10 meters of the earth’s surface) contaminant isolation facilities designed for chemical and radioactive waste (e.g., low-level waste and uranium mill tailings).

Subsystems of a Contaminant Isolation Facility

A contaminant isolation facility generally involves the integration of three subsystems that collectively attempt to prevent the unwanted release of contaminants via the aforementioned five mechanisms. The three subsystems of the contaminant isolation facility include (1) the natural environmental setting (geology, climate, etc.) in which the contaminant isolation facility is located, (2) the engineered subsystem (i.e., active processes and passive engineered barriers), and (3) the institutional controls subsystem (i.e., administrative land use controls). Figure 2 is an illustration of a typical contaminant isolation facility.

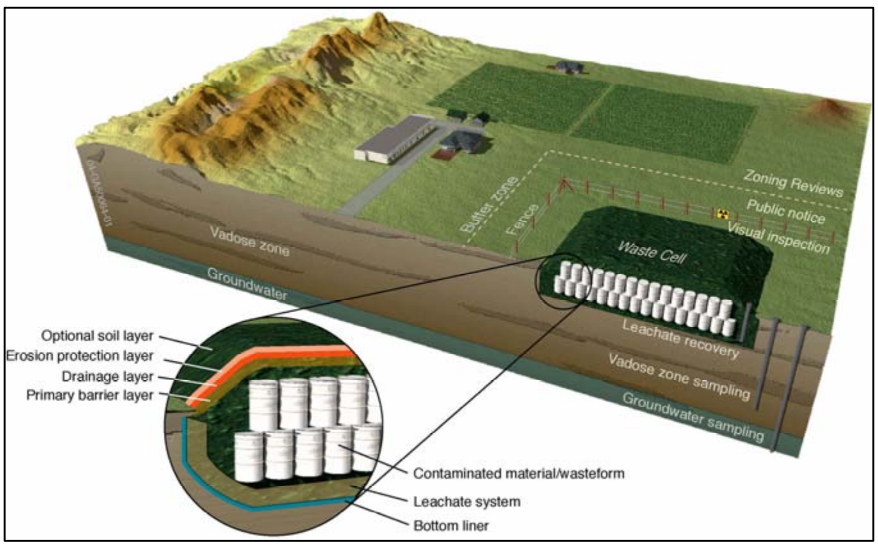

Figure 2. Illustration of a typical contaminant isolation facility. The insert highlights the engineered subsystem (Kostelnik et al., 2004).

Natural Subsystem

The natural subsystem (i.e., environmental setting) in which a contaminant isolation facility is located is of critical importance during the siting process for a new disposal facility. During the siting process, a site's environmental characteristics are evaluated to identify areas most suitable for locating such a facility. For other circumstances in which waste materials were generated at a site and are likely to remain on-site, the natural subsystem is obviously not a factor in the siting process although it remains a critical subsystem. In either scenario, the important environmental characteristics of a site are:

- Geology (geomorphology, geomechanics, seismicity, etc.)
- Hydrogeology (permeability, hydraulic conductivity, etc.)
- Climate (precipitation, temperature, vegetation, etc.)
- Topography (slope, landscape, etc.).

Engineered Subsystem

The engineered subsystem of a contaminant isolation facility serves to augment the natural subsystem. The engineered subsystem could involve active processes as well as passive engineered barriers. Active processes involve ongoing remedial operations at a site. These could include groundwater pump and treat operations, vapor vacuum extraction operations and bio-remediation operations. Passive engineered barriers found at a typical near-surface contaminant isolation facility consist of a surface cover, the stabilized hazardous material and subsurface barriers (bottom liners and side walls). More recent designs also include a leachate recovery system (IAEA, 2001). The insert in Figure 2 illustrates the typical configuration of these various engineered layers.

The engineered cover or top liner of a near-surface contaminant isolation facility performs two critical functions. First, it prevents and minimizes the infiltration of precipitation and surface water run-off into the contaminated material. Second, it prevents or minimizes the potential for direct contact with the contaminants. The engineered cover uses several specific barrier layers, consistent with site-specific requirements, to achieve these two functions.

An engineered cover typically includes an optional soil layer, an erosion protection barrier, a surface-water drainage layer and a low hydraulic conductivity primary protection layer (refer to the Figure 2 insert). Additional radiation/radon barriers and structural stability layers could be required depending on site-specific requirements.

Current designs make use of both natural and synthetic materials. Although the typical cover design using this multiple-layer approach evolved over time, it is important to note that regulatory requirements typically prescribe the minimum performance standards as well as the cover design itself. Alternative design approaches, often considered to be more appropriate given site-specific environmental conditions, must demonstrate equivalency to the prescribed design (Benson et al., 2002; Clarke et al., 2004).

The contaminated material (e.g., tailings, waste, debris) placed in the contaminant isolation facility is generally compacted or otherwise stabilized to reduce the potential for post-closure subsidence and settlement. Stabilization also minimizes porosity and controls the permeability within the contaminant isolation facility. The incorporation of a leachate recovery system and subsurface barriers (e.g., bottom liners), if used, are predicated on site hydrology, ecology, climate, local groundwater characteristics and use patterns and regulatory requirements (USEPA, 2004h).

Institutional Controls Subsystem

Institutional controls are "non-engineered" mechanisms that influence human behavior and land use activity (USEPA, 2002c). According to the USEPA, institutional controls should be used to supplement engineered barriers at residual waste sites (USEPA, 2002c). Institutional controls most often used in the United States include government controls, such as local zoning and groundwater use restrictions and property-based controls, such as deed restrictions and covenants (Borinsky, 1995; Gaspar and Burik, 1998). Chapter III provides further details regarding the types of institutional controls implemented at a contaminant isolation facility.

There are two predominant strategies associated with controlling land use at residual waste sites. One land use strategy attempts to maintain the complete separation of human receptors from the potentially contaminated property. Within this strategy, residual waste areas are isolated and eliminated from further use by society. Because these sites have not been returned to productive use following remediation these sites are often referred to as "sacrifice zones."

A second or alternative land use strategy used at residual waste sites involves actively reusing a portion of the property. At these sites, current and future human activity (residential, industrial, agricultural, etc.) considered appropriate for the area, is evaluated during the remedial planning process (ASTM, 2000a). Land use activity is then limited based on the potential risks associated with the remediated site. This risk-based approach is becoming more acceptable to regulators and stakeholders. Such an approach is also being incorporated into a number of key remediation programs such as the USEPA Brownfields Program and the USDOE Environmental Management Program (USDOE, 2003; USEPA, 2004b) as well as the USNRC nuclear facility license program (USNRC, 2003b).

Management of a Contaminant Isolation Facility

Studies have shown that contaminant isolation facilities are not “closed systems” operating independent of their surroundings (NRC, 1997; USEPA, 1998; Clarke et al., 2004). Instead, there is considerable interaction between the contaminant isolation facility and its surroundings. These interactions include hydrologic, climatic, biologic, geologic and chemical influences at the surface as well as within the vadose and saturated zones.

In fact, studies have shown that chemical, physical and biological processes begin to influence the performance of a contaminant isolation facility soon after its construction (Suter et al., 1993; USDOE, 1997b; USDOE, 1999b). Figure 3 illustrates a number of the key interactions that influence contaminant isolation facility performance.

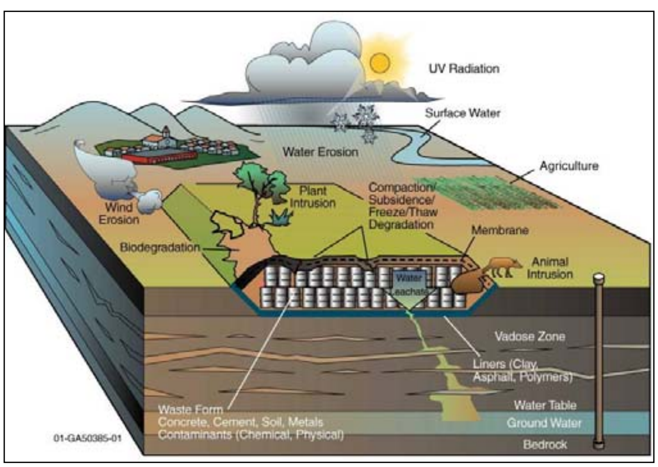

Figure 3. Numerous factors influence contaminant isolation facility performance.

To ensure continued system performance, site stewards must be actively involved in the management of the contaminant isolation facility. This management involves two primary activities (monitor and maintain) related to two of the three subsystems (the engineered subsystem and the institutional control subsystem).

Monitoring

A systematic monitoring program is critical for evaluating the long-term performance of a contaminant isolation facility (USEPA, 1998). Monitoring involves the active investigation and observation of processes, operations, structures and controls applied at a specific site.

Visual inspection of the contaminant isolation facility and all of its physical features continues to be the primary qualitative monitoring technique. These inspections are useful in identifying deficiencies in both the engineered and institutional control subsystems. Natural events, which can affect the engineered structures and could include erosion, bio-intrusion, subsidence, material degradation, infiltration and seepage, can be observed through visual inspections. Likewise, anthropogenic events, such as deliberate human intrusion, vandalism and property restriction violations inconsistent with the land use restrictions, can also be detected through visual inspections.

The second form of monitoring applied at a contaminant isolation facility is quantitative. This method consists of analyzing samples from the area surrounding the contaminant isolation facility, including the vadose zone, the saturated zone and the leachate recovery system. These quantitative methods serve to indirectly detect evidence of performance deficiencies such as increased saturated conductivity or material performance deficiencies. Although the intent of this approach is to provide an early warning of future problems, this approach, in many instances, serves as confirmation of a system failure.

Monitoring measures need to be performed in accordance with a schedule best defined after considering site-specific conditions. Sampling strategies generally are conducted on a monthly, quarterly or annual basis. Site-wide visual inspections are often performed annually or every five years (e.g., CERCLA five-year reviews).

Maintenance

Maintenance activities are required to ensure that the contaminant isolation facility subsystems continue to perform as designed. These activities are needed for active processes, passive engineered barriers and the associated institutional controls.

Maintenance efforts for active remedial processes, which are commonly associated with the ongoing treatment of contaminated groundwater or a treatable source-term in the vadose zone, could include continued power supply, equipment repair and sample management. Maintenance efforts for engineered surface covers could include repairs to damaged layers resulting from surface erosion or bio-intrusion, re-contouring surface features and vegetative controls (cutting, spraying herbicide, etc.). Maintenance of the subsurface barrier components is generally minimal if these components are designed and installed properly. Failure of these components, however, could require repair, replacement or re-remediation of the site.

Maintaining institutional controls differs somewhat from the maintenance of engineered barriers. Maintaining institutional controls requires administrative actions as well as legal enforcement of the controls. Reviewing regional land use change requests, zoning change requests and land transfer records could be maintenance functions that are required to ensure land use restrictions are not inappropriately modified. Information collection, integration and reporting including periodic public notice will also be required.

Institutional Responsibilities

Additional maintenance responsibilities exist beyond the conventional institutional controls. Included within these responsibilities is the need to:

- Maintain the security of the site from inadvertent or intentional intrusion,
- Maintain financial security of the site and associated functions,
- Maintain a multi-generational awareness within the local community,
- Maintain emergency/contingency plans and perform emergency actions when applicable,
- Maintain information/records,
- Evaluate the surrounding environment/ecosystem, and
- Continually assess the performance of the system and identify areas for improvement.

Logic Diagram for Contaminant Isolation Facility Management

The management of a contaminant isolation facility is a complex dynamic process in that individual activities could change over time. Site stewards must be able to recognize such temporal changes and adjust their management approach accordingly.

Figure 4 illustrates a logic diagram applicable to site stewards for assessing the management function of a contaminant isolation facility. The diagram highlights three operational questions related to the presence of existing subsystem components (Active Operations, Engineered Barriers and Land use Restrictions). A positive response to any of these three questions triggers site-specific requirements. Such requirements could include the monitoring and maintenance of remedial processes, engineered barriers or institutional controls. The site-specific monitoring and maintenance requirements can be viewed as the institutional responsibilities of the site stewards.

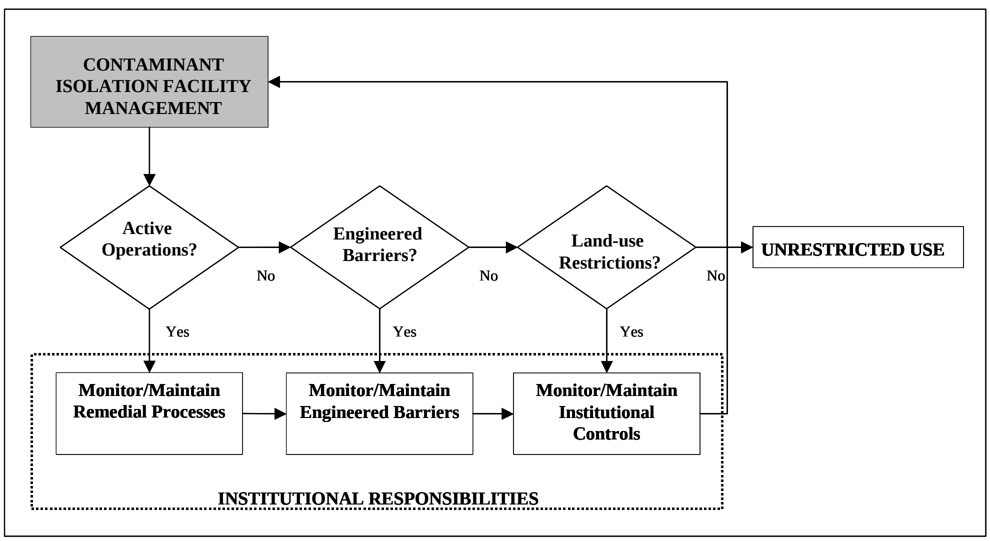

Figure 4. A logic diagram applicable to site stewards for assessing the management functions of a Contaminant Isolation Facility.

An important aspect of institutional responsibilities, as shown in Figure 4, is that some form of institutional control should be present for all sites having a restricted-use classification. Because of this broad applicability, the long-term effectiveness of institutional controls appears to be significant.

The following chapter contains a review of the pertinent literature for institutional controls. This discussion includes an overview of the controls currently in practice. It then focuses on the specific application of institutional controls for the management of residual waste sites.

CHAPTER III

LITERATURE REVIEW OF INSTITUTIONAL CONTROLS

Introduction

Institutional controls are processes, instruments and mechanisms designed to influence human behavior and activity. These controls generally take the form of legal or administrative restrictions. Such controls are also commonly referred to as land use controls (LUCs) (ICMA, 2000) or activity and use limitations (AULs) (Edwards, 2000a). Collectively, institutional controls are most often described in terms of their method of control, the manner in which they are established or the application for which they are intended.

This review begins with an overall introduction to institutional controls and then focuses on the application of these controls with respect to the management of residual contaminants. Included in this review are a summary of institutional control applications, various methods of direct or indirect control and a discussion of the methods for establishing and funding institutional controls. The review also includes an introduction to the legal aspects involved with institutional controls. Various federal, state and local implementation guidance is presented as well as a summary of various evaluations and studies that have investigated the performance of institutional controls.

Institutional Control Applications

There are two primary applications associated with the implementation of institutional controls (Clancy-Hepburn et al., 1995; Pendergrass, 1996). Institutional controls are routinely used as a means of preserving and protecting valuable assets (preservation of land, water, cultural resources, etc.) and as a method of influencing and restricting current and future behavior (e.g., use-restrictions) due to potential incompatibility.

Preservation and Protection

The federal government has routinely used institutional controls to protect specific assets either for preservation or use-restriction purposes. Pendergrass (1996) provides an introduction to a number of federal programs that use institutional controls for preservation purposes. Examples of these types of programs and applications include Historic Preservation, Buried Utility Protection, Ecosystem Preservation, Floodplain Management, Wellhead/Aquifer Protection and Waste Management.

The National Historic Preservation Act (NHPA) of 1966, as amended through 1992, established the federal policy whereby the use of institutional controls, including financial and technical assistance, was encouraged to preserve historic and cultural aspects of the nation. The Act states that *the preservation of the irreplaceable heritage is in the public interest so that its vital legacy of cultural, educational, aesthetic, inspirational, economic, and energy benefits will be maintained and enriched for future generations of Americans* (NHPA 1966). NHPA directs that actions be taken to ensure that significant prehistoric and historic artifacts, and associated records, be managed by an institution with adequate long-term curatorial capabilities (NHPA 1966). Such an institution could be the appropriate State Historic Preservation Program working in cooperation with other nations and states, local governments, Native American tribes, private organizations and individuals.

The U.S. Department of Interior (USDOI) represents the largest federal preservation and protection program. Consisting of eight Bureaus, the USDOI is responsible for managing approximately 20% of the entire U.S. landmass. USDOI's goals include protecting the environment and preserving our nation's natural and cultural resources, managing these natural resources for a healthy environment and a strong economy and providing recreation for America (USDOI, 2003). USDOI's preservation responsibilities include natural resource preservation, wildlife refuges, national parks, cultural resources and national heritage, cooperative conservation, water resource management, mineral resources, Native American affairs, etc.

States and local municipalities have also used various forms of institutional controls to protect their assets. Surprisingly, however, many of these organizations do not always recognize these mechanisms as institutional controls (ASTSWMO, 1997). For example, the protection of buried utilities is a preservation control frequently not recognized as an institutional control. Various states have established procedures for planning and conducting excavations near underground utility facilities (FLDEP, 2002; Illinois 2002; Ohio 1990). The purpose of these laws is to reduce damage to gas, water, oil, steam, telephone, cable television and sewer lines. These laws establish state-level requirements for maintaining location records, which are important for locating all utilities, providing advance notice prior to any excavation, the establishment of one-call statewide information management systems and emergency excavation procedures.

In addition to various government-led preservation controls, numerous private organizations have been established with the primary goal to preserve various ecological assets, such as scenic rivers and natural resources. Major environmental groups, such as the Nature Conservancy and the Sierra Club Foundation, have formed to consolidate membership and promote preservation positions (Nature, 2003; Sierra, 2003). These types of conservation groups achieve their preservation goals through the use of a variety of institutional mechanisms. The Nature Conservancy, for example, often buys then manages areas they deem ecologically important. The Conservancy also negotiates partnerships or conservation easements whereby the Conservancy agrees to manage areas without actually holding title to the property. In addition to these direct methods, conservation organizations are often involved in training and educational programs and they also work with resource-based industries to influence their business practices (Nature, 2003).

Use Restrictions

The second application of institutional controls involves restrictions applied to the use of land. This application limits either current or future behavior because certain land-uses are deemed incompatible with the land's condition or location (Clancy-Hepburn et al., 1995; Hersh et al., 2002).

The National Flood Insurance Program (NFIP), administered by the Federal Emergency Management Agency (FEMA), is an example of a federal institutional control program designed to reduce construction in flood-prone areas. Although participation in this program is voluntary, NFIP offers incentives as a means of attracting community participation (FEMA, 2000). These incentives include the ability to obtain federal flood insurance and low-interest loans. Participating communities that satisfy the federal rules are encouraged to establish then enforce the provisions of the program through state and local zoning laws, ordinances and building codes (FEMA, 2002b).

A second example of a land use restriction program involves the protection of public groundwater supplies. Groundwater is of critical importance to federal, state and local authorities. The Safe Drinking Water Act (SDWA) enacted in 1974 and amended in 1986, established a new program for the protection of public groundwater supplies. The Wellhead Protection (WHP) Program, administered by the U.S. Environmental Protection Agency (USEPA), was the first resource-based approach at the federal level for ensuring that public groundwater supplies were protected from a wide range of potential contaminating sources (USEPA, 1999c; FLDEP, 2003a). With the programmatic goal of protection, the institutional controls established limitations on uses that were deemed inappropriate for groundwater recharge areas.

Institutional Control of Residual Contaminants

Use-restrictions associated with environmentally contaminated sites are one area that is receiving increased attention. Hazardous, radioactive and other toxic substances (i.e., contaminants of concern) have routinely been generated and subsequently disposed of in the shallow subsurface throughout the world (NRC, 2000; Tucker, 2001; USDOE, 2001d; Long, 2002). Hazardous and/or contaminated material that remains on-site following active operations or the completion of remedial actions continues to pose risk to humans and the environment. These risks represent a significant and chronic problem (Edwards, 1997).

Edwards and North (1997) have found that institutional controls were historically used as an interim measure before and during an active remediation program. Under current regulations, institutional controls are not to be used as a substitute for active response actions. CERCLA and RCRA remedies, for sites having residual contamination, often use institutional controls to protect the integrity of engineered barriers as well as to minimize the potential of human exposure to the contaminants (Bellot, 2003b; Miller, 2003).

Institutional controls, however, have become a more integral part of long-term corrective actions (USEPA, 2000). This is primarily because the remediation and subsequent management of contaminated sites is increasing linked to current and future land use projections (CERCLA 1994).

Several studies have shown that land use considerations are complex issues (Mazurek and Hersh, 1997; Wernstedt and Hersh, 1997; Wernstedt and Probst, 1997; Wernstedt et al., 1998). As discussed by White et al. (1993), land use concerns directly affect baseline risk assessments. Areas with land use restrictions are often categorized in ways that define acceptable activities, such as agricultural, industrial, recreational and commercial uses. These projected uses are linked to remediation decisions and, therefore, the classifications serve as a measure of acceptable future risk (Applegate and Dycus, 1998; Hersh et al., 2002).

The USDOE, which is responsible for one of the largest environmental management efforts in the world (USDOE, 1997c), has recently provided a revised post-remediation policy. DOE Policy 455.1, a Policy Statement on the *Use of Risk-Based End States*, provides direction to USDOE management and attempts to establish a common understanding of how the USDOE will consider post-remediation conditions/risk in remediation strategies (USDOE, 2003).

Methods of Control

According to Clancy-Heburn et al. institutional controls can be viewed as *direct* or *indirect* controls (Clancy-Hepburn et al., 1995). Direct mechanisms involve the forced control of another's actions. This is often achieved through legal instruments such as property ownership or regulatory requirements. Indirect mechanisms attempt to influence another's actions but lack the legal authority to enforce these actions. Indirect control mechanisms include such actions as information management, education and effective notices.

Mechanisms for Establishing Institutional Controls

A number of legal mechanisms exist for establishing institutional controls. The literature attempts to differentiate these mechanisms in a variety of ways. A National Research Council (NRC) Committee on the Remediation of Buried and Tank Wastes suggested that typical institutional controls include easements, deed notifications, zoning, permit programs, access controls, government ownership and lease restrictions (NRC, 2000). Edwards (1997) presents a legal interpretation and subsequently divides the most commonly used controls into eight categories. The eight categories are deed restrictions, use restrictions, access controls, compliance monitoring, notice, registry requirements, transfer requirements and zoning. The USEPA recognizes four categories of institutional controls. These are governmental controls, proprietary controls, enforcement and permit controls and informational devices (Bellot, 2003b; Edwards, 2003a). The interpretation presented by Breggin et al. (1998) categorizes institutional controls into three categories: regulatory controls, property-based controls and notice provisions.

For the purposes of this review, the mechanisms for establishing institutional controls will be classified into three primary mechanisms: government controls, property-based controls and public notice (DERTF, 1996; Pendergrass, 1999).

Government Controls

Local, state and federal authorities can establish a variety of controls, which are regulatory in nature. Clancy-Hepburn et al. (1995), Edwards and North (1997), Breggin et al. (1998), English and Inerfeld (1999), Pendergrass (1999), Edwards (2000) and Edwards (2003) provide detailed descriptions of various types of government controls. Of particular interest are zoning, ordinances, orders and decrees and permit systems.

Zoning is the most common mechanism for controlling land use (Borinsky, 1995; Gaspar and Burik, 1998). Although this mechanism is governed by state law, implementation is performed at the local government level by counties or municipalities (Pendergrass, 1999). This mechanism involves the creation of “use” districts (i.e., zones). Appropriate and inappropriate uses are then tied to the land in accordance with these districts/zones. The implementation of zoning laws varies considerably across the country. Exclusionary, cumulative and contract zoning are but a few of the different types of zoning mechanisms being practiced (Clancy-Hepburn et al., 1995). It is important to recognize that zoning laws, however, are not static. Zoning boards, influenced by local and regional pressures, have the authority to change zoning districts and requirements as well as issue variances and exceptions.

Ordinances are legislative acts (laws) generally passed at the local and state levels of government (county, city or state). These governmental bodies use ordinances to establish minimum management requirements and controls that are deemed necessary to protect and safeguard the general health, safety and welfare of the public.

An ordinance of particular interest to residual waste management is state land protection controls. These types of controls refer to state legislation that is enacted to control land use activity. State land protection controls are a means of shifting the enforceability of land use controls from property law to common law, which some believe to be more consistent with long-term land use restrictions (Edwards, 2003a; NCCUSL, 2003; Strasser and Breetz, 2003).

The term “Orders and Decrees” is used in this research to encompass the legally binding agreements (e.g., USEPA Administrative Orders) issued by regulators and other governmental requirements (e.g., Federal Departmental Orders) as well as judicial decrees (e.g., court decisions). These agreements describe actions that must be taken. With regard to residual contaminants, these orders and decrees define the requirements for continued environmental protection.

Permits are another institutional mechanism employed at local and state government levels to control land use activity. Permit requests trigger the review and approval of the governmental permitting authority (Edwards, 2003c). This type of control is routinely used to manage site development and often involves excavation permits, building permits and groundwater-use permits (USDOE, 2000a).

Property-based Controls

Common-law property-based controls, also referred to as proprietary controls, serve as a second mechanism for limiting land use. Such methods often involve restrictions or limitations on a property created in the conveyance of the property from one party to another (DERTF, 1996; Edwards and North, 1997; Breggin et al., 1998; Pendergrass, 1999). Property-based controls can be described in terms of deed restrictions, contractual mechanisms and continued government ownership.

Although not a true legal term, deed restrictions generally refers to covenants, servitudes and easements that are placed in a deed to control future land use at that property (Clancy-Hepburn et al., 1995). Covenants are promises made by one landowner to a subsequent landowner in connection with the conveyance of property (USEPA, 2004c). Servitudes are burdens placed on a property for the benefit of another. Easements are rights conveyed by one property owner to another party with regard to the first party's land (USEPA, 2004i).

Deed restrictions serve as the most common property-based control for sites with residual contaminants. This is in part due to the provisions of CERCLA, Section 120(h)(3)(C), which deals with the transfer of real property. It requires that a federal agency transferring real property to a non-federal entity include a covenant in the deed of transfer warranting that all remedial action necessary to protect human health and the environment has been taken prior to the date of the transfer with respect to any hazardous substance remaining on the property. This provision also requires that the remedy, including institutional controls, is operating properly and successfully (CERCLA 1994).

Private parties can also make contractual arrangements to restrict land use. This form of institutional control is enforceable by and restrictive of only the parties involved in the contract. Third parties, including state, federal and local governments, if not party to the contract, cannot intervene (Edwards, 2003c).

In addition to the aforementioned property-based controls, several authors have suggested that continued government ownership of sites with residual hazards be included as a viable property-based institutional control (Applegate and Dycus, 1998; English and Inerfeld, 1999; NRC, 2000). Presumably this mechanism would minimize the likelihood of property transfer and thereby reduce the probability of inappropriate future uses.

Public Notice

The dissemination of information (e.g., public notice) is a third category of institutional controls. This mechanism is useful for maintaining a viable knowledge basis (e.g., information management) and for informing the general public and interested stakeholders with regard to the condition of a site containing residual contamination. Public notice fosters continued diligence, which will be necessary for sites with long-term use and activity restrictions.

A primary objective of using notices as an institutional control is to inform people of the potential hazards so that their behavior is positively influenced. Notices can be provided in a variety of manners to satisfy site-specific requirements. For example, a notice could involve disclosure via deed notices, deed restrictions or covenants within land records during the time of property transfer, broad public publication (e.g., Federal Register), listing of contaminated sites within a state registry and on-site signage

(Breggin et al., 1998; Pendergrass, 1999; ASTM, 2000b).

Funding Mechanisms

A variety of funding mechanisms may be used to cover the costs associated with the implementation of institutional controls. Uncertainty remains, however, concerning the timing and magnitude of implementation costs (USGAO, 1990; ASTSWMO, 1997). Potential funding mechanisms include governmental appropriations, government corporations, special-purpose public authorities, public-private partnerships, insurance instruments and trust funds (Maurer, 2003). Government appropriations, insurance instruments and trust funds appear to be the most widely used funding mechanisms.

Government appropriations serve as the predominant funding mechanism for the federal implementation of institution controls. U.S. Congressional action is required for the expenditure of all federal funding. These actions include congressional approval in terms of federal authorizations as well as federal appropriations and are required annually. Similar actions are conducted for state-level appropriations.

The private sector is investigating alternative funding mechanisms for non-federal facilities. For example, the environmental insurance industry is responding to the risk of institutional control failure by offering pollution legal liability (PLL) insurance (Maurer, 2003). These insurance policies cover client costs associated with environmental damage resulting from the emission, discharge, release or escape of contaminants.

Trust funds are being investigated for both federal and non-federal facilities. Bauer and Probst (2000) have provided a review of trust funds for financing the oversight and management of contaminated sites. Trust funds offer several advantages. One advantage that trust funds offer is that they separate the benefits of owning property from the burdens of maintaining it (e.g., beneficiaries and trustees). A second advantage is that the legal framework is well defined for trust funds. This framework includes procedures for allocating economic assets as well as enforceable rules for how, and by whom, the assets will be managed (Bauer and Probst, 2000). A disadvantage of federal trust funds is that the federal government can unilaterally change the terms of administration for the trust.

Several variations of trust funds have been reported through the literature. These examples include the Industri-Plex Custodial Trust (Wernstedt and Probst, 1997), the Pennsylvania Guardian Trust (PaDEP, 2002; Alper and Reshen, 2003) and the Tennessee Perpetual Care Trust (Brown, 1999).

Trust funds vary considerably because the mission, objectives and scope of individual Trusts are routinely established to satisfy site-specific requirements. For example, the Industri-Plex Custodial Trust had a focus towards site re-use (Wernstedt and Probst, 1997). The Pennsylvania Guardian Trust was established to investigate the use of a not-for-profit, public/private entity for managing of post-remediation obligations (Alper and Reshen, 2003). The Tennessee Perpetual Care Trust focused on the long-term maintenance and monitoring costs associated with the Oak Ridge Reservation's Environmental Management Waste Management Facility only and does not have provisions if the facility has a release (Brown, 1999). Due to the limited experience represented by these trusts, their long-term viability is inconclusive at this time.

Legal Considerations for the Institutional Control of Residual Hazards

The federal government, states, municipalities and private entities face significant environmental challenges associated with the remediation and post-remediation management of residual waste sites. These challenges represent long-term institutional management obligations. The fulfillment of these obligations involves the coupling of acceptable remedies, long-term controls consistent with desired land use and performance monitoring (Finger, 1997).

In recognition of such obligations, the U.S. federal government has enacted key environmental legislation to specifically "protect human health and safeguard the natural environment — air, water and land — upon which life depends" (CERCLA 1994).

CERCLA

CERCLA, commonly known as Superfund, was enacted on December 11, 1980 (GI, 2001; CERCLA 1994). CERCLA establishes the framework for the federal response to the release of hazardous substances that endanger public health or the environment. An amendment to CERCLA, the Superfund Amendments and Reauthorization Act (SARA), was approved on October 17, 1986. SARA incorporated experience obtained in the administration of the Superfund program during its first six years. In addition, the Emergency Planning and Community Right to Know Act (EPCRA) was also passed on October 17, 1986. The purpose of EPCRA was to encourage emergency planning as well as provide the public and local governments with information concerning potential chemical hazards present in their communities.

CERCLA established a process for determining how best to remediate abandoned, hazardous waste sites (USEPA, 1989). The first step of the process involves a preliminary site screening (i.e., scoring of potential hazards). If a site scores sufficiently high, it is listed on the National Priorities List (NPL). NPL sites then proceed through a process known as the Remedial Investigation and Feasibility Study (RI/FS) process. Each step of the RI/FS process improves the definition of the contaminants of concern and identifies the best remediation alternatives. The Remedial Investigation stage defines the extent of the contamination and develops preliminary baseline risk assessments. The Feasibility Study stage focuses on alternative treatments based on the contaminants of concern. The Record of Decision (ROD) formally documents the selected remedy and estimates the magnitude of residual risk remaining (CERCLA 1994).

Although CERCLA baseline risk assessments consider risk in the absence of any institutional controls, it is important to consider the estimated risks associated with residual waste sites with institutional controls in accordance with projected land uses as well as the risk when institutional controls are removed (White et al., 1993).

The USEPA defines institutional controls as non-engineered instruments such as administrative and/or legal controls that minimize the potential for human exposure to contamination by limiting land or resource use (USEPA, 2000). The USEPA specifically excludes access controls, fences and physical barriers in its definition of institutional controls.

CERCLA establishes several key requirements with regard to the implementation of institutional controls for managing residual contaminants. First, CERCLA stresses the importance of permanent remedies and treatment technologies in cleaning up hazardous waste sites rather than the containment or removal of contaminants.

While institutional controls alone are not to be selected simply as a substitute for a more permanent engineered control (CERCLA 1994), institutional controls can and are continuing to play a substantial role in many final remedies. For example, an informal survey of USEPA Record of Decisions (RODs) (USEPA, 2003d) found that institutional controls were part of approximately 68% of all final remedies. Similarly, the Association of State and Territorial Solid Waste Management Officials (ASTSWMO) found that approximately 70% of remedies employed at non-NPL sites from 1993 to 1997 included some form of institutional control (ASTSWMO, 1998).

CERCLA also provides requirements with regard to state responsibilities. In accordance with CERCLA section 104(c)(3)(A), the state must provide its assurance to assume responsibility for operation and maintenance of implemented remedial actions for the expected life of such actions. This includes the state's assurance that any institutional controls implemented as part of the remedial action at a site are in-place, are reliable and will remain in-place after the initiation of the operating and maintenance phase (CERCLA 1994). To ensure that the final remedy remains effective, the USEPA also requires that a review be conducted every five years for those sites where contamination/waste has been left on site at levels that require limited use and restricted exposure (USEPA, 2001b).

One potential deficiency in the CERCLA process could arise when institutional controls are not explicitly defined in the ROD. As discussed by Breggin et al. (1999), the USEPA does not have legal authority to require public participation post-ROD. Therefore, if the selection of specific institutional controls is deferred until that time, community involvement could be limited for a major portion of the remedy selection.

RCRA

The U.S. Congress enacted the Resources Conservation and Recovery Act (RCRA) in 1976 (RCRA 1976). RCRA facilities are typically industrial properties and this law focuses on wastes that are actively managed, while CERCLA focuses on properties that were commonly abandoned contaminated sites. RCRA, similar to CERCLA, has the primary objective of maintaining human health and safety. RCRA, however, differs from CERCLA in several ways.

RCRA was primarily established to minimize future pollution that could result from solid waste landfills and to take a more prescriptive approach in its legislation. By specifically defining “hazardous” waste and associated contaminants of concern, RCRA’s approach serves as an incentive for manufacturers, transporters and users of these products and materials to self regulate themselves and thereby reduce the quantity of these materials. Second, RCRA is technology-specific and defines acceptable treatment technology for various waste stream applications such as RCRA-specific designs for landfill covers.

Despite this more prescriptive approach, RCRA language is more vague with regard to institutional controls (USDOE, 2000a). Although RCRA is not specific in defining the use of institutional controls, the USEPA interpretation of the regulations are intended to be consistent with CERCLA (Bellot, 2003b). As such, institutional controls are not intended to be the sole remedy but rather they should complement engineered barriers (USEPA, 2000). Their implementation, however, can vary substantially from state to state as RCRA is a state-delegated program (USEPA, 2002c).

Brownfields

The "Small Business Liability Relief and Brownfields Revitalization Act" was signed into law January 11, 2002 (USEPA, 2002d). This legislation defines Brownfields as abandoned, idle or under-utilized industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination (USEPA, 2002a).

Brownfields sites continue to gain increased attention within the USEPA and the states. At many of these sites, contaminants and associated hazards remain after environmental remediation is completed because cleanup levels are related to projected future land use. For example, if sites are projected for industrial use the cleanup levels could be less stringent than for unrestricted-use sites, e.g., cleanup to an industrial-use standard rather than a residential-use standard.

Residual contaminants are wastes left in-place or disposed of on-site as well as residual contamination of soils, facilities, surface water and groundwater. Brownfields sites could therefore require monitoring, inspections and other institutional controls. Two critical issues have been identified with regard to the use of institutional controls at Brownfields sites. These concerns include public awareness and acceptance of the institutional controls as well as the long-term effectiveness of selected institutional controls (McTiernan, 2000)

Guidance for Institutional Control Implementation

To improve the effectiveness and implementation of institutional controls, various guidance documents have been developed. These guides have been produced for various applications and by various organizations including federal and state governments.

Federal Guidance

Institutional controls for managing residual contaminants are allowable tools under a variety of federal statutes including 10-CFR-61, CERCLA, RCRA and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP). As such, the responsible federal organization has issued guidance for their implementation.

The USEPA has issued guidance, directed toward site managers, for the implementation of CERCLA and RCRA Corrective Actions (USEPA, 2000). This guidance is also applicable to interested stakeholders and the regulated community. The USEPA recognizes institutional controls as a vital part of the decision process for the management of residual contaminants. Appropriate institutional controls are believed to improve the protectiveness of the final remedy, although the enforceability of institutional controls remains a question (Edwards, 2000b).

The U.S. Nuclear Regulatory Commission (USNRC) is responsible for regulating nuclear materials and facilities. USNRC responsibilities include establishing standards for protection against radiation (10-CFR-20, 1991) as well as licensing land disposal facilities for low-level radioactive waste (10-CFR-61, 1982). Regulations require the landowner or custodial agent to implement an institutional control program to restrict physical access to a disposal site. Such a program should include environmental monitoring, periodic surveillance, custodial care and administration of appropriate funding to carry out these institutional controls (10-CFR-61, 1982). The USNRC requires that licensees demonstrate the adequacy of institutional controls with regard to site decommissioning leading to USNRC license termination (USNRC, 2002). As part of the license termination process, USNRC staff review and verify detailed information concerning the proposed institutional controls (USNRC, 2002; USNRC, 2003b; USNRC, 2004).

Similarly, the USDOD has issued a guide for the establishment of institutional controls at military installations being closed (USDOD, 1998). This guide is relevant to various types of military facilities including Base Realignment and Closure (BRAC) sites, Formerly Used Defense Sites (FUDS) and Formerly Utilized Sites Remedial Action Program (FUSRAP) sites (USDOD, 2000a). This guidance, consistent with and reliant on CERCLA, suggests two common situations in which institutional controls can play an important role. Institutional controls may be appropriate to protect the integrity of engineered controls. Second, institutional controls may be necessary to limit the exposure of individuals to residual contamination by limiting reuse activities. In addition, this guide suggests that if institutional controls are to be used as part of the final remedy action, early stakeholder involvement and concurrence could improve the effectiveness of the controls (USDOD, 1998).

Security has always been one of the concerns associated with the management of residual contaminants. The use of institutional controls has received increased attention in the past several years. FEMA has recently developed additional guidance for integrating human-caused hazards into mitigation planning (FEMA, 2002b; FEMA, 2002a). These new security threats add an additional challenge with regard to maintaining the long-term effectiveness of institutional controls at sites with residual hazards.

State Guidance

In addition to the federal guidance, states are also developing guidance for the implementation of institutional controls. The Environmental Law Institute (ELI) has conducted several studies regarding the use of institutional controls by state regulatory agencies. ELI reported that as of 2002, 43 states rely on some form of institutional controls to manage sites with residual contaminants (Pendergrass, 2003). However, only 26 states have specific state statutory authority involving various aspects of institutional controls.

An example is the State of Oregon whose Department of Environmental Quality, Waste Management and Cleanup Division has produced guidance for its organization's implementation of institutional controls (Christensen et al., 1998). This guide provides useful descriptions of the types of institutional controls that the State of Oregon utilizes as well as discussions of the advantages and disadvantages of each. In addition, this guide suggests that institutional controls not only restrict uses but could also at times require an affirmative action such as monitoring and remedy review (Christensen et al., 1998).

The State of Colorado passed Senate Bill 145 in 2001. This legislation provides the Colorado Department of Public Health and the Environment with the legal authority to establish and enforce environmental covenants (Miller, 2003). Through the passage of this legislation, the state overcame the uncertainties associated with enforcing common property law covenants and ensured that the state regulators have the enforcement mechanism required to compel compliance (Miller, 2003).

The State of Florida has also taken an aggressive role in formulating state statutory guidance for institutional controls (FLDEP, 2002). This guidance recommends enforcement actions if the following occur: a.) the restrictive covenant or conservation easement has been violated; b.) the restrictive covenant or conservation easement has been improperly removed; c.) local government repeals an institutional control ordinance; d.) ownership of the property has changed; and e.) any time that the restrictions are not protecting human health or the environment. In addition, the state maintains a registry of sites with institutional controls (FLDEP, 2003b).

Uniform Environmental Covenant Act

A number of deficiencies have been reported with regard to the implementation of institutional controls at hazardous waste sites (Edwards, 2000a; Edwards, 2003b). These deficiencies include lack of notice, implementation, monitoring and enforcement (Gaspar and Burik, 1998; Hocking and Martino, 2003; Hocking and Martino, 2004). The question of enforcement of institutional controls appears centered on two important themes. One concern is grounded in the legal review of common property law and the second concern deals with the reliability of government administration with regard to environmental protection (NRC, 2000; Edwards, 2003a; Miller, 2003).

Several national efforts are attempting to standardize the implementation of institutional controls to overcome these deficiencies. The American Society for Testing and Materials (ASTM) has established a Standard Guide for the use of institutional controls (Edwards, 1997). This Guide was developed in part because of these varying views of institutional controls as well as due to concerns raised about the long-term effectiveness of institutional controls. Within this Guide the ASTM describes institutional controls as *legal or administrative restrictions on the use of, or access to a site or facility*

(ASTM, 2000b).

The National Conference of Commissioners on Uniform State Laws has approved the Uniform Environmental Covenant Act (UECA) in an attempt to eliminate many of the common law impediments associated with the implementation of institutional controls (NCCUSL, 2003). The language of this act attempts to improve the implementation of environmental servitudes among the various state jurisdictions by reducing uncertainty and transaction costs (Strasser, ; Strasser and Breetz, 2003).

Performance Evaluation of Institutional Controls

As discussed previously, various types of institutional controls have been implemented for a variety of purposes. The use of institutional controls for the management of residual contaminants is one such application. The effectiveness of institutional controls for this specific application is of particular concern due to the nature of the contaminants and the duration of the hazards. Several studies have attempted to evaluate the effectiveness of institutional controls with regard to the management of residual hazards.

Surveys

The ASTSWMO surveyed states in 1997 to determine to what extent institutional controls have been used nationally (ASTSWMO, 1997). Forty-two states responded to the survey, which showed that the use of institutional controls was a required part of the remedy in 31 states when the final remedy resulted in a restricted use classification. The factors influencing the selection and implementation of institutional controls were found to be: cost, proximity of human and environmental targets, technical impracticality and anticipated future land use.

Although the majority of responding states implement institutional controls under their own statutes, rules, and health codes, local public officials are the primary agents monitoring and maintaining the institutional controls through land use zoning and local ordinances. As a result, the vast majority of institutional control-related information is managed, maintained and controlled via local property records in the form of deed restrictions or deed notices. Local ordinances, zoning and building permit records as well as local health department records and well permit records are also areas where institutional control information is managed and maintained. With regard to the effectiveness of the selected institutional controls, most states indicated that they have not been used long enough to determine whether these controls will be effective over the long term (ASTSWMO, 1997).

The International City/County Management Association (ICMA) also conducted a targeted survey in 1997 in part to determine what types of institutional controls local and state governments were employing at former hazardous waste sites (Gaspar and Burik, 1998). Results of the survey included responses received from 27 local governments from 16 different states. The study highlighted several areas of concern. For example, the study indicated that there was confusion among the respondents with regard to what level of government (i.e., local versus state) is responsible for implementation of the institutional controls. In addition, the findings indicated that 74% of local respondents did not have adequate experience implementing institutional controls despite the fact that the most common institutional controls were traditional zoning (56%), groundwater regulation (26%) and deed restrictions (19%). Finally, the enforcement of institutional controls was found to be minimal and primarily relied on institutional memory, citizen complaints and informal inspections.

The Northeast-Midwest Institute has also issued the results of their state-wide survey (Bartsch and Deane, 2002). Forty-one states provided responses to this survey that focused on state voluntary compliance and Brownfields programs. The results suggest that individual states view the use of institutional controls quite differently. Some states discourage the use of such controls within these programs while others have moved forward to strengthen their effectiveness by establishing statutory provisions for institutional controls (Edwards, 2003a).

Case Studies

A number of case studies have been documented in which the performance of institutional controls have been investigated (Lowrie and Greenberg, ; Mazurek and Hersh, 1997; Wernstedt and Hersh, 1997; Wernstedt and Probst, 1997; James M. McElfish et al., 1998; Lowrie and Greenberg, 1998). Resources for the Future (RFF) has completed several case studies that have specifically investigated the role that land use plays (Mazurek and Hersh, 1997; Wernstedt and Hersh, 1997; Wernstedt and Probst, 1997; Hersh et al., 2002). The ELI has also developed a number of case studies that have focused on the use of institutional controls (James M. McElfish et al., 1998; Pendergrass et al., 1999).

One of the ELI studies involved an analysis of the use of institutional controls at the Grand Junction Uranium Mill Tailings Remedial Action (UMTRA) project site (Pendergrass et al., 1999). This project involved the remediation of approximately 5000 properties in the Grand Junction, CO area. This case highlighted several issues that could influence the long-term effectiveness of institutional controls. Multiple federal and state programs were involved in this project and each of these programs had separate requirements and funding mechanisms. This lack of coordination was evident by a difference of opinions regarding near-term land use as well as unresolved regulatory issues (i.e., groundwater treatment at the Climax Site). This case also pointed out the importance of public perception. For example, participation in this program was voluntary and because the public viewed the process as wasteful and driven by the federal government, not all owners of contaminated properties participated in the remedial action project.

Assessments/Studies

English et al. (1997) provides a preliminary assessment of the public's acceptability of institutional controls. Although not definitive, this report suggests that characteristics of the site, contamination, technical remedy, surrounding area and social/political setting as well as the institutional control itself influence the public's acceptance of institutional controls (English et al., 1997). Institutional controls must be carefully designed and tailored to site-specific conditions if they are to produce the desired effects. Institutional controls must be appropriate, verifiable, enforceable, durable and flexible (i.e., adaptable to a variety of sites and surroundings) (English and Inerfeld, 1999).

The National Research Council (NRC) reported on the broader but related issue of long-term institutional management (LTIM) (NRC, 2000). The NRC defines LTIM as the ability, over long periods of time, to ensure that the public, worker health and safety and the environment are protected when potentially hazardous contaminants are left on sites. To achieve this protection, the NRC identified three basic measures: contaminant reduction, contaminant isolation and stewardship activities. For LTIM to remain effective, there should be the means to detect impending or actual failure and also the authority and will to require those responsible to correct the problem (NRC, 2000). The NRC suggests that LTIM programs contain the following characteristics: defense in depth, complementarity and consistency, foresight, accountability, transparency/ visibility, feasibility, stability through time, iteration and follow-through/flexibility.

The longevity and durability of institutional controls continues to be of significant concern (USGAO, 2005). An analysis of successes and deficiencies of CERCLA five-year reviews provides some insight into the role institutional controls could play in ensuring remedy protectiveness (Hocking and Martino, 2003; Hocking and Martino, 2004). This study noted that remedy deficiencies, as identified by CERCLA five-year reviews, fall into several categories: remedy technology, public acceptability and institutional controls. The institutional control deficiencies included examples of improper monitoring, improper information management, lack of notice, potential violations of use restrictions and lack of implementation (Hocking and Martino, 2003; Hocking and Martino, 2004).

The National Environmental Policy Institute (NEPI) has provided an analysis of the related concept of stewardship (NEPI, 1999). NEPI defines stewardship as *a systematic means of ensuring that future decision-makers concerned with the safety and protection, conditions of use, and potential further cleanup of sites with residual or long-*

term contamination have the proper knowledge, awareness and tools passed on from previous generations of site decision-makers to make informed decisions about site management. As such, the long-term effectiveness of institutional controls is a critical component of stewardship.

Lowrie et al. (2003) suggests that for stewardship efforts to be effective it should: 1) be incorporated into the mission of the responsible organization, 2) involve local communities and stakeholders, 3) involve redundant safety systems and techniques, 4) remain flexible and innovative, and 5) identify and obtain stable financial resources to fulfill its obligations (Lowrie et al., 2003).

Because of uncertainties associated with the long-term viability of institutional controls the concept of "Rolling Stewardship" has been suggested (NEPI, 1999; Russell, 2000). Rolling stewardship builds on the concept of stewardship by focusing on the links needed between generations. For example, although current generations cannot determine the actions future generations will take, current generations could ensure that the future generations are aware of residual contamination and are provided the proper tools to make sound management decisions.

The concept of rolling stewardship appears to be a viable management approach that shows promise with regard to strengthening the long-term performance of institutional controls. This approach focuses on ensuring that the knowledge, tools and infrastructure are in place to empower the future decision-makers. Rather than assuming perpetual guarantees, usually associated with the concept of CERCLA, rolling stewardship asks "will the solution remain viable for a generation?" rather than "will the solution remain viable for the next millennium and beyond?" (NEPI, 1999).

The issue of stewardship is central to many of the USDOE sites currently undergoing remediation and "closure." As such, local citizens groups at these sites are working to influence the conditions the sites will be left in and identify the post-remediation obligations. The Rocky Flats Stewardship Working Group has developed a "Toolbox" that aids in the planning of long-term stewardship. This toolbox provides a process for identifying the requirements for site stewardship and provides a framework for considering detailed issues (RFSWG, 2002).

Findings and Summary

The described literature review has shown that institutional controls are commonly used practices for preservation purposes, use restriction and information dissemination. Institutional controls are routine elements of federal, state and local operations. Various types of operations make use of institutional controls including historical and cultural preservation, utility protection, ecological preservation, floodplain management, groundwater protection and waste management.

The management of residual contaminants requires multiple controls. Engineered controls are practices that modify the physical environment and the residual hazards. Institutional controls are practices designed to modify human behavior. A combination of both types of controls improves the likelihood that residual contaminants will remain isolated from potential receptors. This concept, referred to as *layering* and *defense-in-depth*, is advocated by numerous studies (USDOD, 1998; NRC, 2000; USEPA, 2000).

As noted, numerous studies have shown that the use of institutional controls for residual waste management applications is becoming an increasingly significant element in selected remedies (ASTSWMO, 1997; ASTSWMO, 1998; Gaspar and Burik, 1998). Final remedies that include institutional controls establish obligations for and responsibilities of future generations (English and Inerfeld, 1999). As such, current generations need to act appropriately as trustees and stewards with regard to present resources on behalf of future generations (Finger, 1997; STGWG, 1999).

The long-term performance of institutional controls, however, remains an open question. Studies have highlighted deficiencies and failures of institutional controls (English et al., 1997; Hocking and Martino, 2004). Monitoring and enforcement measures are critical if institutional controls are to remain effective and durable over the long-term (DERTF, 1996). Affirmative action, including broad and periodic notice, will be needed to ensure that information regarding residual contaminants is readily available to multi-generational stakeholders. Coordination of institutional controls is complicated because of multi-organizational involvement. If responsibilities and authority are not clearly defined then management conditions will likely worsen over time and will impact maintenance and enforcement efforts.

The legal authority required to maintain and enforce institutional controls is not always clearly defined (Borinsky, 1995; Edwards, 2000b; Edwards, 2000a; PaDEP, 2002). The government's enforcement ability depends on various statutory and regulatory requirements. For institutional controls, such as deed restrictions, to remain effective and enforceable, they need to be incorporated into state statutory law (English and Inerfeld, 1999; Miller, 2003).

The results of this literature review begin to illustrate the deficiencies associated with the implementation of institutional controls. Deficiencies, expressed in terms of their potential effectiveness and enforceability, have been noted. This research will add to this body of literature by investigating how and why institutional controls could fail. This research will use a series of case studies to further investigate how institutional controls are currently being implemented. Then a failure analysis will be conducted of these sites to better understand how and why failures occur. The final stage of this analysis will investigate if monitoring and mitigation methods can make the systems more robust and thus less prone to failure.

CHAPTER IV

RESEARCH METHODOLOGY

Introduction

The selected research methodology uses a multiple case study design to investigate the complex dynamics of long-term contaminant isolation. Case studies when selected, as a research approach, have been shown by Yin and others to be a valuable research methodology (Eisenhardt, 1989; Eisenhardt, 1991; Yin, 1994; Audet and d'Ambiose, 2001). The case study approach offers several advantages over other research techniques. Specific to this research, the key advantages are that case studies:

- Provide insight into the dynamics of a complex situation,
- Successfully tackle questions of "why" and "how,"
- Provide the investigator the ability to retain a holistic view of individual cases yet the flexibility to explore embedded units of analysis across cases, and
- Provides an all-inclusive approach including both quantitative and qualitative evidence.

The case study approach represents a form of empirical inquiry. While case studies do not represent a sample of a population, they are useful in expanding and generalizing a theory (Yin, 1994). As such, selected case studies are used to extract valuable insights into why some residual contaminant isolation practices have succeeded and why others have failed.

Case Study Approach

Figure 5 illustrates the case study development process used throughout this research. As illustrated, this research approach involves six distinct steps. The details associated with the research hypothesis (Step 1) were presented in Chapter I. The details associated with the remaining five research steps are discussed further in this chapter.

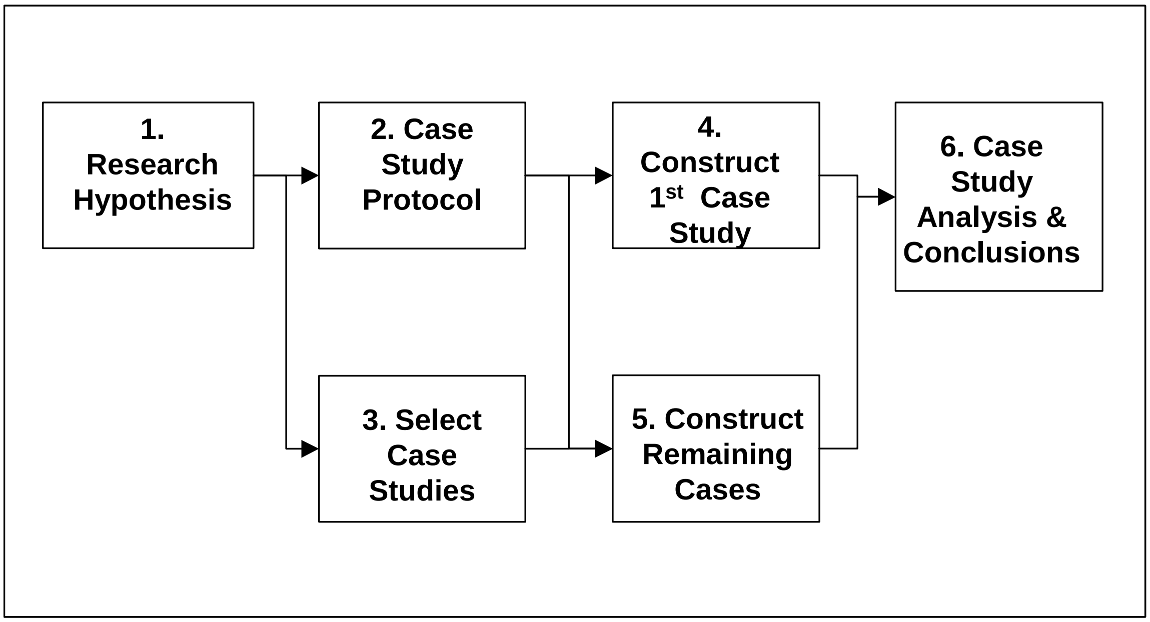

Figure 5. Diagram showing the case study development process used for this research.

Case Study Protocol

The case study research approach is an iterative process. The second step of this process involves the development of a case study protocol. The protocol serves as a guide throughout this research by identifying and refining key research questions as well as describing the data collection, management and evaluation tasks.

The following key questions were considered throughout this research effort and associated theories were continually refined. Considerations included:

Why does system failure occur?

- What aspect or aspects of the system actually fail?
- Are there precursors to failure?
- Is system failure imminent? If so, is it detectible?
- What are the consequences resulting from system failure?

How do institutional controls influence system performance?

- Is the loss of one control key to system failure or is there an accumulation of minor failures that form a critical mass?
- Does "decision irreversibility" occur?
- Is there adequate recovery time after making "wrong" decisions?

How do long-term planning assumptions subsequently influence system performance?

- What were the long-term planning assumptions?
- Are they valid and similar for all cases?

How do institutions (i.e., organizations) implement contaminant isolation systems?

- What is the role and durability of the institution?
- How does institutional mission influence institutional performance?
- Are there distinguishing factors between different types of institutions (i.e., federal, state, local, private)?

How have current practices captured lessons learned from historic practices?

- How do current decision networks compare to historic decision networks?
- Are there specific decision pathways that lead to failure?
- Are there redundancies built into the system?

Data Collection

A considerable amount of information was required to understand the circumstances of each selected case and to adequately represent these conditions in the case study reports. To aid in this effort, the protocol included a data collection checklist. The checklist consisted of two parts. Part A, shown in Table 1, includes a discussion of the characteristics of each site. Important site characteristics include environmental, waste, societal, regulatory and contaminant isolation facility characteristics. Part B, shown in Table 2, includes a discussion of how important management functions and activities were employed at each selected site.

Table 1. Case Study Checklist Part A, Site Characteristics.

Site Characteristics		Comments
Background		
Environmental Characteristics		
	Annual Precipitation	
	Surface Waters	
	Aquifer/Groundwater	
	Biological Indicators	
	Annual Freeze/Thaw Cycles	
	Ecosystem “Value”	
	Size	
	Site Geology	
Waste Characteristics		
	Primary Contaminants of Concern	
	Primary Exposure Routes	
	Primary Risk	
Societal Characteristics		
	Population Density within 1 mi. and 10 mi.	
	Demographic Pattern	
	Current Regional Land Use	
	Historic Regional Land Use	
	Current Site Land Use	
	Potential Alternative Land Use(s)	
Regulatory Characteristics		
	Principle Regulation	
	Current Land Owner	
	Land Transfers	
	Former Land Owner(s)	
	Potentially Responsible Parties	
System Characteristics		
	Engineered Barriers Description	
	Institutional Controls Description	
	Date of Site Closure	
	State of Practice at that time	
	Repair Actions to Date	
Graphics		
	Photographs	
	Maps	
	Timeline	

Table 2. Case Study Checklist Part B, Functions and Activities.

Functions	Activities	Comments
Maintain the Engineered Contaminant Control System		
	Verify Engineered System Construction (i.e., QA/QC)	
	Establish System Monitoring Plan	
	Perform System Monitoring (i.e., after release or integrated system)	
	Analyze and Report Data (i.e., monthly, quarterly, annually)	
	Maintain Active Processes (pump & treat, biorem, etc.)	
	Conduct Active Repairs	
Monitor the Environment & Ecosystem		
	Define Environmental, Ecological & Bioindicators	
	Establish Monitoring Plan	
	Perform Active Monitoring	
	Analyze and Report Data	
Maintain Site Security		
	Establish Security Plan	
	Maintain Security Mechanisms (i.e., Access Controls)	
	Detect Security Violations	
	Deter Security Violations	
Enforce Legal Controls		
	Define Legal Responsibility (i.e., local, state, fed, multiple)	
	Establish Property-based Controls (i.e., Real Estate Provisions, easements, covenants, restrictions)	
	Maintain Reporting Requirements	
Maintain Financial Security		
	Establish Financial Requirements (for monitoring, repair, replace, emergency actions, etc.)	
	Establish Funding Mechanisms (insurance, tax, trust, etc.)	
	Maintain Funding (i.e., long-term financial security)	
Maintain Community Awareness		
	Identify Site Stakeholders	
	Establish Community Awareness Program	
	Define Community Awareness procedures and schedule	
	Maintain Community Awareness Program	
Perform Information Management		
	Define Information Users	
	Define Information Requirements	
	Establish Information Management System	
	Integrate All Monitoring and Other Relevant Data	
	Maintain Information Management System	
	Maintain Data Current with Information Technology Platforms	
Perform Emergency Actions		
	Establish Emergency Preparedness Plans	
	Obtain Emergency Response Equipment	
	Train Emergency Response Teams	
	Maintain Emergency Response Equipment & Team	
Continuous Improvement of System Operations		
	Integrate All Residual Hazards Management System Functions	
	Define Best Available Technology	
	Analyze Cost-Effectiveness of Repair versus Replace versus Re-remediate	

This research uses various sources of information to obtain the details necessary to populate the developed tables, including published documentation, archival records, personal interviews and direct field observations. The data collection process was performed in three phases: Phase 1 – Historical Data, Phase 2 – Site Visits, and Phase 3 – Data Checklist Completion. This process was completed for each individual case selected for this research.

The initial phase of data collection included obtaining electronic sources of information to establish a general understanding of the critical factors involved at the selected site. Obtained sources included site-specific as well as government internet sites, journal publications and electronic news media sources. This information served to establish the initial foundation for each of the cases.

The second phase of data collection involved a more thorough investigation to provide greater understanding of the site and its surrounding environment. Site visits were scheduled and conducted for all selected case studies. Site visits provided a unique perspective and added substantially to the case study development. Site photographs taken during site visits documented the current condition of each site. Copies of original "source" records obtained helped establish key facts associated with each case. Personal interviews and discussions with site representatives provided important insights that were not always evident in other sources.

The third phase of the data collection process involved data checklist completion and data verification. The primary focus of this phase was ensuring data completeness and accuracy of the datasets. Follow-up discussions with site representatives were important in clarifying key issues and obtaining additional documentation.

Data Management

Information obtained during the data collection process was organized and maintained to ensure accuracy and consistency throughout the project. To aid in the data collection process, as well as to support review of the evidence, the bibliographic database software *Endnote* was used. *EndNote* is a reference and image database (ResearchSoft, 2002). *Endnote,* Version 6, has expanded features, including graphics-management capabilities. It specializes in storing, managing and searching reference libraries.

Data Evaluation

The data and information collected from multiple sources were correlated to help establish the facts associated with each case. Source documents offered the strongest evidence of how past events actually occurred. When source documents were unavailable, multiple sources of corroborative information were obtained to validate site events.

Individual Case Study Reports

Case study reports present the facts associated with each selected case and are presented in Chapter V. These reports identify the key factors influencing the success and failures of the individual contaminant isolation systems. A chronological timeline of the major events associated with each of the sites is included. Each case study report presents the observations and findings of each case as well as historic and current photographs.

Cross-Case Conclusions

A cross-case evaluation of all selected case studies is presented at the end of Chapter V. This analysis highlights the similarities and differences between the individual cases. Through this cross-case comparison (i.e., similar cases or similar units of analysis), key patterns are identified.

Fault Tree Analysis

Chapter VI expands on the cross-case conclusions with a discussion of the potential error pathways that could lead to system failure. Several different analytical techniques were evaluated for conducting this analysis. Influence diagrams were evaluated but the technique was found to be too general for this analysis. Event trees and decision trees were also considered but these techniques were found to be too site-specific. Fault tree analysis (FTA) is an analytical technique that describes the collection of events that must occur to explain a described state of a system. FTA was selected for this analysis because it could best utilize the information from the individual cases as well as from the cross-case observations.

The FTA process is initiated by first defining an undesired state of the system. An analysis of the details of the system is then performed to determine logical ways in which the undesired event could occur (Vesely et al., 1981). In this manner, FTA is a useful tool in clarifying how undesired events can occur and, likewise, how mitigation efforts can reduce system failure.

For the purposes of this research, FTA provides a graphical means of displaying the qualitative information included in the case studies. Chapter VI presents this FTA for the selected case studies associated with this research.

Case Study Selection

Selection Criteria

Case studies applicable to this research involve sites containing a variety of on-site residual contaminants, such as radioactive waste, hazardous materials, chemical munitions, etc. The case study selection criteria for this research consisted of the following:

- Operations/Remedial Action phase completed,
- Known, persistent (i.e., half-lives greater than 100 years) contaminated materials remain on-site in the shallow subsurface (i.e., in the top 10 meters),
- Engineered and Institutional Controls are part of the remedial action,
- System performance information is available, and
- Regulatory structure is defined (e.g., CERCLA, UMTRCA).

CHAPTER V

CASE STUDY REPORTS

Selected Case Studies

The remediation of contaminated sites involves federal and non-federal properties as well as various regulatory drivers. A primary regulation governing the management of residual contaminants is CERCLA, as defined in Chapter III. This regulation addresses the remediation and subsequent management of both federal and non-federal properties. CERCLA-applicable sites were therefore a major source of potential case studies.

Additional case studies were selected from the Uranium Mill Tailings Radiation Control Act (UMTRCA) program. This program involved the containment of residual contaminants generated from the mining and milling of uranium ore. Sites associated with this program represent some of the earliest modern containment operations and thus provide insight into system performance within the current regulatory framework.

Seven sites were selected and investigated as case studies. These sites include:

- Anaconda/Old Works Superfund Site, Anaconda, MT
- Love Canal Chemical Waste Disposal Cell, Niagara Falls, NY
- Maxey Flats Low-level Waste (LLW) Disposal Cell, Hillsboro, KY
- Rocky Mountain Arsenal, Commerce City, CO
- Spring Valley Site, Spring Valley, Washington, D.C.
- Burrell UMTRCA Disposal Cell, Burrell, PA
- Canonsburg UMTRCA Disposal Cell, Canonsburg, PA.

Table 3 summarizes applicable regulations at each site. Included in Table 3 are the regulatory drivers for each case, the lead federal regulatory agency, the primary responsible party and the major regulatory actions that occurred for each site.

Table 3. Regulatory introduction for selected case studies.

Case	**Regulatory Driver**	**Federal Regulatory Agency**	**Primary Responsible Party**	**Regulatory Actions**
Anaconda	CERCLA	USEPA	ARCO	1987, 1991, & 1994 RODs
Love Canal	CERCLA	USEPA	Occidental	1985, 1988 & 1991 RODs
Maxey Flats	CERCLA	USEPA	USDOE	1991 ROD
Rocky Mountain Arsenal	CERCLA, RMANWRA	USEPA	USDOD	1995 & 1996 RODs
Spring Valley	CERCLA	USEPA	USDOD	Non-time Critical Removal Actions
Burrell	UMTRCA	USNRC	USDOE	1987 Cell completed
Canonsburg	UMTRCA	USNRC	USDOE	1985 Cell completed

The following sections of this chapter contain the individual reports for the selected case studies. Each report includes a summary of the historic events of each case, a chronological timeline of the major events, a summary of the contaminant isolation facility controls employed at each site and personal observations of the case, based on personal interviews with site representatives and visual inspections.

Anaconda/Old Works Case Study

Historical Events

The Anaconda Mineral Company (AMC) established the Anaconda/Old Works Smelter site in 1883. The site was established to process copper ore that was being mined in Butte, MT some 30 miles away (see Figure 6). The location of this site was selected because of the dependable water supply provided by Warm Springs Creek (USEPA, 1994c).

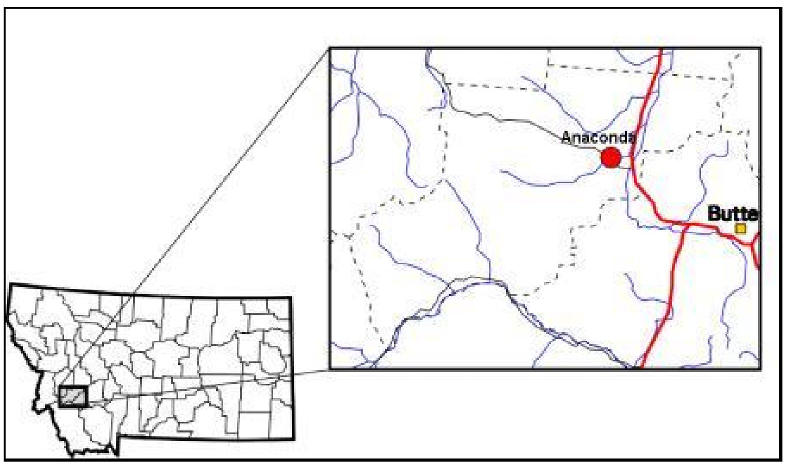

Figure 6. Map showing location of Anaconda site (USEPA, 2004a).

The site involves several specific operational areas. Construction of the Upper Works area took place from 1883 to 1884. In 1888, the Lower Works was constructed to expand the facility's processing capacity. The two Works operated in concert with two copper smelters. The smelters were connected to brick stacks atop adjacent hills by masonry flues (ARCO, 1993).

The Old Works and the two associated smelters operated from 1884 to 1901.

Operations focused on the processing of copper ore. The initial processing step involved separating out ore containing a copper concentration that was greater than 6%. Ore of this concentration was sent directly to the smelters and processed. Slag and flue ash were the residual wastes produced from this process. Ore containing a copper concentration less than 6% required additional pre-processing. This material was first crushed, segregated, concentrated and then processed in the smelters. These additional processing steps subsequently resulted in additional waste streams such as jig tailings, which were discharged onto the floodplain (ARCO, 1993).

Operations at the Old Works ended in 1901. The Old Works operations were replaced with a newer smelting operation, known as the Washoe Works (later known as the Anaconda Reduction Works). This facility was located across the valley from the Old Works and operated from 1902 through 1980 (see Figure 7).

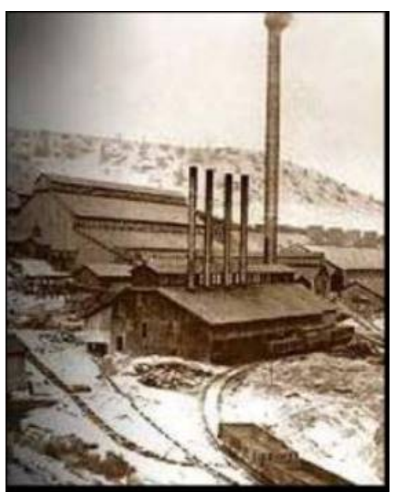

Figure 7. Historic photograph of the Anaconda smelter operations (Troon, 2004).

During the 1930s and 1940s, portions of the residual waste were reworked.

Portions of the waste piles were retrieved and reprocessed with advanced techniques. From 1940 to 1943, approximately 26 million pounds of copper and more than 1 million pounds of silver were retrieved from the reworking of a portion of the site known as the Red Sands area.

The Atlantic Richfield Company (ARCO) acquired the AMC in 1977. ARCO continued mineral processing operations at Anaconda until 1980.

In 1983, the USEPA placed the Anaconda site on the NPL, which initiated a series of site investigations. These investigations defined the Anaconda NPL site as an area encompassing approximately 300 square miles. The waste volumes associated with this site have been estimated to be approximately 230 million cubic yards of concentrated mine tailings, 30 million cubic yards of furnace slag, 500,000 cubic yards of flue dust, 20,000 acres of contaminated soil and millions of gallons of contaminated groundwater.

Because of its size and complexity, the Anaconda site was subdivided into 15 smaller, manageable Operable Units (OUs). One of the OUs, the Old Works/East Anaconda Development Area (OW/EADA), is the primary focus of this case study. While additional OUs have been and are currently being investigated and remediated, the final OU to be resolved will be the Anaconda Soils, Community Soils, and Regional Water and Wastes OU.

In October 1984, ARCO entered into an Administrative Order Consent and began to conduct a remedial investigation of the site. An expedited RI/FS was entered into in July 1986 for the Mill Creek portion of the site. Families with young children were temporarily relocated due to the elevated arsenic levels in soil. A 1987-ROD determined that permanent relocation was warranted. A second Administrative Order Consent was established in September 1988 for the Flue Dust and Smelter Hill OUs. A 1991-ROD was finalized for these sites. An Action Memorandum was signed in July 1991 for the Old Works area. This Action included stabilization of the Red Sands, repairs to Warm Springs Creek levees and access control fencing. The March 1994 ROD defined the remedial actions for the OW/EADA OU (USEPA, 1994c).

The OW/EADA OU encompasses approximately 1,300 acres. Approximately 1.4 million cubic yards of waste material (jig tailings, “heap roast” slag, Red Sands and other wastes) is associated with this OU. To support the remedial planning process, the OW/EADA OU was further divided into six subareas: the Old Works Structural area, the Heap Roast Slag and Waste Piles, the Warm Springs Creek floodplain, Red Sands, East Anaconda yard and the Drag Strip (ARCO, 1993).

Human health risks resulting from the site are associated with five chemicals: arsenic, cadmium, lead, zinc and copper (USEPA, 1994c). The historical release and transport mechanisms for these contaminants include discarded waste materials, aerial deposition from stack emissions, in situ leaching from waste material, fluvial erosion and redeposition of wastes and demolition of contaminated structures (ARCO, 1993; USEPA, 1994c). Since no humans live within the OU, and current and future land use was assumed to remain recreational and commercial, the potential receptor population was assumed to be recreational visitors and on-site workers (USEPA, 1994c). Given this scenario, the 1994-ROD determined that the most plausible routes of human exposure for this OU were direct ingestion of dust, soil or surface wastes, inhalation exposure to respirable particulate matter and ingestion of contaminants via groundwater. As such, the theoretical Reasonable Maximum Exposure cancer risk for on-site workers was determined to be greater than 1×10^{-4}, with the range being 2×10^{-5} to 4×10^{-4} (USEPA, 1994c).

The selected remedy for the OW/EADA OU requires both engineered and institutional controls. The engineered controls include:

- Construction of engineered covers over waste materials exceeding arsenic levels of 1000 parts per million (ppm) for areas designated as recreational and potentially commercial,
- Treatment of soils exceeding arsenic levels of 1000 ppm for areas designated as recreational and potentially commercial,
- Engineered covers or treatment of soils exceeding arsenic levels of 500 ppm in current commercial areas,
- Construction of surface controls to manage surface water runoff, and
- Repair and upgrades to the Warm Springs Creek levees.

Institutional controls selected for the OW/EADA OU are intended to assure that future land and water use is consistent with residual risks, preserve and maintain the remedial structures, assure that future construction be performed consistent with the remedial actions and ensure that future remediation be conducted as future development occurs (USEPA, 2001c).

To achieve these objectives four layers of institutional controls are planned for this OU (USEPA, 2001c). The first institutional control layer is the Community Protective Measures Program (CPMP). CPMP is primarily an informational process including public notices, warning signs, maps, remedial status reports and public health advisories. The second layer of institutional controls is the Anaconda Deer Lodge County

Master Plan (ADL, 1992a) and Anaconda-Deer Lodge County Development Permit System (ADL, 1992b). All proposed new development within the impacted area is required to obtain a county permit. This permit system provides a means of identifying potential future remediation that would be required in association with the proposed residential or commercial development. This remediation would then have to be performed at the time of development to ensure that the appropriate arsenic levels are maintained consistent with the land use.

The final two layers are not in existence at the time of this writing. It is anticipated that the final set of institutional controls will be defined in the last Regional OU. The third protective layer is control of groundwater. It is envisioned that the State of Montana or the local water district will establish procedures for managing groundwater use. The fourth envisioned layer of control is specific to the area of the site where waste has been left in-place. Restrictive covenants, conservation easements and dedicated development areas are anticipated to form the foundation for these controls.

A significant feature of the remedial plan for the OW/EADA OU involved the development of a "Jack Nicklaus Signature Golf Course" on a portion of the site. This golf course, which incorporated innovative "irrigated mining caps" into its design, supported an economic re-use of the property for recreational purposes (ADL, 1992a; Manning, 2003). The USEPA, the State of Montana and the Anaconda-Deer Lodge County classified the golf course and the associated Old Works Historic Trail System as new, dedicated developments.

In April 1994, the USEPA issued a Unilateral Administrative Order to ARCO to implement the preferred alternative remedy (USEPA, 1994c; USEPA, 1994a; USEPA, 1994d). On May 5, 1994 the property for the golf course and the Old Works Historic Trail System was transferred from ARCO to the Anaconda-Deer Lodge County to be operated by the Old Works Golf Course, Inc. a Montana nonprofit corporation (Montana, 1994a; Montana, 1994b). Included in the land transfer were specific restrictive covenants designed to ensure that the site's operations remain consistent with the selected remedy (Burnham, 1994; Montana, 1994b). In addition, the operation and maintenance (O&M) responsibilities, management insurance and contingency funding requirements and the subsequent land conversion requirements are defined in the property conveyance agreement (Burnham, 1994; Montana, 1994b).

Construction of the Jack Nicklaus Signature Golf Course began in June 1994 (see Figure 8) and was completed in 1996 (see Figure 9). The course was opened for business in May 1997. Construction in the last sub-area of this OU was completed in 2001. The OU is considered to be in an interim status because the remediation of groundwater in this area has been deferred to the Anaconda Regional Water, Waste, & Soils OU (USEPA, 1999b; USEPA, 2001a; USEPA, 2003a).

Two CERLCA five-year reviews have been completed at the Anaconda site to date. These reviews are a means of validating that the selected remedies are being maintained and implemented as expected. The first five-year review was released by the USEPA in November 1994 (USEPA, 1994b). The second five-year review was released by the USEPA in December 1999 (USEPA, 1999b). Both reviews found that the remedy at the OW/EADA were protective of human health and the environment consistent with the ROD (USEPA, 1994c).

Figure 8. Construction of the Old Works Golf Course (Troon, 2004).

Figure 9. Photograph of Old Works Golf Course with the remnants of the Lower Works in the background.

Observations

The Anaconda site was visited October 3, 2003. Included as part of this visit were discussions with Mr. Milo Manning of the Anaconda Environmental Education Institute. Mr. Manning coordinates the USEPA Technical Assistance Grant (TAG) and maintains a copy of the site's Administrative Record and a local information repository. Mr. Manning provided access to this information as well as his personal insight concerning this case. Discussions were also held with Mr. Brian Bartkowiac of the Montana Department of Environmental Quality. Mr. Bartkowiac provided copies of additional site information such as the Institutional Controls Design Package (USEPA, 2001c). An informal tour of the Anaconda area was also conducted during this visit.

The management system installed at the Anaconda Smelter Site serves as a good example with respect to all functions and activities discussed in Table 2. The only possible weakness evident at this site is in the area of environmental and ecological monitoring. This environmental monitoring was not obvious on the Old Works OU although there are two related management activities. One, there is a nature trail integral to the OU, which indirectly supports this objective through public awareness and education. Second, there is a stronger ecological component at the Spring Creek OU that could be incorporated into the final OU.

The Anaconda site exhibited strong local involvement in the site design and with community awareness. There was a local information repository present in Anaconda. The USEPA, via a TAG, supported this local involvement. The Old Works Golf Course also promotes its unique background (see Figure 10).

The remedial design selected for the Anaconda site involved an innovative “re-use” of a portion of the impacted area. This “re-use” alternative design was even less expensive than the more conventional capping design (Manning, 2003).

Figure 10. Photograph of an educational poster displayed at the Old Works Golf Course.

Portions of the remediated properties were transferred to a non-profit organization for operation and maintenance. The responsibilities associated with this transfer include maintaining the engineered controls and the institutional controls consistent with the ROD. Restrictive covenants and revisionary provisions were placed in the Deed transfer to ensure consistent operations long-term.

Multi-agency involvement and cooperation was evident at the Anaconda Site. This involvement included federal, state and local government participation. This involvement also appeared evident during the remedial design phase as well as during the post-ROD operations.

Strong local government involvement was evident at this site, particularly with regard to future land transfers and land development. For example, the county established a Development Permit System for the area. This system requires all proposed development within the impacted area obtain a county permit to ensure that the proposed development is consistent with existing land use classifications. During the review process for these development permits, any additional future remediation would need to be identified. Thus this permitting process ensures that future land use remains consistent with current conditions or requires that additional remediation be performed.

Table 4 is a chronological timeline for the Anaconda Case Study. This timeline highlights the key events that occurred at this site. Table 5 is a summary of the contaminant isolation facility subsystem controls present at the Anaconda site.

Table 4. Chronological timeline of key events for the Anaconda Case Study.

1883	Construction of the Upper Works in Anaconda, MT.
1884	Copper smelting operations begin at the Upper Works.
1888	Construction of the Lower Works expands processing capacity.
1901	Operations end at the Upper and Lower Works.
1902-1980	Copper smelting operations performed at the Anaconda Reduction Works.
1977	Atlantic Richfield Company (ARCO) acquires Anaconda Mineral Company.
1980	Operations end at the Anaconda site.
1980	CERCLA enacted by Congress.
1983	Anaconda site placed on the National Priority List.
1984	ARCO and the USEPA enter into Administrative Order Consent and begin to conduct a Remedial Investigation of the site.
1986	Expedited Remedial Investigation/Feasibility Study (RI/FS) entered into for the Mill Creek operable unit.
1987	ROD signed for Mill Creek OU determines that permanent relocation is warranted.
1988	A second Administrative Order Consent established for the Flue Dust and Smelter Hill OUs.
1991	ROD signed for the Flue Dust and Smelter Hill OUs.
1991	Action Memorandum was signed for the Old Works area.
1994	ROD signed for the Old Works/East Anaconda Development Area OU.
1994	Portions of Old Works OU transferred from ARCO to Anaconda-Deer Lodge County.
1994-1996	Construction of the Old Works Golf Course on portions of OU with residual waste.
1994	First 5-year review of CERCLA remedial actions conducted.
1997	Old Works Golf Course opens to the public.
1999	Second 5-year review of CERCLA remedial actions conducted.
Present	On-going remedial operations in remaining OUs.

Table 5. Summary of contaminant isolation facility subsystem controls in place at the Anaconda Site.

Subsystem	Control	Description
Engineered	Physical Site Security	1. Private property signs around perimeter of site 2. Golf course office and maintenance staff
	Active Processes	3. Surface and groundwater monitoring system
	Surface Covers	4. Multi-layer cap
	Subsurface Barriers	5. Groundwater drainage system stabilized waste
Institutional	Information Management	6. OU monitoring data collected 7. CERCLA Five-year Reviews 8. Administrative records 9. Local information repository
	Stakeholder Awareness	10. Local and national recognition
	Orders & Decrees	11. Several Orders used during remediation process
	Permits	12. Anaconda-Deer Lodge County Development Permit System
	Deed Restriction	13. Property conveyance requires O&M, management insurance and contingency funding
	Contract	14. Property management via the Old Works Golf Course, Inc.
	Ordinance/Statutes	15. CERCLA

Love Canal Case Study

Historical Events

The origins of Love Canal date back more than 100 years. In the 1890s, an entrepreneur named William T. Love had a vision to create a “model city” in the Niagara Falls region of New York State. Love was attracted to the region because of the Niagara Falls. Love’s plan was to construct a canal between the upper and lower reaches of the Niagara River. This canal was to be used for two primary purposes. First, the canal would serve as an important transportation route around the Falls for commerce between Lake Erie and Lake Ontario. Second, it would serve as a source of hydroelectric power, which Love needed for his model industrial city.

Love acquired property rights in the La Salle region of the City of Niagara Falls. The area’s clay soils were a positive attribute for construction of the canal. In 1894, construction of the canal began with both state and private finances. A portion of the canal, measuring between ½ to 1 mile, was constructed. The canal, however, was never finished, as the result of financial constraints. The idle site subsequently served as a swimming hole for local residents for some 40 years.

In 1941, Elon H. Hooker became interested in the former Love Canal as a potential disposal site for by-products resulting from the Hooker Electrochemical Company (Hooker). The 16-acre site was close to the Hooker operations; therefore, transportation costs would be low. Hooker investigated the site and determined that the low hydraulic conductivity clay soils made the site suitable for containing residue hazardous waste from its operations. In 1942, Hooker acquired the property and began disposing chemical waste into the former canal.

Hooker disposed of waste in the former canal from 1942 through 1953 (Mazur, 1998). The dimensions of the canal at this time measured 3000 feet long and varied from 60 to 80 feet wide. The depth varied from 8 to 16 feet. Hooker conducted disposal operations in the northern section of the canal from 1943 through 1946. The southern portion of the canal served the period from 1946 through 1953. In addition, Hooker dug a number of disposal pits outside of the canal. These pits measured approximately 40 feet by 40 feet and were 25 feet in depth. After reaching capacity in 1953, Hooker filled the site with layers of dirt.

The waste disposed of by Hooker consisted of liquid and solid chemical residues and by-products from Hooker's chemical manufacturing processes. The solid waste was disposed of in 55-gallon metal and fiberboard drums while liquid waste was sometimes disposed of directly into the canal from tank trucks. The USEPA estimates that approximately 21,000 tons of chemicals were disposed of in the canal (USEPA, 1988). The primary contaminants of concern according to the 1988 ROD include chlorides, chlorobenzene, chlorophenols, dioxin, mercaptans, metals, pesticides, phenols and toluenes (USEPA, 1988; USEPA, 1991b).

In addition to Hooker, the City of Niagara Falls used Love Canal for the disposal of municipal waste (Zuesse, 1981). There are also claims that the U.S. Army used the canal for the disposal of chemical waste during World War II (WWII).

Following WWII, a population growth spurred the housing market in the Niagara Falls area. New housing projects began to expand the city eastward in the direction of Love Canal. Beginning in 1942, the LaSalle Housing Development was established one block from Love Canal. By the early 1950s, small single-family homes began to surround the rectangular canal site.

As the city's population increased its infrastructure continued to expand to accommodate the demand. In the early 1950s the Niagara Falls Board of Education (Board) approached Hooker with regard to its interest in acquiring a portion of the canal property. The Board was interested in acquiring a suitable property for a new school. It has been reported that Hooker informed the Board of the type of waste disposed of in the canal and suggested that this site was not suitable for excavation or construction. On at least two occasions, Hooker appeared at Board meetings to again present their warnings (Zuesse, 1981). In 1953, the entire Love Canal property was transferred to the Board for $1. Language in the Deed acknowledged that chemical waste was buried on the site and that Hooker was released of all liability and risk associated with the site (NYS, 1953; 1979; Zuesse, 1981; Whelan, 1985).

In 1954, the Board built the 99th Street School on the acquired Love Canal property. During the initial excavation for the school, waste was encountered. Construction continued and the 99th Street School opened in 1955. In addition to this construction project, the Board sold portions of the former Love Canal property for residential development (see Figure 11). From 1955 through 1962, additional portions of the property were used for the construction of streets, sidewalks and residential development. Storm sewers were installed at a 10-foot depth under sections of Wheatfield and Read Avenue. These construction activities involved disturbances to the clay soils, which served as the containment system for the Love Canal disposal cell.

Figure 11. Historical aerial photograph of 99th Street School, surrounding neighborhood and original Love Canal disposal cell. (ETF 1998)

Public health concerns and questions began to surface in 1976. During this time, annual precipitation was significantly higher than the 30-year average of 36 inches (Mazur, 1998). For example, annual precipitation for the years 1976 and 1977 were 47 and 50 inches respectively.

In 1978, Michael Brown ran a series of articles in the Niagara Gazette (1980). These articles suggested health problems such as miscarriages, birth defects and cancer were being observed that were resulting from contaminants leaking from the disposal site. National attention began to focus on the neighborhood of Love Canal.

On April 25, 1978, the New York Department of Health ordered the installation of a protective fence around the canal. In addition, a series of public meetings were held in May 1978. Residents complained of a lack of information as well as contradictory information from county and state officials. As a result, local residents began to organize themselves. Two community organizations began to form in July 1978. Ms. Karen Schroeder began to organize residents whose homes were on 99th Street. These homes ran alongside the former canal and were considered part of the “inner ring” homes (Mazur, 1998). Likewise, Ms. Lois Gibbs began to organize the broader Love Canal neighborhood. This second group, which included homeowners from throughout the Love Canal neighborhood, became know as the Love Canal Homeowners Association (LCHA) (Gibbs and Levine, 1982; Gibbs, 1998; Mazur, 1998). The Ecumentical Task Force of the Niagara Frontier provides a detailed daily log of events that transpired during this time (ETF, 1998).

In August 1978, the State of New York issued a Health Emergency following release of preliminary health findings that the residents of the Love Canal were exhibiting an above normal number of miscarriages and birth defects. The New York Health Commissioner, Mr. Whalen, ordered residents to not eat food from their gardens. He also ordered pregnant women and children under the age of two to move out of the Love Canal neighborhood, although the state did not provide funding and did not make any additional recommendations to the remaining residents.

Later in August 1978, New York Governor Carey visited Love Canal and held a public meeting at the 99th Street School. The Governor announced that the state would buy the inner ring homes and would begin health studies in other portions of the neighborhood. President Carter declared the site a federal emergency, freeing up federal funding to support the relocation (NYS, 1988). The 236 homeowners from the inner rings began to sell their homes to the state and move out of the area. The area was fenced off and remediation efforts began. A system of drains was installed along the sides of the canal to lower the water table. Leachate was collected from the canal and treated on site and a three-foot clay cap was placed over the canal.

In 1979, preliminary results began to surface from the health studies initiated as part of the 1978 evacuation. In February 1979, the State of New York announced the temporary relocation of families living between 97th and 103rd street with pregnant women and children under two years of age.

An initial lawsuit was filed September 1979 against Occidental Chemical Corporation (Occidental), which had acquired Hooker, and three New York State agencies. In December 1979, the federal Justice Department initiated a lawsuit against Occidental in connection with Love Canal (1979). This latter suit was eventually settled in December 1995. Under the terms of the agreement, Occidental agreed to pay the U.S. government $129 million to cover the costs of clean-up and interest (USDOJ, 1995a).

On May 17, 1980, preliminary results from a USEPA study suggested possible chromosome damage in residents tested. On May 19, 1980, two USEPA representatives were detained as “hostages” at the offices of the LCHA. On May 21, 1980, President Carter declared a second federal emergency (NYS, 1988; USEPA, 2003c). This decision defined an Emergency Declaration Area (EDA) involving approximately 232 acres and provided federal support to relocate approximately 500 families and initiate remedial actions (NYS, 1988; USEPA, 2003c).

The U.S. federal government enacted new legislation, CERCLA, on December 11, 1980 (CERCLA 1994). Remediation efforts at the Love Canal involved multiple operable units, several RODS, seven remedial stages and three Explanations of Significant Differences (ESDs). The remedial stages included: 1) Initial emergency actions, 2) Landfill containment, 3) Excavation of sewer/creek sediments, 4) Treatment and disposal of sewer/creek sediment, 5) Remediation of 93rd Street School soils, 6) EDA home maintenance and 7) Buyout of homes in the EDA.

The 1988 ROD considered six remedial alternatives for the remediation of this site (USEPA, 1988; USEPA, 1991b). The ROD determined that the most plausible routes of exposure were inhalation or inadvertent ingestion of contaminated soil. This could most likely occur from children playing on the site. The theoretical cumulative cancer risk for the no-action alternative was determined to be 2.4×10^{-4}. If the site were disturbed without implementing direct contact or dust control measures, the cumulative cancer risk was estimated to increase to 1.3×10^{-3}.

The selected remedy called for soil excavation, on-site solidification and a low-permeable cover. Specifically, the selected remedy required:

- Excavation of approximately 7500 cubic yards of contaminated soil;
- On-site solidification of the excavated material;
- Re-disposal of the solidified material back into the same unit of contamination;
- Treatability studies to evaluate the effectiveness of the solidification process; and
- A low-permeability cap installed over the unit of contamination.

In 1990, the USEPA determined that the excavated materials should be classified as RCRA F039 wastes (i.e., wastes containing dioxin) and should be treated to meet the universal treatment standards (UTS) for dioxin at 1 ppb. This treatment was performed at commercial facilities and the residues from the treatment were disposed of at a RCRA Subtitle C Landfill outside of the State of New York. In addition, contaminated sewer and creek sediments were analyzed, segregated, treated and disposed. A groundwater-monitoring program was also established in accordance with RCRA.

The landfill cover and leachate collection system was completed in 1985. The site was deemed construction complete on September 29, 1999. The sewer, sediment and other waste materials were shipped off-site for disposal in 2000.

The first five-year review of the Love Canal site was conducted in June 2003 in accordance with CERCLA requirements (USEPA, 2003b). The purpose of the review was to ensure that the implemented remedies remained protective of human health and the environment. This review concluded that the remedies as implemented continue to provide adequate control to the known contaminants.

Institutional controls at this site include a permanent easement on the site property by the State of New York. This easement provides for the exclusive use and occupancy of the property by the state. Through a Consent Decree, the state has granted Occidental exclusive use of the site for continued maintenance (see Figure 12). Adjacent vacant properties are being maintained by zoning and deed restrictions (USEPA, 2003b). The deeds for these properties require that the state be notified if these properties are being considered for use other than commercial or light industrial. The state is also to be notified if these properties are sold (USEPA, 2004e).

The USEPA issued a Notice of Intent to delete (i.e., de-list) the Love Canal site from the NPL in the Federal Register, March 17, 2004 (DePalma, 2004; Thompson, 2004). This announcement states that the USEPA has determined that all appropriate response actions under CERCLA have been implemented and that no additional response actions are required (USEPA, 2004e). The Love Canal site was de-listed from the NPL on September 30, 2004 (USEPA, 2004d).

Figure 12. Photograph showing active maintenance at Love Canal.

Observations

The Love Canal area was visited on June 10, 2003. Although site personnel were not available at that time for an on-site tour, the site and its surroundings were observable from outside the access controls. Additional information was obtained from the Love Canal Collection at the State University of New York at Buffalo University Archives. Follow-up interviews were also conducted with Mr. Mike Basile, Public Affairs Officer, USEPA Niagara Falls Office (Basile, 2004).

The Love Canal Case can be viewed as two separate cases: the original Love Canal and the current Love Canal. The original Love Canal case involves those events from the 1950s through the 1970s that resulted in the site being placed on the NPL. The current Love Canal involves the events resulting from the CERCLA remediation and represents the current configuration of the site.

The original Love Canal disposal cell consisted of a low-hydraulic conductivity clay cap installed over the waste constituents, which were placed into the natural low-hydraulic conductivity clay soils. The site was fenced and separated from the surrounding area. There appeared to have been little government involvement, little information management or public notice at that time. The primary legal control was private property restrictions.

Following the original disposal cell construction, the surrounding population encroached up to the site boundary (ingress scenario). Portions of the site were subsequently transferred to new owners. Notice was provided to the new owners, prior to and at the time of transfer, as to the types of waste disposed of on-site and their location (NYS, 1953). The new owners further transferred portions of the site to a second set of owners. It is not clear whether these later transfers included public notice.

These various owners disturbed the cell cover during construction operations on the site. Natural events, such as multiple, consecutive years of above average precipitation, contributed to contaminant migration from the disposal cell. These events contributed to the site being placed on the NPL, which led to its remediation and its current configuration.

The current Love Canal can be described as a sacrifice zone that is fenced off and separated from the surrounding population. No re-use potential is evident for this immediate site. Although there is no formal buffer zone beyond the site's fenced boundary, many properties associated with the former "outer ring" still remain vacant (see Figure 13). This surrounding area appears to be changing and new development is progressing up to the fence boundary along portions of the site. Properties to the north and west of the site continue to remain zoned as residential (see Figures 14 and 15). Properties to the east of Love Canal are being re-zoned light industrial (Basile, 2004).

This is consistent with the recommendation of the New York Habitability Study (NYS, 1988).

Figure 13. Photograph of vacant lots west of the current Love Canal site.

Figure 14. Photograph of new senior citizen housing at southeastern Love Canal.

Figure 15. Photograph of residential property adjacent to Lave Canal.

The remediation of the site captured national attention and directly contributed to the enactment of CERCLA. The agency involvement included the USEPA, the State of New York and the City of Niagara Falls.

Although Love Canal continues to attract national attention, there is little local stakeholder involvement evident at the site. Local residents expressed very little interest in the site during informal discussions held with them as part of the site visit. In addition, the residential name for the community has been changed from Love Canal to Black Creek. Finally, as described in the USEPA Five-year Review Report, only two individuals, a New York State representative and a Congressional aid, attended the open house during the five-year review (USEPA, 2003b).

There is a local, pre-ROD, historic information repository at the State University of New York at Buffalo. Also, the local USEPA office in Niagara Falls maintains a second public reading room specific to Love Canal (Basile, 2004). This local office has been maintained by the USEPA since 1982 (USEPA, 2003b).

A grassed soil cover overlays the disposal cell. The site is being maintained and the grass is routinely cut (see Figure 12). Groundwater and leachate are monitored and site maintenance personnel maintain operational support facilities at this site.

Table 6 is a chronological timeline for the Love Canal Case Study. This timeline highlights the key events that occurred at this site. Table 7 is a summary of the contaminant isolation facility subsystem controls present at the Love Canal site.

Table 6. Chronological timeline of key events for the Love Canal Case Study.

1894	William T. Love begins construction of canal.
1941	Hooker acquires abandoned canal.
1942	Hooker begins chemical waste disposal in canal.
1942-1953	Waste disposal of 20,000-25,000 tons. 1943-1946 – disposal in northern portion of canal. 1946-1953 – disposal in southern portion of canal.
1953	Hooker transfers canal property to Niagara Falls Board of Education. (April 28)
1954	Construction of the Niagara Falls 99th Street School.
1955	Niagara Falls 99th Street School opens.
1955-1962	Portions of property transferred from Niagara Falls School Board to the City of Niagara Falls for infrastructure construction.
1976-1977	Years of high precipitation.
1976	New York Department of Environmental Quality visits site.
1977	The USEPA initiates air sampling in residential basements.
1978	Niagara Gazette publishes a series of articles on area health problems. (May)
1978	New York issues a Health Emergency. (August 2)
1978	NY Governor visits site and announces state will buy inner-ring homes. 236 homeowners begin to move out. President Carter issues federal emergency. (August 7)
1978	Initial remedial actions begin. (October 10)
1979	NY State recommends temporary relocation of pregnant women and children living on outer-ring. (February 8)
1979-1980	National media attention focuses on Love Canal neighborhood.
1979	Initial lawsuit filed against Occidental. (September)
1980	The USEPA reports on chromosome damage. (May 17)
1980	Two USEPA representatives taken “hostage.” (May 19)
1980	Federal health emergency declared. (May 22)
1980	President Carter announces federal government’s intent to purchase outer-ring homes. (October)
1980	CERCLA signed by President Carter. (December 12)
1985-1991	USEPA documents remedial actions in multiple Records of Decisions.
1995	Landfill cover and leachate system completed.
1995	Occidental agrees to $129M settlement with the USDOJ and the USEPA. (December)
1999	Site was deemed construction complete. (September)
2003	First Five-Year CERCLA Review. (June)
2004	The USEPA proposes NPL site de-listing. (March)
2004	Love Canal is de-listed from the NPL. (September)

Table 7. Summary of contaminant isolation facility subsystem controls in place at the current Love Canal Site.

Subsystem	Control	Description
Engineered	Physical Site Security	1. Fenced disposal dell 2. Emergency contact signs 3. Site maintenance office
	Surface Covers	4. Multi-layer cap
	Subsurface Barriers	5. Stabilized waste
	Active Processes	6. Leachate collection/treatment system
Institutional	Information Management	7. Monitoring data collected by Occidental 8. CERCLA Five-year Review 9. Administrative records 10. Local information repositories
	Stakeholder Awareness	11. Love Canal retains national attention 12. Local information repositories
	Consent Decree	13. Multiple emergency decrees issued
	Zoning Restrictions	14. Light industrial zoning restrictions placed on property east of canal; residential elsewhere.
	Deed Restrictions	15. Deed restrictions placed on properties east of canal
	Government Ownership	16. State of New York ownership of property
	Ordinance/Statutes	17. CERCLA

Maxey Flats Case Study

Historical Events

The Maxey Flats Disposal Site, located near Hillsboro, Kentucky (see Figure 16), was used for low-level radioactive waste (LLW) disposal from 1963 until December 1977 (Kentucky, 1968). The Nuclear Engineering Company operated the facility at the 252-acre site that it leased from the Commonwealth of Kentucky for 25 years beginning in 1963 (Kentucky, 1963). Approximately 4.8 million cubic feet of LLW, containing more than 2.4 million curies of radioactivity, was deposited into 52 unlined earthen trenches at this facility (USEPA, 1986; USEPA, 1991a). The trenches, ranging in size from 15- to 670-feet long, 10- to 70-feet wide and 10- to 35-feet deep, occupy some 40 acres (USEPA, 1991a).

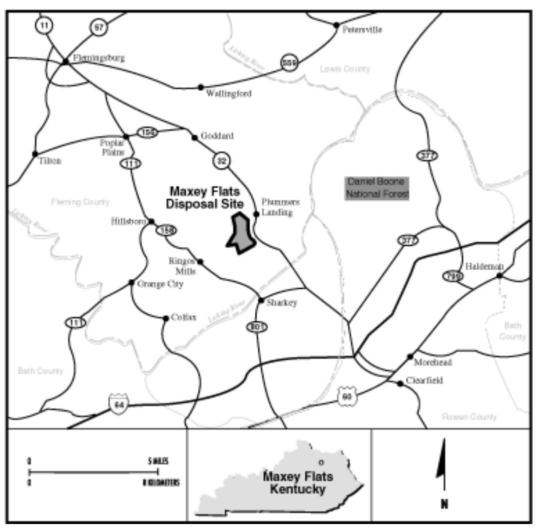

Figure 16. Map showing location of Maxey Flats Disposal Site (USEPA, 2001d).

Operational problems began to arise in the early 1970s (USEPA, 1991a). As the disposal trenches were filled with waste, they were subsequently covered with a three-foot low-hydraulic conductivity soil cap to prevent infiltration of precipitation. Subsidence problems with the soil cap, however, began to impact its performance. Repeated subsidence occurrences resulted in preferential infiltration routes through the cap. The infiltrated water accumulated in the disposal trenches and subsequently migrated from the trenches. The discovery of contaminated leachate some 300 feet from the source trenches ultimately prompted the site's closure in 1977 (USDOJ, 1995b).

The Maxey Flats Disposal Site was placed on the NPL in 1986 to be remediated under CERCLA (USEPA, 1986; CERCLA 1994). There were 832 Potentially Responsible Parties identified, including the USDOE, other federal agencies, federal contractors, medical facilities, physicians, clinics, industry, state agencies, transporters, broker/haulers and the landowner. The primary contaminants of concern were: plutonium^{238}, plutonium$^{239/240}$, strontium^{90}, tritium, uranium^{235}, uranium^{238}, cobalt^{60}, carbon^{14}, benzene, toluene, xylenes, arsenic and cyanide. The off-site groundwater exposure pathway was determined to be the dominant pathway with tritium being the major contaminant of concern (USEPA, 1991a).

The ROD was finalized in September 1991 (USEPA, 1991a). The settling private parties, the settling federal agencies, the Commonwealth of Kentucky and the USEPA signed two Consent Decrees in 1995 (USDOJ, 1995b). Under one decree, six federal agencies (the U.S. Army, Air Force, Navy, DOE, National Aeronautics and Space Administration [NASA] and National Institute of Health [NIH]) agreed to pay approximately $45M of the cleanup costs. Under the second decree, state, federal and private parties agreed to pay $8.5M of additional costs (USDOJ, 1995b).

Approximately one million gallons of contaminated leachate was removed from the original disposal trenches between 1998 and 2000 (USEPA, 2001d). This water was solidified and the resulting “concrete” was disposed of in earth-mounded concrete bunkers that were constructed at the disposal facility. A “natural stabilization” remedy was then selected and implemented for the final remediation of Maxey Flats. This remedy required the “initial” closure of the site, contouring of the site to reduce erosion and the subsequent capping of the site to prevent infiltration. The “interim” remediation cap, shown in Figure 17, was completed in 2003 and consists of a layer of compacted clay (21 inches) and a 40-mil polypropylene liner. This geomembrane-cap covers approximately 60 acres. Monitoring wells have been located under the cap and within the trenches to measure trench water levels. Additional groundwater monitoring wells are located around the perimeter of the site to identify any off-site contaminant migration.

Figure 17. Photograph of the Maxey Flats interim geomembrane-cap.

Following completion of the “initial site closure” phase, the selected remedy further requires a 100-year “interim maintenance period,” which is to be followed by the “final site closure” and a permanent “custodial maintenance” phase. The interim maintenance period involves the establishment and management of a buffer zone (an additional 450 acres) around the site, posting of perimeter signs and fences, installation of permanent site monuments, active maintenance and continued surface water and groundwater monitoring. The objectives of this phase of management are to minimize further infiltration of precipitation into the disposal trenches, prevent or mitigate the release of hazardous substances, control site drainage to minimize the potential for erosion, implement institutional controls, implement environmental monitoring and allow natural subsidence to further stabilize the site, thus improving the foundation for the final site cap (USEPA, 2002b).

The system’s performance is being monitored via: 1) Groundwater wells installed adjacent to the disposal site and at the base of the surrounding hills (see Figure 18), 2) Water-level monitors located within selected disposal trenches, 3) Surface-water discharge flow meters for the site detention basins, 4) Erosion control monuments, and 5) Cap subsidence reference benchmarks (IT-Corporation, 2000).

Information obtained during the interim maintenance period is maintained by the Commonwealth and submitted to the USEPA. This monitoring information is not maintained in the CERCLA Administrative Record or at local public reading locations. Local public reading rooms, which maintain copies of the CERCLA Administrative Record, generally maintain only pre-ROD information. Post-ROD monitoring information is, however, available to interested stakeholders through Freedom of Information procedures via the Commonwealth of Kentucky (Heath, 2003).

Figure 18. Photograph of groundwater monitoring station.

The Commonwealth of Kentucky remains the lead organization responsible for the long-term management of the Maxey Flat Disposal Site. Land use restrictions have been placed in property Deeds to prevent future inappropriate uses of this property (Kentucky, 1995; Kentucky, 2003). These restrictions prohibit the use of groundwater from the property, limit all action at the site that could disturb the integrity of the engineered controls and limit access to the property to Commonwealth personnel or their agents.

A $10 million Emergency Trust Account (in 1996 dollars), as defined in the Consent Decree, has been established by the Commonwealth of Kentucky to cover emergency actions arising during the interim maintenance period (Hamilton, 2003). Funds remaining in this account following the site’s final closure will be returned to the Commonwealth. These funds are not associated with emergency actions for the post-closure custodial maintenance period.

Observations

The Maxey Flats site was visited on June 6, 2003. Mr. Omar Heath, Maxey Flats Project Manager for the Commonwealth of Kentucky, Department of Environmental Protection, Waste Management Division, provided a tour of the facility. Additional information was gathered from the Maxey Flats Administrative Record located at the Morehead University Library.

Maxey Flats can be described as a permanent sacrifice zone. The 60-acre disposal cell is capped with a geosynthetic membrane. The cell's perimeter is fenced to restrict access (see Figure 19). No re-use potential is evident at this site. The disposal cell is also surrounded by a 450-acre buffer zone, which is primarily wooded. The buffer zone is not fenced but it is posted with warning signs.

Commonwealth of Kentucky personnel serve as local site stewards and maintain an office at the site, which is staffed during normal work hours (see Figure 20). The site is actively maintained. Routine maintenance includes site inspections, groundwater monitoring, surface runoff monitoring, cap repairs and erosion monument monitoring.

Figure 19. Photograph of access controls surrounding the Maxey Flats disposal cell.

Figure 20. Photograph of administrative area supporting Maxey Flats.

In addition to the site office, there is a local information repository at nearby Morehead University. This repository maintains a copy of the site's administrative record. This record is quite complete with regard to pre-ROD information. Little post-ROD information was observed.

The site appeared to have benefited from an active public involvement during the RI/FS process and other pre-ROD activities. Currently there was little public involvement observed at the site.

The site is currently considered to be in an interim maintenance period. This interim period is scheduled to last for 100 years to support natural subsidence at the site. Following this interim period the site will receive a final cover. Site stewards have indicated that the interim maintenance period could be reduced from 100 years if it appears that no further subsidence is anticipated.

A financial trust has been established to support this site during the 100-year interim maintenance period. This trust only supports emergency actions at this site for the 100-year interim maintenance period (Hamilton, 2003). State appropriations are still being used to fund the operation and maintenance activities. Following the interim maintenance period, the funds in this trust are to be returned to the state. This trust is not expected to support the final cap construction.

Table 8 is a chronological timeline for the Maxey Flats Case Study. This timeline highlights the key events that occurred at this site. Table 9 is a summary of the engineered and institutional controls present at the Maxey Flats Disposal Site.

Table 8. Chronological timeline of key events for the Maxey Flats Case Study.

1963	Commonwealth of Kentucky leases 252 acres to Nuclear Engineering Company
1963	Commonwealth of Kentucky issues Low-Level Radioactive Waste disposal license to Nuclear Engineering Company
1963-1977	4.8M cubic feet of LLW is disposed of at Maxey Flats
1972	Studies by the Kentucky Department of Health and Environmental Monitoring reveal radionuclide migration
1973-1986	Additional studies during this timeframe. Also, an Interim Action is conducted to treat 6 million gallons of trench leachate. Leachate is treated on-site.
1987-1991	RI/FS is conducted under CERCLA.
1988-1989	USEPA emergency actions are conducted. These include solidification of leachate and on-site disposal.
1991	Record of Decision (ROD) is signed
1992-1995	Various legal actions and negotiations occur.
1995	Two Consent Decrees are signed.
1996-2003	Remedial Actions as specified in the ROD are conducted.
2002	First Five-year CERCLA Review report released.
2003	Initial Remediation Phase is completed. This phase includes construction of the 60-acre synthetic cap.
2004~2100	Projected Interim Maintenance Period to be conducted by the Commonwealth of Kentucky.

Table 9. Summary of contaminant isolation facility subsystem controls in place at the Maxey Flats Site.

Subsystem	Control	Description
Engineered	Physical Site Security	1. 450-acre buffer zone surrounding disposal cell 2. Fenced disposal cell 3. Warning signs 4. Site office
	Surface Covers	5. Multi-layer geosynthetic cap
	Subsurface Barriers	6. Stabilized waste 7. Concrete cells
Institutional	Information Management	8. Monitoring data collected by Kentucky 9. CERCLA Five-year Review 10. Administrative records 11. Local information repositories
	Stakeholder Awareness	12. Local citizen advisory group during RI/FS 13. Local information repositories
	Consent Decree	14. Multiple decrees issued
	Deed Restrictions	15. Land-use restrictions placed in property deeds
	Government Ownership	16. Commonwealth of Kentucky ownership of property
	Ordinance/Statutes	17. CERCLA
	Financial Security	18. Trust Fund established for emergencies during interim maintenance period

Rocky Mountain Arsenal Case Study

Historical Events

The Rocky Mountain Arsenal (RMA) was created in 1942 when the U.S. Army purchased 17,000 acres northeast of Denver, CO. (USGAO, 1997). The site was established under the control of the U.S. Army in support of World War II (WWII) military operations. Specifically, RMA was established to manufacture chemical warfare agents.

RMA is located approximately 8 miles from the City of Denver, CO., east of Commerce City, CO and west of the Denver International Airport, as shown in Figure 21. The site encompasses a 27 square mile area (17,000 acres).

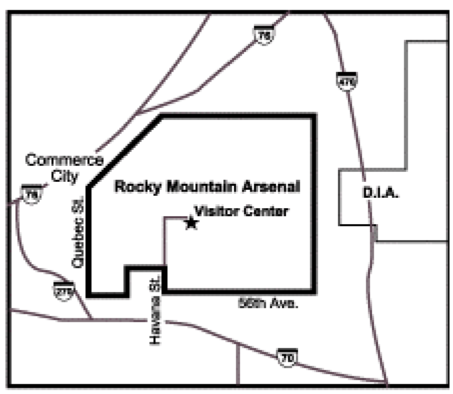

Figure 21. Map showing location of RMA (USDOD, 2001b).

Facility construction and manufacturing operations began at RMA in 1942 (see Figure 22). Initial operations were performed at the South Plants complex. The products produced at these facilities included mustard gas, lewisite and chlorine gas. Production continued for the duration of WWII.

Figure 22. Historic photograph of production at RMA in 1942 (USDOD, 2001b).

Following WWII, production declined at RMA resulting in excess capacity and facilities. Portions of the South Plants complex were leased to private industry for the manufacture of chemicals and pesticides. Nine companies conducted manufacturing operations at the South Plants between 1946 and 1982. Three primary leases included the Julius Hyman and Company from 1947 to 1952, the Shell Oil Company (Shell) from 1952 to 1982 and Colorado Fuel and Iron from 1946 to 1948.

In the early 1950s, the Army constructed the North Plants complex. In 1952, the Army initiated operations at these facilities. The North Plants were used from 1953 until 1957 for the manufacturing of the nerve agent GB (i.e., Sarin).

In addition, various incendiary munitions were also manufactured at RMA at this time. These munitions included M-47 bombs filled with napalm gel and M-74 bomblets filled with a mixture of agents. These munitions were manufactured at RMA in support of WWII, the Korean War and the Vietnam War.

Waste generated at RMA throughout the 1940s, 1950s and 1960s was disposed of on-site in basins, pits, trenches and burn pits. Liquid waste from RMA was often treated and discharged into catch basins. In 1961, the Army drilled a 12,045-foot-deep injection well. From 1961 until 1966 approximately 165 million gallons of treated effluent waste was disposed of in this manner (USEPA, 1996).

On December 6, 1982, the USEPA, Army, Shell and the Colorado Department of Health signed a Memorandum of Agreement to investigate the decontamination of RMA. Despite this agreement, various parties pursued numerous legal actions and lawsuits during the 1980s and into the 1990s.

A significant event occurred in 1986. A winter roost of bald eagles was discovered on the Arsenal (see Figure 23). The presence of bald eagles, an endangered species, prompted the involvement of the U.S. Fish and Wildlife Service (USFWS). In 1987, the USFWS began managing the site's abundant wildlife, which included roughly 300 wildlife species (USDOD, 2001b).

Figure 23. Bald Eagles were discovered at RMA in 1986.

In 1989, the U.S. Army, Shell, the U.S. Department of Interior (USDOI) (i.e., the

USFWS) and the Agency for Toxic Substance and Disease Registry signed a Federal Facility Agreement (USDOD, 2001a).

In 1992, Congress enacted the Rocky Mountain Arsenal National Wildlife Refuge Act of 1992 (RMANWRA 1992). This Public Law #102-402 designated the transfer of RMA from the Army to the USDOI and designated the site to be managed as a unit within the National Wildlife Refuge system (USFWS, 1996). Figure 24 shows the signs designating RMA as a wildlife refuge.

Figure 24. Rocky Mountain Arsenal became a National Wildlife Refuge in 1992.

The current regional land use is a combination of rural, industrial and residential. With the surrounding population steadily increasing (ingress scenario), additional conversion of rural lands to industrial and residential areas is expected. This conversion is expected to affect RMA. For example, such a conversion is anticipated to continue to increase surface runoff and is expected to transform intermittent streams to perennial streams (Jackson, 2003).

RMA is classified as a temperate grassland region (see Figure 25). This area is considered a transition zone between mountain and plains habitat. As of 1996, 88% of

RMA was vegetated. Vegetation is a combination of early successional plant communities (41%), crested wheatgrass (19%) and a mix (28%) of shrubland, riparian woodland, marshes, wetlands and deciduous tree groves (USEPA, 1996).

Figure 25. Photograph of RMA terrain, with Denver in the background.

RMA has a large wildlife population. Wildlife is dominated by species of prairie, steppe and savanna communities. Twenty-six species of mammals and 176 species of birds have been observed on RMA. Included are populations of deer, bald eagles, hawks, waterfowl and the rare Cassin’s and Brewer’s sparrows (USEPA, 1996).

Two RODs were approved for the arsenal. On December 19, 1995, the Off-site ROD was signed. On June 11, 1996 the on-site ROD was signed. To coordinate and implement the remedial actions specified in the RODs, a tri-party organization, the Remediation Venture Office (RVO), was formed in October 1996 between the U.S. Army, Shell and USFWS.

More than 600 chemicals have been associated with activities at RMA (USEPA, 1996). Principal contaminants include: organochlorine pesticides, metals (arsenic, mercury) and chlorinated and aromatic solvents. Human health risks are associated with four chemicals: aldrin, dieldrin, dibromochloropropane (DBCP) and arsenic. The 1996-ROD determined that the most plausible routes of human exposure were consumption, dermal contact and inhalation. The highest risks are associated with the central portions of RMA where chemical processing and disposal occurred. The theoretical cumulative cancer risk for the no-action alternative was determined to be greater than 1×10^{-4} (USEPA, 1996).

The remedial actions at RMA fall under CERCLA and are incorporated into two operable units (OU). The On-post OU addresses contamination within the fenced-in 27 square miles of RMA proper. The Off-post OU addresses contamination outside of the RMA site (USEPA, 1996).

The On-post OU addresses 3000 acres of soil, 15 groundwater plumes and 798 structures. The selected remedy requires (USDOD, 2000b):

- Continued operation of groundwater treatment systems,
- Maintaining lake surface water levels to support aquatic ecosystems,
- Continued monitoring of surface and groundwater,
- Construction of a Toxic Substances Control Act (TSCA) compliant landfill,
- Demolition and on-site disposal of contaminated structures,
- In-situ stabilization of contaminated soils,
- In-situ thermal treatment of selected waste (i.e., Hex Pit), and
- Excavation and on-site disposal of contaminated soils and debris in a double-lined

RCRA-compliant landfill (see Figure 26).

Figure 26. Photograph of RCRA landfill under construction at RMA.

The Final Interim Institutional Plan was published February 2003 (RMA-RVO, 2003). This plan defines the following institutional controls for the RMA:

- Land Use Controls: residential development is prohibited, groundwater and surface water use as a potable source is prohibited, and fish and game consumption is prohibited.
- Preservation: wildlife habitats are to be preserved; hydrogeologic characteristics are to be protected.
- Access Control via multiple and redundant layers: a perimeter fence with controlled access points, a second inner layer is the Central Remediation Area (CRA) restricted to workers, and a third inner exclusion zone layer established for worker protection.

- Groundwater monitoring wells are protected via signs. The Army is responsible for ongoing operations and maintenance.
- A Wildlife Management Plan will be developed by the USFWS. This will include protective measures for caps and covers.
- Off-site institutional controls include notices of well restrictions.

Additional institutional responsibilities include the acquisition and delivery of 4000 acre-feet of potable water to the South Adams County Water and Sanitation District, establishment of a Trust Fund to cover an RMA Medical Monitoring Program and five-year CERCLA reviews to evaluate the remedy defined in the 1996-ROD. As of 2003, the Trust Fund was not yet established.

Active remedial operations are expected to run through 2011 and cost approximately $2.2B. On April 2, 2004, administrative jurisdiction of 4930 acres was transferred from the Army to the USFWS (USDOD, 2004; USFWS, 2004). This federal to federal land transfer did not include any environmental warranties or covenants (USDOD, 2004). A public ceremony commemorating this transfer took place April 17, 2004 (Rundle, 2004).

Observations

RMA was visited on September 10, 2003. Included as part of this visit were discussions with Mr. Tom Jackson, USFWS. Mr. Jackson provided information concerning this case and hosted a tour of RMA. Following this tour, additional information was obtained from the RMA Technical Information Center. Ms. Amira Hamdy, the Research Librarian, provided valuable source material relevant to this case study.

RMA is a large site that includes both sacrifice zones and re-use areas. The configuration of the remediated arsenal will have the contaminated material consolidated into the center of the site and the perimeter areas will serve both as a buffer zone as well as a dedicated wildlife preserve.

There is strong multi-agency involvement still evident at the site. Participating agencies include the USDOD/Army, USDOI/USFWS, USEPA, State of Colorado and the local county.

The property has been in federal ownership since the 1940s when the arsenal was developed. With the enactment of the RMANWRA, this property will remain in permanent federal ownership. As such, the entire site will eventually transfer to the USDOI for the USFWS to serve as the site stewards. This is an important component of the long-term institutional management.

With the USFWS as the site steward the environmental and ecological monitoring aspects of the site are expected to grow. This increased monitoring will likely offset the anticipated reduction in monitoring by the USDOD following completion of remedial activities.

There is strong public interest evident at this site. This interest could be attributable in part to the fact that active remedial operations are still being performed at this site. Also, with this site transitioning into the National Wildlife Refuge, the USDOI is actively promoting its positive attributes.

The local site stewards maintain a comprehensive administrative record at the site. This information repository is available to the general public. All monitoring information appears to be well maintained and is being integrated by the local stewards.

Currently, activities at the site are well funded. The entire remedial operation at RMA is anticipated to be $2.2B.

Table 10 is a chronological timeline for the RMA Case Study. This timeline highlights the key events that occurred at this site. Table 11 is a summary of the contaminant isolation facility subsystem controls present at the RMA site.

Table 10. Chronological timeline of key events for the Rocky Mountain Arsenal Case Study.

1942	RMA created by congressional action; operations begin at South Plants
1946	Manufacturing sites leased to private industry: 1946-1948 Colorado Fuel & Iron 1947-1952 Julius Hyman and Company 1952-1982 Shell Oil Company (Shell)
1952	Shell acquires Julius Hyman and Company
1952	Army initiated operations at the North Plants complex
1953 – 1957	Nerve agent GB (i.e., Sarin) manufactured at North Plants
1956	Basin F disposal pond installed on RMA
1959	Crop damage observed around RMA
1961	Army drills 12,045-foot-deep injection well
1961- 1966	165 million gallons of effluent waste disposed of
1974	Interim Response actions begin at RMA
1982	Production stops at RMA
1982	The USEPA, Army, Shell and Colorado Department of Health sign MOA
1984	USEPA CERCLA RI/FS begins
1986	Bald Eagle roosts discovered on RMA
1987	The USFWS begins managing RMA wildlife
1989	Federal Facilities Agreement signed
1992	Congress designates RMA a National Wildlife Refuge
1996	USEPA Record of Decision finalized
2000	First five-year review conducted
2004	Army transfers 4930 acres to the USFWS
2011	Proposed completion date

Table 11. Summary of contaminant isolation facility subsystem controls in place at the Rocky Mountain Arsenal Site.

Subsystem	Control	Description
Engineered	Physical Site Security	1. Entire perimeter of site is fenced, including wildlife buffer area 2. Site access office 3. Exclusion zones identified for active remediation areas
	Active Processes	4. Groundwater treatment systems 5. Leachate collection/treatment system
	Surface Covers	6. Multi-layer cap
	Subsurface Barriers	7. Stabilized waste 8. Subsurface liners
Institutional	Information Management	9. Monitoring data collected 10. CERCLA Five-year Review 11. Administrative records 12. Local information repository
	Stakeholder Awareness	13. RMA retains local and national attention
	Ordinance/Statutes	14. Rocky Mountain Arsenal National Wildlife Refuge Act
	Orders & Decrees	15. Federal Facility Agreement
	Government Ownership	16. Federal ownership of property

Spring Valley Case Study

Historical Events

Spring Valley, located in the northwestern quadrant of Washington, D.C., is home to approximately 13,000 people and includes more than 1200 private residences and numerous businesses (Tucker, 2001). A key portion of this neighborhood involves the land currently and previously occupied by the American University.

American University's beginnings date back to 1889, when the Methodist Episcopal Church acquired a 90-acre tract of land in then rural northwestern Washington, D.C. (Gordon et al., 1994a; Gordon et al., 1994b). The area, previously known as the Davis Farm, as shown in Figure 27, was acquired to be the site of a new post-graduate university. The initial groundbreaking ceremony for the university occurred in 1896 for Hurst Hall, although the university's initial class was not admitted until 1914 due to financial constraints (Tucker, 2001).

Figure 27. Photograph of the entrance to the Davis Farm (AU-Archives, 2002).

World events significantly influenced the university's operations from the very beginning. On August 1, 1914, World War I (WWI) began in Europe. This conflict quickly escalated and on April 22, 1915, Germany used chlorine gas for the first time. Chemical warfare continued to expand on both sides and in July 1917, Germany was the first country to use mustard gas (Gordon et al., 1994a).

On April 30, 1917, the Board of Trustees for American University offered the use of their campus to the U.S. government in support of the country's war efforts. The U.S. government accepted this lease offer and initially established two independent entities on the university property. On May 28, 1917, the Department of War established Camp American University and on July 21, 1917 the U.S. Bureau of Mines established the American University Experiment Station (AUES) (Sagar, 1965; Gordon et al., 1994a; Gordon et al., 1994b; Fiala, 2001).

Camp American University, later renamed Camp Leach, was operated by the Army Corps of Engineers. The mission of this Camp was to train portions of the U.S. Army's Engineering Corps. An estimated 100,000 soldiers received training at this site (USEPA, 1999a). The various engineering units trained at the Camp included Gas and Flame Regiments, Construction Regiments and Camouflage Regiments (Gordon et al., 1994b).

At the time WWI began, the United States did not possess a chemical warfare capability. The U.S. Bureau of Mines did, however, have experience with noxious mine gases and rescue equipment. Because of this experience, the Bureau was commissioned to establish the AUES and support the war efforts through large-scale testing of gases. Within eight months of its creation, and consistent with the recommendations of the Bureau, President Wilson transferred control of AUES from the Bureau to the War

Department (Gordon et al., 1994a; Gordon et al., 1994b).

Activities at AUES included toxic material studies for both offensive and defensive applications, pyrotechnical investigations, medical research and gas mask research. Toxic materials already in use in Europe (mustard gas, phosgene and superpalite) as well as new chemical agents (cyanogen chloride, bromobenzyl cyanide, etc.) were developed, manufactured and tested at AUES (Gordon et al., 1994b). To facilitate these operations, numerous structures were erected on university property. These structures included permanent facilities, temporary structures, laboratory units (as shown in Figure 28) and field-testing areas.

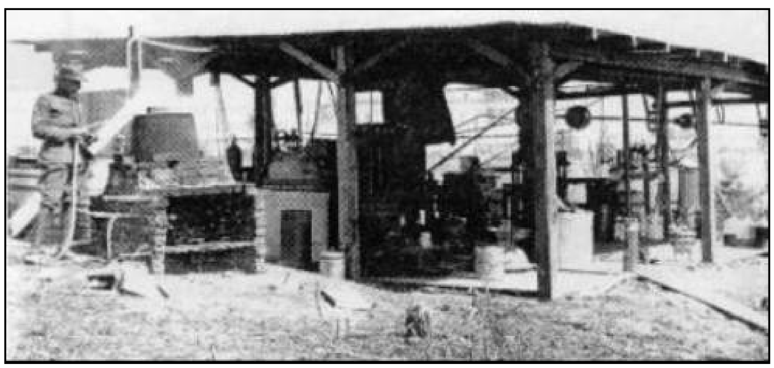

Figure 28. Photograph of open-air chemical weapons laboratory (AU-Archives, 2002).

WWI ended in November 1918. Shortly thereafter, in December 1918, the War Department ordered the suspension of operations and the demobilization of AUES (Gordon et al., 1994b). The extent of operations at that time is shown in Figure 29. Demobilization efforts included returning the property to its original landscape (Arnold, 2002). Temporary wooden structures were demolished, trenches and pits were backfilled and, following negotiations, permanent structures were transferred to the university. The majority of the property was returned to the American University and other property owners during 1920 and the remaining portions were returned in 1921 (Gordon et al., 1994b; Fiala, 2001; Arnold, 2002).

Figure 29. Aerial photograph of Spring Valley area taken in 1918 (AU-Archives, 2002).

Classes resumed on the American University campus in 1924. The university and the surrounding area benefited from the infrastructure upgrades made by the War Department, which included enhanced utility supply lines (i.e., water, gas), improved and paved roadways and rail service. The area surrounding American University continued to develop and additional residential homes were constructed (Gordon et al., 1994b).

The university again supported the U.S. government during WWII. Portions of the university were leased to the government, although the use of the property was limited to classroom education rather then any chemical operations (Engel, 1941; Gordon et al., 1994b).

Following WWII, the population of Washington, D.C. continued to grow and expand. The population in the Spring Valley area was reported to have doubled during the 1940s and additional residential developments were constructed throughout the area (Gordon et al., 1994b). Portions of the university property were transferred for development during that timeframe and as recently as 1990 (Santana, 2002).

In 1986, American University was also expanding. A major construction project included the development of the Adnan Khasshogi Sports and Convocation Center (Jaffe, 2000; Vogel, 2001; Arnold, 2002). Prior to construction, university representatives requested a review of historic records with regard to the past military operations. The USEPA and the U.S. Army Corps of Engineers (USACE) reviewed historic aerial photographs (see Figure 28) and concluded there was no evidence to take further action (Jaffe, 2000; Tucker, 2001; Vogel, 2001; Arnold, 2002; USGAO, 2002a).

On January 5, 1993, construction workers were excavating trenches along the 52nd Court area in Spring Valley when they uncovered several unknown items (Taylor, 1993; Jaffe, 2000; Tucker, 2001; Vogel, 2001; USGAO, 2002a). The USACE conducted an emergency response and subsequently recovered approximately 141 suspect objects, including 43 containing chemical agents (Tucker, 2001; USACE, 2001; Vogel, 2001). Subsequent to these actions, the USACE initiated "Operation Safe Removal," which included a broad area survey of approximately 492 properties (USACE, 2001; USACE, 2002). Numerous anomalies were identified and investigated as part of this action. The majority of anomalies were found to be construction debris and ordnance fragments, however, several intact ordnance were also recovered. This two-year effort concluded in a second "no further action" decision in 1996 (USACE, 2001; USGAO, 2002a). The District of Columbia subsequently questioned this decision. As a result of these questions, the USACE reviewed this decision and identified that there was an error in their previous survey (USACE, 2001; Vogel, 2001; USACE, 2002).

In 1998, the USACE re-investigated a point of interest from the previous survey (USACE, 2003). This geophysical investigation centered on the Glenbrook Road area of Spring Valley. Two large metallic anomalies were identified at 4801 Glenbrook Road, which was the residence of the South Korean ambassador as shown in Figure 30 (Vogel, 2001; USACE, 2002). During 1999, remedial operations began that ultimately recovered more than 600 items, including 288 ordnance-related items of which 14 were determined to contain chemical agents (Fiala, 2001; USACE, 2002; USGAO, 2002a; USACE, 2003).

Figure 30. Photograph of remedial operations at Spring Valley.

As a result of these discoveries, an expanded area involving 61 private residences as well as portions of American University were surveyed in 2000 (Fiala, 2001). These surveys identified elevated arsenic levels in soils and additional buried anomolies (Fiala, 2001). In 2001, the soil surveying was expanded to include 1200 residential properties and 400 non-residential lots (Fiala, 2001; USACE, 2001). Remedial operations have also continued to expand along adjacent properties in the Glenbook Road region (USACE, 2002; USGAO, 2002a). As of 2001, the impact area included 70 acres of American University and 591 acres of homeowner residences, including 14 embassy residences (Fiala, 2001). The selected remedy is excavation and off-site landfill disposal (USACE, 2003). The remediation endpoint for arsenic-contaminated soils is 20 mg/kg, which is a risk-based value for residential surface soils corresponding to a cancer risk of 1 x 10^{-4}. (USACE, 2003).

The primary health risks prevalent at the Spring Valley site include injuries or deaths resulting from ordnance explosions, leaking chemical agents and exposure to arsenic-contaminated soils (USGAO, 2002a). The costs associated with remedial operations have continued to escalate (USGAO, 2002a). As of 2002, the projected cost of remediation for the Spring Valley site was $125M (USGAO, 2002a). In addition, several civil lawsuits have been filed concerning potential damages resulting from the site's residual hazards (Anderson, 2001; Santana, 2002).

Observations

The Spring Valley site was visited April 17, 2002. Included as part of this visit were discussions with Mr. George Arnold, the American University Archivist. Mr. Arnold provided background information concerning this case and made available for review the university's archive collection. This collection contained valuable source material relevant to this case study. An area tour was also conducted as part this site visit. This included observations at the active USACE remediation site along Glenbrook Road.

The Spring Valley case can be viewed from two distinct timeframes: the original Spring Valley case and the current Spring Valley case. The original Spring Valley case involves those events from the 1920s through the 1980s. The current Spring Valley case involves relatively current events since the discovery of chemical weapons ordinance in 1993 and represents the current activities at the site.

Waste disposal at the original Spring Valley site involved shallow land disposal in earthen pits and trenches. No information management system was maintained. No active public involvement was evident. No local government involvement was evident. No monitoring was evident. Site security was not a concern.

Following the landscape remediation in the 1920s (i.e., surface leveling and on-site shallow land disposal), the properties were returned to American University and the surrounding landowners. These lands were re-used by the university and other property owners. Portions of these properties were subsequently transferred to other owners as the general population began to encroach on the site (ingress scenario).

Considerable development occurred at this site and its surrounding areas. No significant events were reported for some 70 years. Issues began to surface in the early 1990s.

The current Spring Valley case can be characterized by a series of non-time critical and emergency actions. These actions arose as the result of the unexpected discovery of ordinance and chemical contaminants. As a result of these actions, there remains an elevated interest by the local community. Local information repositories are maintained that include administrative records as well as historic archives.

Active operations are taking place throughout the Spring Valley area as shown in Figure 31. These actions include non-time critical removal actions and emergency removal actions as well as area surveys to further characterize the site and define the problems.

Figure 31. The USACE coordinates remedial operations at Spring Valley.

Several legal disputes are still under consideration. These disputes appear to be focused on the issue of accountability with regard to the original on-site disposal. Multiple agencies are involved with the current Spring Valley site. These include the USDOD, USEPA and District of Columbia.

Table 12 is a chronological timeline for the Spring Valley Case Study. This timeline highlights the key events that occurred at this site. Table 13 is a summary of the subsystem controls present at the Spring Valley site.

Table 12. Chronological timeline of key events for the Spring Valley Case Study.

1889-1890	Methodist Episcopal Church acquires 90 acres in NW Washington, D.C. to establish a post-graduate university.
1896	Groundbreaking ceremony for first university building, Hurst Hall.
1914	WWI begins in Europe. (August 1)
1915	Germany uses chlorine gas. (April 22)
1917	American University Board of Trustees offers use of the campus to the U.S. government in support of WWI via lease arrangement. (April 30)
1917	Camp American University established by the Army Corps. (May 28)
1917	Germany uses mustard gas. (July)
1917	American University Experiment Station established by the Bureau of Mines. (July 21)
1918	President Wilson transfers AUES to the War Department. (July 25)
1918	WWI ends. (November 9)
1918	War Department suspends operations and orders demobilization of AUES. (December)
1921	Property transferred back to American University. (June 30)
1924	American University resumes academic operations on campus.
1937-1941	Portions of American University property leased to the U.S. government in support of WWII.
1986	American University, preparing for a large construction project, requests the U.S. Army review historic records concerning past operations. Army concludes No Further Action needed. (October)
1993	Excavation at a nearby residence discovers ordnance and unknown chemicals. (January 5) A total of 141 munitions were found with 43 containing chemical agents.
1993-1994	Army Corps conducts emergency actions and area survey of 53 additional locations.
1996	Army concludes No Further Action required. (June) The USEPA concurs.
1997	The District of Columbia, Department of Health, raises additional concerns. Army discovers an error in its survey locations. (September)
1998	Army Corps uncovers two buried ordnance pits at the South Korean Ambassador's residence during its re-survey. (February)
1998-2001	Emergency actions and active remediation.
2002	Army Corps initiates a broader survey of 1483 properties.

Table 13. Summary of contaminant isolation facility subsystem controls in place at the current Spring Valley Site.

Subsystem	Control	Description
Engineered	Physical Site Security	1. Site security at current Removal Action sites
	Surface Covers	2. Earthen-covered shallow burial from original disposal
	Subsurface Barriers	3. Unlined shallow burial from original disposal
	Active Processes	4. Emergency and non-time critical removal actions 5. Site surveys and site sampling
Institutional	Information Management	6. Local information repository 7. Survey and sampling data collected 8. Administrative records
	Stakeholder Awareness	9. Spring Valley has local and federal attention
	Ordinance/Statutes	10. CERCLA

Canonsburg UMTRCA Disposal Cell Case Study

Historical Events

The Canonsburg UMTRCA Disposal cell is located within the Borough of Canonsburg, PA, which is located 20 miles southwest of Pittsburgh, PA, as shown in Figure 32. The site is directly adjacent to Chartiers Creek on the north and west, Strabane Ave. on the east and a railroad on the south.

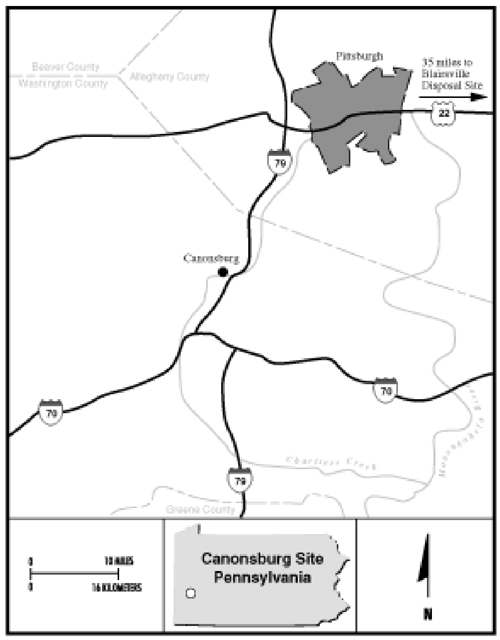

Figure 32. Map showing location of Canonsburg UMTRCA site (USDOE, 2001f).

The site's association with radioactive material began in 1911. At that time, a 19-acre site within the Borough and owned by Standard Chemical, was selected as the location for a radium extraction plant (USDOE, 1997a; USDOE, 2001b). This plant extracted radium from uranium ore. In addition to the extracted radium, large volumes of tailings were produced as operational by-products. These uranium tailings contained naturally occurring radioactive material. This material decays to radium and produces radon, a radioactive gas. In addition to this radioactive material, the tailings contained trace metals that were associated with the ore as well as the chemicals used during the extraction process.

Standard Chemical operated this radium extraction plant from 1911 until 1922. Operations continued at the site between 1930 and 1942 for the extraction of uranium and radium salts (USDOE, 2002c). In 1942, Vitro Manufacturing Company (Vitro), later known as Vitro Corporation of America, acquired the property (USDOE, 2002c). From 1942 through 1957, Vitro processed uranium ore under contract to the federal government. In 1957, the Vitro plant closed. From 1957 through 1966 the site was used for storage under an Atomic Energy Commission contract (USDOE, 2002c). In 1967, the property was purchased by the Canon Development Company and portions of the site were leased to private companies for light industrial use as the Canon Industrial Park (USDOE, 1996; USDOE, 1997a; USDOE, 2002c).

The UMTRCA of 1978 established the requirements for the clean-up of 24 abandoned mill tailing sites that had processed uranium and related ores for the federal government. Under UMTRCA, the USEPA was directed to set general standards for the clean-up at these sites and vicinity properties. In addition, UMTRCA authorized the USDOE to clean-up the sites to meet USEPA standards and authorized the USNRC to oversee and certify the clean-up and license the completed disposal cell (USNRC, 2003a; UMTRCA 1978).

In 1982, the USDOE and the Commonwealth of Pennsylvania entered into a Cooperative Agreement. This agreement defined the roles and responsibilities of each party as they related to the remediation of the Canonsburg site. Included in this agreement was definition of the cost-sharing arrangements. These arrangements stated that the USDOE was accountable for 100% of the site assessment costs and 90% of the site remediation costs. The Commonwealth of Pennsylvania was accountable for 10% of the site remediation costs, although the USDOE was accountable for 90% of the Commonwealth's costs. Thus, the USDOE was accountable for 99% of the site remediation costs (USDOE, 1996).

In accordance with UMTRCA, the Commonwealth of Pennsylvania acquired the designated properties during the period of November 1983 through February 1985 (USDOE, 1995). The Commonwealth acquired these parcels through its Department of Environmental Resources. Subsequent to these acquisitions the site has been organized into three parcels, Area A, B and C. Figure 33 is a map of the site showing these areas.

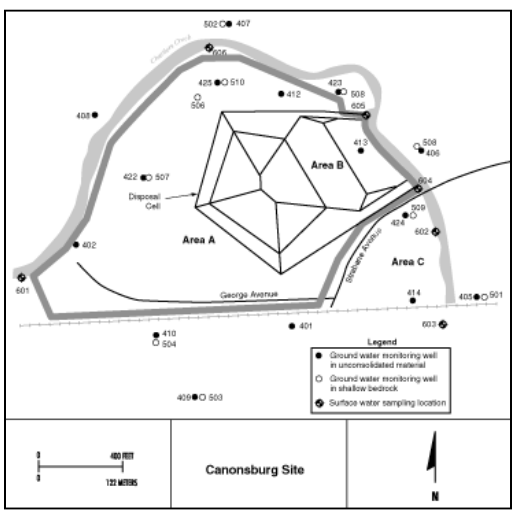

Figure 33. Site map showing Areas A, B, C and the disposal cell (USDOE, 1995).

Remedial actions at the Canonsburg site began in 1983. In addition to these three primary site parcels (Areas A, B and C), approximately 163 vicinity properties were also identified as being potentially contaminated. The remedial operations involved the on-site consolidation and stabilization of residual radioactive material (RRM) from the former processing operations. The estimated volume of RRM consolidated at the Canonsburg site ranges from 192,000 to 376,100 cubic yards (USDOE, 1996; USDOE, 2001f; USDOE, 2002c; USDOE, 2004b). This includes RRM from the three primary site parcels as well as from the 163 adjacent properties. The total activity of this RRM is estimated to be 100 curies (USDOE, 2004b).

One vicinity property, the Burrell site, was handled under a separate remedial action due to the volume of RRM transported from the Canonsburg site and subsequently located at that site. Approximately 54,000 cubic yards of material were moved from the Canonsburg site to the Burrell site from 1956 and 1957. Refer to the Burrell Case Study for additional details on this site.

The consolidated RRM was disposed of on-site in the Canonsburg Disposal Cell. This disposal cell is approximately six acres in size. The cell includes a multi-layer engineered cover as well as engineered subsurface barriers. A compacted clay bottom-liner serves as the base layer on which the RRM tailings were placed. The RRM was then covered with a 3-foot radon barrier, which consists of a clay-and-soil mixture. The radon barrier was subsequently covered with a two-foot-thick riprap erosion protection layer of rock and a one-foot-thick soil layer that was seeded with native grass (USDOE, 1996; USDOE, 2002c). Construction of the disposal cell were completed in 1985.

Following the completion of remedial actions and concurrence by the USNRC, the Commonwealth of Pennsylvania transferred the ownership of two primary properties

(Areas A and B) to the United States on September 13, 1995 (Pennsylvania, 1994). The third portion, Area C, was to be transferred to the Borough of Canonsburg for public use consistent with provisions of UMTRCA (USDOE, 1995; USDOE, 1996; UMTRCA 1978). According to recent USDOE reports, the Commonwealth still retains title to Area C and is currently attempting to sell it (USDOE, 2004b; USDOE, 2004a).

In 1996, the USNRC issued a license for the Canonsburg Disposal Cell and management of the Canonsburg site was transferred to the DOE Grand Junction Office, which manages the site through its Long-Term Surveillance and Maintenance Program (LTSM) (USDOE, 1997a). The LTSM Program was established to maintain human health and environmental protection at former nuclear research and development sites (USDOE, 2004b). In December 2003, the DOE Office of Legacy Management (LM) was established. The LTSM Program responsibilities have been incorporated into this new LM organization (USDOE, 2004b).

A long-term surveillance plan was prepared specifically for the Canonsburg site. This surveillance plan defines the management requirements for the site. These requirements include: annual inspections of the site to evaluate the condition of surface features, routine site maintenance including cutting the grass at least once each year and control of other vegetation, performing other maintenance as necessary and continuing to monitor groundwater.

The surveillance plan also defines the specific institutional controls that need to be implemented at the site. These institutional controls include:

- Access controls/fencing,
- Warning signs,

- Site markers and monuments,
- Erosion control markers along Chartiers Creek,
- Annual inspections,
- Routine maintenance, and
- Groundwater monitoring (USDOE, 1995).

The site has required a variety of maintenance actions since the disposal cell was completed. The most significant maintenance repair included the stabilization of the stream bank of Chartiers Creek, which runs adjacent to the disposal cell. Bank erosion was reported in the late 1990s. The eroded areas were repaired in 2000-2001 (USDOE, 2002a). Included in these repairs were the decommissioning of impacted groundwater wells and the replacement with new wells.

The site monitoring program includes annual requirements for both surface water and groundwater monitoring. Groundwater monitoring is expected to continue at the site due to detection of uranium, at levels in excess of the maximum concentration limit, in two groundwater wells (USDOE, 2002a; USDOE, 2004a).

Observations

The Canonsburg site was visited June 13, 2003. Since there are no local site stewards at this site, this visit was un-hosted, but approved by Mr. Carl Jacobson of the LTSM Project Office in Grand Junction, CO. Mr. Jacobson provided a map of the site and an access key for the locked access gate. Following this visit, additional information was obtained from Grand Junction and other sources to complete this case study.

The Canonsburg UMTRCA Site can best be described as a permanent “sacrifice zone." There is no buffer zone around the disposal cell. At the present time, the site that involves Areas A and B, as illustrated in Figure 33, is fenced off and separated from local use, as shown in Figure 34. Area C is adjacent to the disposal cell. This area is not fenced but warning signs are present at this location.

Figure 34. Photograph of Canonsburg UMTRCA Disposal Cell.

There is no re-use evident at the site. However, because of the site's location within the Borough of Canonsburg and its very close proximity to the local population, there would appear to be considerable potential for the area's re-use. For example, the USDOE reports that the State of Pennsylvania is considering the sale of Area C (USDOE, 2004a).

The current land use of the immediate area is primarily residential, although historic land use was a combination of industrial and residential use. The population of Canonsburg was approximately 9200 as of 1990. The site is highly visible as it is directly adjacent to a public roadway, a railroad track, residential housing and Chartiers Creek.

There is no local involvement evident at the site. There was no evidence of a local information repository or of local community involvement. The responsible site stewards are located more than 1000 miles away in Grand Junction, CO. Notification arrangements have been made with state and federal agencies to notify the site stewards if certain natural events happen in the general vicinity of the site (USDOE, 2001c). These events include earthquakes and floods.

There was multi-agency involvement and cooperation at the Canonsburg site. This appeared particularly evident during the remedial design phase. This involvement included multiple federal agencies (USEPA, USDOE, USNRC, USACE) and the State of Pennsylvania. Local government participation, however, was not obvious.

The site is being maintained. The cell has a grassed soil cover. The grass is cut at least annually. The site stewards also perform an annual inspection (USDOE, 2004b). Annual inspections include surface water and groundwater monitoring (USDOE, 2004c). Groundwater samples continue to detect uranium (USDOE, 2002a).

The cell is directly adjacent to Chartiers Creek as shown in Figure 35. Bank erosion along the creek damaged two groundwater wells and erosion monuments since the cell was completed. These wells have since been repaired.

The DOE in Grand Junction, CO maintains information relative to this site. This information appears to be maintained in paper form. A limited amount of information is also available and distributed in electronic form via the Internet. Additional information is also becoming displayed in a geographical information system (GIS) format. Performance data appears to be readily maintained by site stewards. This information appears to be integrated and evaluated and performance trends are being determined.

Figure 35. Photograph of Chartiers Creek with Canonsburg Disposal Cell in background.

Table 14 is a chronological timeline for the Canonsburg Case Study. This timeline highlights the key events that occurred at this site. Table 15 is a summary of the contaminant isolation facility subsystem controls present at the Canonsburg site.

Table 14. Chronological timeline of key events for the Canonsburg Case Study.

1911	Standard Chemical acquires 19 acres in Canonsburg, PA. Property is adjacent to railroad tracks and Chartiers Creek.
1911-1922	Standard Chemical operates radium extraction processing plant.
1930-1942	Additional extraction operations conducted at site.
1942	Vitro Manufacturing Company (Vitro), later known as Vitro Corporation of America, acquires property.
1942-1957	Vitro operates radium extraction processing plant at site.
1956-1957	Vitro ships 11,600 tons of RRM to Burrell site.
1957	Vitro extraction plant closes.
1957-1966	Property and facilities used for storage under an Atomic Energy Commission contract.
1967	The Canon Development Company purchases the property.
1967	Portions of property leased private industry as part of Canon Industrial Park.
1978	UMTRCA enacted.
1982	Commonwealth of Pennsylvania and the USDOE sign Cooperative Agreement.
1983	The Commonwealth of Pennsylvania and the U.S. government take title to the property.
1983	Record of Decision signed.
1983-1985	Remedial actions at site.
1985	UMTRCA disposal cell completed on-site.
1995	Commonwealth of Pennsylvania transfers ownership of two primary portions of the site to the U.S. government (USDOE).
1996	U.S. Nuclear Regulatory Commission issues license for disposal cell.
1996	USDOE/USNRC concur that remedial action is complete and is site transferred to USDOE LTSM Program.
2000-2001	Chartiers Creek bank erosion repairs completed.
2003	LTSM responsibilities transferred to new DOE Office of LM.
2004	Proposed sell of a portion of the site (Area C).

Table 15. Summary of contaminant isolation facility subsystem controls in place at the Canonsburg Site.

Subsystem	Control	Description
Engineered	Physical Site Security	1. Disposal cell area is fenced 2. Warning signs posted on fence
	Surface Covers	3. Multi-layer cap
	Subsurface Barriers	4. Low-permeable compacted clay bottom liner 5. Groundwater monitoring wells
Institutional	Information Management	6. Annual site inspections (reports available for 2001) 7. Groundwater measurements - Levels measured annually - Samples collected annually 8. Records maintained at Grand Junction, CO
	Stakeholder Awareness	9. Internet webpage maintained
	Ordinance/Statutes	10. The Uranium Mill Tailings Radiation Control Act of 1978
	Orders & Decrees	11. U.S. Department of Energy and State of Pennsylvania Cooperative Agreement
	Government Ownership	12. Federal ownership of disposal cell area 13. State ownership of adjacent property

Burrell UMTRCA Disposal Cell Case Study

Historical Events

The Burrell UMTRCA Disposal Site is located in a rural setting approximately 1 mile from the Borough of Blairsville in Indiana County, PA and approximately 40 miles east of Pittsburgh, PA, as shown in Figure 36. The Conemaugh River directly borders the site on the south. A railroad track of the Norfolk Southern Rail Corporation directly borders the site on the north (USDOE, 2001a).

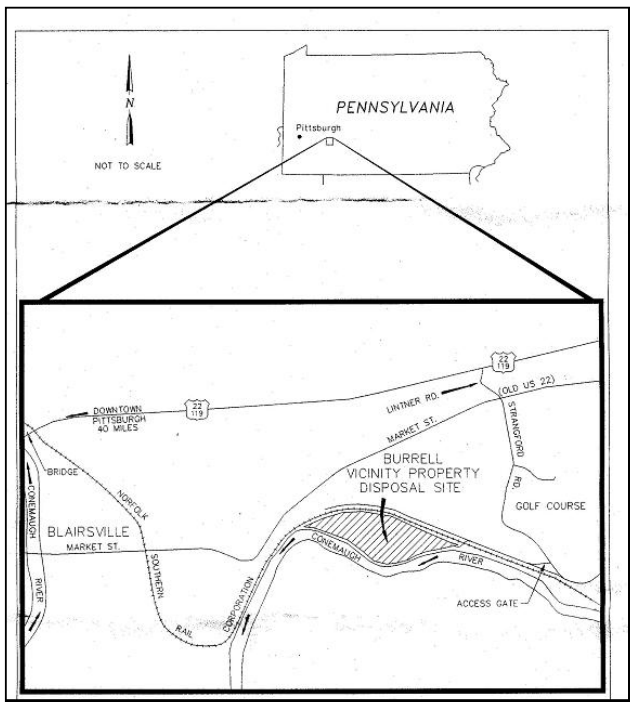

Figure 36. Map showing location of Burrell UMTRCA Disposal Cell (USDOE, 2000b).

The property has been associated with rail service since 1882 when the Western Pennsylvania Railroad Company acquired the property (USDOE, 2002b). Ownership of the Burrell site property has changed several times since the 1880s. Each of the subsequent owners has been a railroad company that has continued to use and modify or enhance the property for the purposes of supporting rail operations.

During the 1940s the Pennsylvania Railroad Company used the area as a landfill and a considerable amount of fill material was placed on the property to level its grade. This fill material consisted of gravelly loam, cinders, gravel, sandstone, construction debris, etc. As a result of these activities, the site is in essence, a small man-made plateau consisting of fill material measuring 50 to 60 feet in depth. Beneath this fill, claystone and shales of the Pennsylvanian Casselman Formation underlie the entire site (USDOE, 2000b).

A portion of this fill material, approximately 11,600 tons of RRM, was transported from the previously discussed Canonsburg site, from 1956 through 1957 (USDOE, 2000b). Since the Canonsburg site was classified as an UMTRCA Title I site, the Burrell site was subsequently classified as a “vicinity property” also subject to environmental remediation under UMTRCA. Due to the large volume of RRM involved, an on-site disposal cell was constructed at Burrell rather than relocating the material back to the Canonsburg site.

UMTRCA established the requirements for the environmental remediation of 24 abandoned, uranium mill tailing sites located throughout the U.S. Each of these sites was involved with the mining or processing of uranium and related ores for the federal government (USDOE, 2001g). UMTRCA directed the USDOE to coordinate the remediation of these sites, authorized the USEPA to establish standards for the remediation of these sites and authorized the USNRC to certify and license the completed disposal cells (USNRC, 2003a; UMTRCA 1978).

On July 14, 1986, the U.S. federal government (i.e., the USDOE) took title to the land from the Commonwealth of Pennsylvania (USDOE, 2000b).The Burrell site encompasses approximately 72 acres. RRM has been consolidated into a five-acre on-site disposal cell. The cell contains 86,000 tons of RRM with the total cell radioactivity calculated to be 4 Ci ^{226}Ra (USDOE, 2001a). The Burrell disposal cell was capped and closed in 1987. The disposal cell is intended to properly function for 1000 years but at a minimum it is required to last at least 200 years (USDOE, 2001a).

The Burrell Disposal Cell cap consists of three layers. A 3-foot-thick low-permeability radon barrier, consisting of a compacted soil layer, was installed directly above the RRM. The purpose of this primary layer is to prevent the escape of radon gas and prevent the infiltration of precipitation. Above the radon barrier a 1-foot-thick soil-bedding layer was installed. The purpose of this second drainage layer was to promote precipitation runoff. The third, and outer-most layer, consists of a 1-foot-thick riprap layer. This cover layer was designed to prevent surface erosion (USDOE, 2001a).

Soon after the cell was constructed, the USDOE began to report observations of plant growth on the cell’s riprap cover. These observations were reported in 1988. Within three years of the cell’s construction, a diverse plant community was reported to be present on the cell cap. Within ten years of construction, the two top layers of the cap, the riprap cover layer and the compacted soil drainage layer, were believed to have been penetrated by the vegetative community (USDOE, 1999b; Waugh, 2004). The vegetative growth was evident during the site visit and is shown in Figure 37.

Figure 37. Photograph of Burrell UMTRCA Disposal Cell illustrating vegetative community present on riprap cover.

In 1988, the DOE Grand Junction Office was assigned the responsibility of managing the site, as well as all UMTRCA sites, through the DOE LTSM Program. The LTSM Program was established to maintain human health and environmental protection at former nuclear research and development sites (USDOE, 2004b). In December 2003, the DOE LM Office was established. The LTSM Program responsibilities have been incorporated into this new LM organization (USDOE, 2004b).

Ongoing LM management responsibilities include the development and implementation of a long-term surveillance and maintenance plan for each site. A long-term surveillance plan was prepared for the Burrell site. In accordance with this long-term surveillance plan, the USDOE maintains access controls, permanent markers and signs; conducts annual inspections; performs routine maintenance as necessary; monitors the groundwater; and maintains appropriate emergency response capabilities (USDOE, 2000b; USDOE, 2004a).

The initial long-term surveillance and monitoring plan required monitoring both groundwater and surface water at the site as a best management practice to evaluate potential performance trends. Recommended changes to the monitoring plan have been noted in the 2002 Annual Compliance Report (USDOE, 2000b). These modifications include discontinuing vegetation control on the cell cover, reducing groundwater monitoring frequency to once every five years, elimination of two wells for groundwater monitoring, eliminating surface water monitoring on the Conemough River, discontinuing analyses for ammonia, cyanide, gross alpha, radium-226, radium-228 and vanadium and removing reference to a site marker that was never installed.

Observations

The Burrell site was visited on June 12, 2003. Since there are no local site stewards at this site this visit was un-hosted but approved by Mr. Carl Jacobson of the LTSM Project Office in Grand Junction, CO. Mr. Jacobson provided a map of the site and an access key for the locked access gate. Following this visit, additional information was obtained from Grand Junction and other sources to complete this case study.

The Burrell UMTRCA Site can best be described as a permanent “sacrifice zone.” There is no re-use potential evident at the site. The disposal cell area is fenced off and separated from local use. A second gate and warning sign was located at the main entrance road on neighboring railroad property. This gate was observed to be damaged and permanently open during the site visit. Apparently, this had been a recurring problem. The LTSM Project Office, with the concurrence of the USNRC, removed this gate later in 2003 (USDOE, 2004d; USDOE, 2004b; USDOE, 2004a).

There is no local involvement evident at the site. There was no evidence of a local information repository or of local community involvement. The responsible site stewards are located in Grand Junction, CO, which is more than 1000 miles away. Notification arrangements have been made with state and federal agencies to notify the site stewards if certain natural events happen in the general vicinity of the site (USDOE, 2001c). These events include earthquakes and floods.

There was multi-agency involvement and cooperation at the Burrell site, particularly during the remedial design phase. This involvement included multiple federal agencies (USEPA, USDOE, USNRC, USACE) and the State of Pennsylvania. Local government participation was not obvious.

Original post-closure environmental monitoring at this site involved groundwater and surface water sampling. However, within 15 years of the cell completion, monitoring has been reduced. Surface water is no longer monitored and the groundwater sampling frequency has been reduced from annual sampling to once every five years (USDOE, 2004c).

The engineered cover on the disposal cell has experienced unanticipated plant growth. Within one year of construction, local plant species were found growing on the cover. These plants were established communities on the cover within three to five years. The site stewards attempted to minimize the growth of these plants through periodic spraying of herbicides. This practice has since been halted. Site stewards have estimated that the hydraulic conductivity through the barrier has increased by two orders of magnitude as the result of the plant growth. A revised risk analysis, however, showed that this plant growth did not increase the risk potential to unacceptable levels (USDOE, 2004a). This decision is to be reevaluated in 10 or 20 years (USDOE, 2004a).

The DOE Grand Junction, CO Office maintains information relative to this site. This information appears to be maintained in paper form. A limited amount of information is also available and distributed in electronic form via the Internet. Additional information is also becoming displayed in a GIS format. Performance data appears to be readily maintained by site stewards. This information appears to be integrated and evaluated and performance trends are being determined.

Table 16 is a chronological timeline for the Burrell Case Study. This timeline highlights the key events that occurred at this site. Table 17 is a summary of the contaminant isolation facility subsystem controls present at the Burrell site.

Table 16. Chronological timeline of key events for the Burrell Case Study.

1882	Portions of property acquired by Western PA Railroad.
1937	Portions of property acquired by PA Railroad Co.
1940s	PA Railroad constructs berm along Conemaugh River.
1940-1960	Railroad wastes disposed of on property .
1956-1957	Vitro Rare Metals Plant in Canonsburg, PA ships 11,600 tons of RRM to Burrell site.
1978	UMTRCA enacted.
1979	Environmental assessment of site performed.
1980	Mr. George Burrows takes title of property.
1986	U.S. government (i.e., the USDOE) takes title to the property.
1986-1987	Remedial actions at site performed.
1987	UMTRCA disposal cell completed on-site.
1988	Growth of plants observed on rock cover.
1990	Plant community established on rock cover.
1994	USDOE/USNRC concur that remedial action complete and site transferred to DOE LTSM Program.
1995-1997	Plant intrusion field studies conducted.
1999	Determination made to stop herbicide spraying of cover.
2000	Long-term surveillance plan revised - vegetative controls discontinued - surface water sampling discontinued - groundwater sampling frequency changed from annual to 5 years
2003	LTSM responsibilities transferred to new DOE Office of LM.

Table 17. Summary of contaminant isolation facility subsystem controls in place at the Burrell Site.

Subsystem	Control	Description
Engineered	Physical Site Security	1. Disposal cell area is fenced 2. Warning signs posted on fence 3. Access road has sign and gate, although gate is permanently open and in a state of decay
	Surface Covers	4. Multi-layer cap
	Subsurface Barriers	5. Groundwater monitoring wells
Institutional	Information Management	6. Annual site inspections (reports available for 2002 and 2003) 7. Groundwater measurements • Levels measured annually • Samples collected every 5 years 8. Records maintained at Grand Junction, CO
	Stakeholder Awareness	9. Internet webpage maintained
	Ordinance/Statutes	10. The Uranium Mill Tailings Radiation Control Act of 1978
	Orders & Decrees	11. U.S. Department of Energy and State of Pennsylvania Cooperative Agreement
	Government Ownership	12. Federal Ownership

Case Study Summary

These seven case studies illustrate the variations currently being used to isolate residual contaminants at various sites in different states and managed by a variety of responsible parties. Each of these cases highlights the historic events and the regulatory framework that have shaped the site's current situation. These studies also describe the types of controls that are being used to maintain isolation of the known contaminants.

The contaminant isolation facility constructed at each of these sites and the management structure employed to maintain the integrity of the contaminant isolation facility have been described. This discussion presents an overview of the subsystem elements that are being used at each location. The two primary subsystems employed are the engineered subsystem and the institutional controls subsystem.

Although each of the cases has unique contaminant isolation facility configurations they all share a multi-control approach. Table 18 summarizes the controls implemented at each of the selected case studies. As discussed in Chapter II, each of these controls must be monitored and maintained to ensure their long-term effectiveness. As evidenced in these case studies, not all controls are performing as expected. Several of the cases exhibit errors at the individual control levels. Table 19 highlights the individual controls that could be precursors to future problems including contaminant isolation facility failure. Chapter VI will begin to explore the failure mechanisms evident in these controls.

Table 18. Summary of current controls implemented at the selected case studies.

	Information Management	Stakeholder Awareness	Zoning	Ordinances	Orders & Decrees	Permit System	Deed Restrictions	Contracts	Government Ownership	Physical Site Security	Surface Covers	Subsurface Barriers	Active Processes
Anaconda	★	★	NA	★	★	★	★	★	NA	★	★	★	★
Love Canal (original)	NA	★	NA	NA	NA	NA	NA	NA	NA	★	★	★	NA
Love Canal (current)	★	★	★	★	★	NA	★	★	★	★	★	★	★
Maxey Flats	★	★	★	★	★	NA	★	NA	★	★	★	★	★
Rocky Mt. Arsenal	★	★	NA	★	★	NA	NA	NA	★	★	★	★	★
Spring Valley (original)	NA	NA	NA	NA	NA	NA	NA	★	NA	★	★	★	NA
Spring Valley (current)	★	★	NA	★	NA	NA	NA	NA	NA	★	★	★	★
Canonsburg	★	★	NA	★	★	NA	NA	★	★	★	★	★	NA
Burrell	★	★	NA	★	★	NA	NA	★	★	★	★	★	NA

★ = Controls in place
NA = Controls Not Applied at this Site

Table 19. Summary of individual controls exhibiting error characteristics at the selected case studies.

	Information Management	Stakeholder Awareness	Zoning	Ordinances	Orders & Decrees	Permit System	Deed Restrictions	Contracts	Government Ownership	Physical Site Security	Surface Covers	Subsurface Barriers	Active Processes
Anaconda	+	+	**NA**	+	+	+	+	+	**NA**	+	+	+	+
Love Canal (original)	**NA**	—	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	+	+	+	**NA**
Love Canal (current)	+	—	+	+	+	**NA**	+	+	+	—	+	+	+
Maxey Flats	+	+	+	+	+	**NA**	+	**NA**	+	+	+	+	+
Rocky Mt. Arsenal	+	+	**NA**	+	+	**NA**	**NA**	**NA**	+	+	+	+	+
Spring Valley (original)	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	—	**NA**	—	—	—	**NA**
Spring Valley (current)	+	+	**NA**	+	**NA**	**NA**	**NA**	**NA**	**NA**	+	+	+	+
Canonsburg	+	—	**NA**	+	+	**NA**	**NA**	+	—	+	+	+	**NA**
Burrell	+	—	**NA**	+	+	**NA**	**NA**	+	+	+	—	+	**NA**

\+ = Controls in place
— = Controls exhibiting "Error" characteristics
NA = Controls Not Applied at this site

CHAPTER VI

CROSS CASE ANALYSIS

The case studies presented in Chapter V highlight the various institutional controls and engineered barriers used to isolate contaminants for long periods. The individual mechanisms used as well as how they are applied, tend to differ from site to site. In each of these cases, multiple controls are being employed. The applied controls can be viewed as a collection of institutional and engineered controls as presented in Table 18.

The combination of selected controls is believed to offer increased protection against system failure. This approach is often referred to as defense-in-depth or a layering of controls (NRC, 2000). Through the application of multiple controls, the contaminant isolation facility is considered to be more robust and less likely to result in the re-exposure of receptors to the residual contaminants.

This chapter evaluates the complete set of institutional controls and engineered barriers routinely employed at contaminant isolation facilities. The individual controls are analyzed to determine how these controls could ultimately fail. This evaluation describes the most probable error pathways for each control as well as identifies interactions between controls.

This analysis is focused on unintentional precursors and events that could contribute to failure. Intentional violations and deliberate acts with the intent to destroy or damage the contaminant isolation facility, such as sabotage, fraud or other illegal actions, present unique concerns and are not included in this analysis.

Fault Tree Analysis (FTA)

As previously stated, FTA is an analytical technique that describes the collection of events that must occur to explain a described state of a system. Fault trees are routinely used by the USNRC for reliability engineering (Vesely et al., 1981; Gertman and Blackman, 1994). Recently, master logic diagrams have been used to evaluate active chemical storage plants (Papazoglou and Aneziris, 2003).

The FTA process is initiated by first defining an undesired state of the system. For the purposes of this research the undesired state is described as *Failure of Contaminant Isolation Facility Controls.* An analysis of the details of this condition was then performed to determine logical ways in which the undesired event could occur (Vesely et al., 1981).

Fault trees were developed and are presented that illustrate the major potential failure pathways for each of the contaminant isolation facility controls. It is believed that this is the first application of FTA for the evaluation of the effectiveness of long-term management of residual waste sites.

Fault trees are cause-and-effect diagrams useful for evaluating the root causes of failure modes. These trees provide a graphical means of displaying the qualitative information included in the case studies.

This FTA taxonomy is useful for organizing and analyzing institutional controls and engineered barriers. These trees provide a logical approach for clarifying how the undesired event (e.g., control error) could occur and, likewise, how mitigation efforts can reduce system failure.

Additionally, if more quantitative data becomes available, FTA could be used to estimate the probability of the undesired state occurring.

FTA Symbology

This FTA uses a simplified set of standard symbols to represent fault events and logic gates as shown in Figure 38. Functional descriptions of what occurred or did not occur are described in each symbol. The top event, represented by an oval, describes the system fault. This is the undesired state of the system. Basic faults are intermediate events representing observable problems. These basic fault events are illustrated as rectangles. Circles are used to represent initiating events. Initiating events represent the lowest point of examination for this research and require no further development. Diamonds represent undeveloped events either because of insufficient consequences or because of inadequate information. A triangle is a transfer symbol, which indicates that this branch of the tree is further developed in another portion of the tree.

Two types of logic gates are used to connect events as input and output. The And-Gate is used to represent the situation in which the output event occurs only when all of the input events occur. The Or-Gate represents the situation in which the output occurs if at least one of the inputs occurs. In terms of strengthening controls and thus reducing the likelihood of failure, the And-Gate is viewed as the more robust condition because multiple input events are required for the output to occur. Conversely, the conditions illustrated with an Or-Gate are less robust because these gates indicate that a single point failure could lead to the undesired output state.

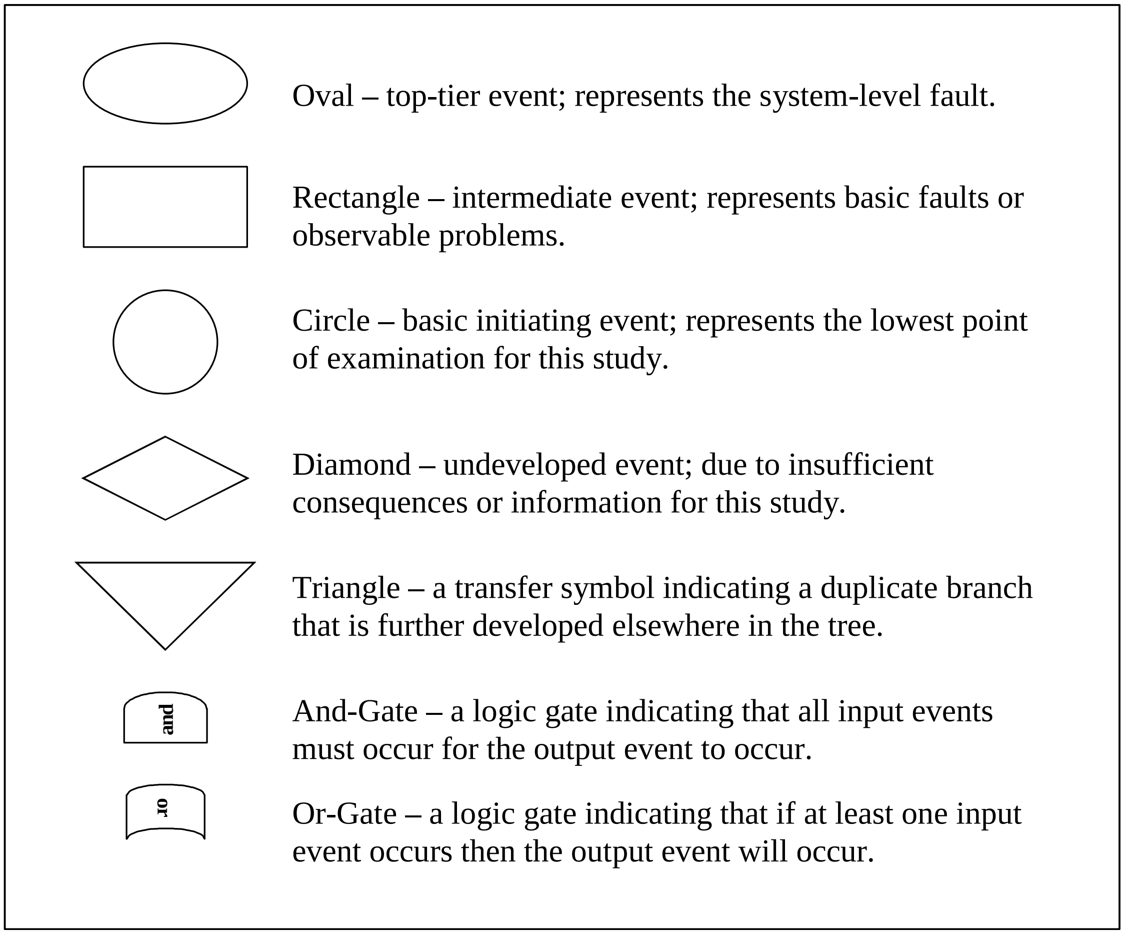

Figure 38. A simplified set of standard symbols is used in FTA to represent fault events and logic gates.

Contaminant Isolation Facility Failure Analysis

The results of the case study analysis presented in Chapter V highlight the variations currently being used to isolate residual contaminants. These studies have shown that the various controls can be logically organized for further analysis. Table 18 summarizes the controls used at each of the selected case studies. Errors within these various controls can be viewed as intermediate events potentially contributing to the ultimate failure of the contaminant isolation facility. As such, each of these events are organized within a fault tree for further analysis. This analysis describes how potential errors for each of the individual controls could occur. This analysis is not an evaluation of facility failure but rather an analysis of individual control error. Further analysis at the site-specific facility level will be required consistent with the individual controls implemented at each selected site.

Figure 39 represents the fault tree for the undesired state of the system, which is *Failure of Contaminant Isolation Facility Controls.* This figure shows two primary categories of controls representing the errors of the two subsystems: *Institutional Control Error* and *Engineered Barrier Error*. An Or-Gate connects these two events to the system-level fault.

Contributing to the subsystem-level faults are 13 individual events, labeled A through M. These events, shown in Figure 39, correspond to the error events of the various individual institutional controls and engineered barriers employed by site stewards at the contaminant isolation facilities evaluated in the case studies. All of these events are connected with Or-Gates, which illustrates the independent nature of each event.

To further explore the mechanisms leading to potential system failure, the 13 events (A through M) were analyzed in greater detail and were expanded into individual branches of the tree. These branches are presented in the following sections.

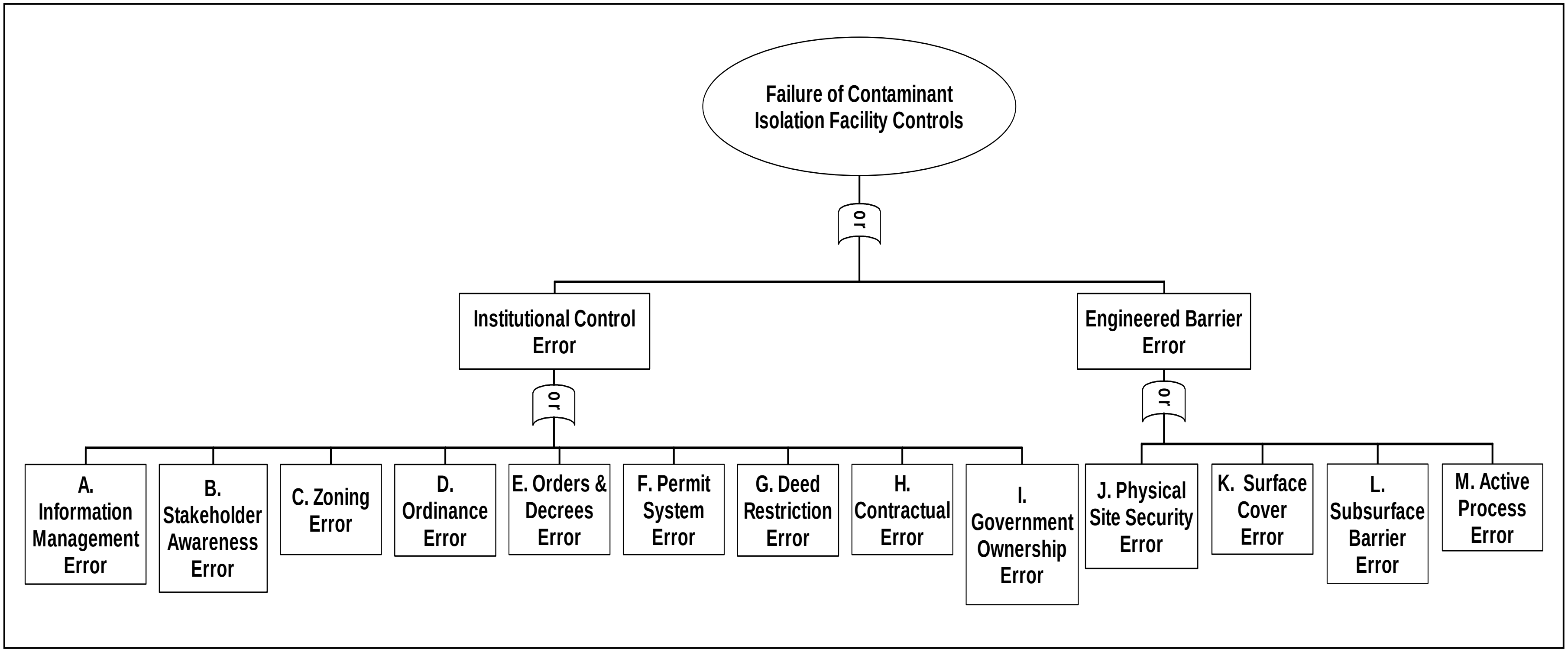

Figure 39. Contaminant isolation facility system-level and primary intermediate-level faults.

Analysis of Contaminant Isolation Facility Control Branches

The 13 events, labeled A through M as illustrated in Figure 39, represent the undesired error state of individual controls used for the management of contaminant isolation facilities. These events represent the error conditions of the individual institutional controls and engineered barriers.

Each of these 13 control-error modes has been further evaluated to better understand how each undesired state can occur. Identifying the unique events that contribute to each of these error states has resulted in the development of individual branches of the system fault tree. All events within these branches are numbered sequentially from left to right within each sub-branch. Further descriptions of each event are provided in the accompanying tables.

Information Management Error

Figure 40 illustrates the complete fault tree for the *Information Management Error* (A) branch. All events within this tree are connected by Or-Gates, indicating that only one input event is needed to occur for the corresponding output event to occur. Contributing events leading to *Information Management Error* (A) include *Input Error* (1), *Analysis Error* (2) and *Output Error* (3). Further descriptions of these intermediate events and their subsequent faults, initiating events and undeveloped events are presented in Table 20.

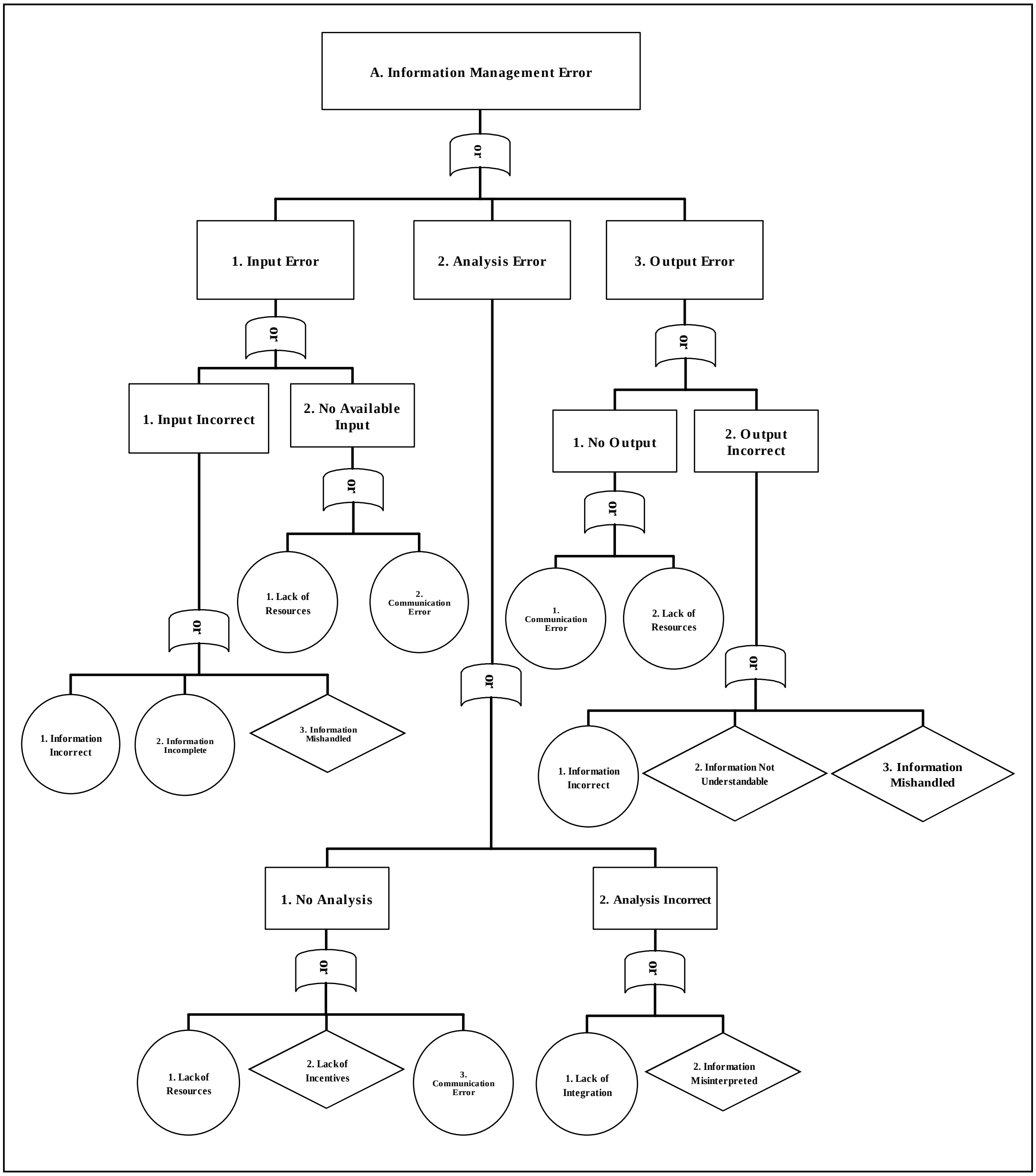

Figure 40. Information Management Error branch.

Table 20. Description of events contributing to the Information Management Error.

Label	Event	Description
A.	Information Management Error	Basic fault: contributes to Institutional Control Error via the loss of knowledge.
1.	Input Error	Basic fault: indicates problems with regard to the input stream of information management.
1.1	Input Incorrect	Basic fault: indicates that the input is not correct.
1.1.1	Information Incorrect	Initiating event: indicates that the information is not correct, it is inaccurate or it is wrong.
1.1.2	Information Incomplete	Initiating event: indicates that the information is not complete (i.e., portions of data are missing).
1.1.3	Information Mishandled	Undeveloped event: indicates that the information is not managed properly. This includes data migration to newer media.
1.2	No Available Input	Basic fault: indicates that there is no input to information management.
1.2.1	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
1.2.2	Communication Error	Initiating event: indicates that information is not properly transmitted or received.
2.	Analysis Error	Basic fault: indicates that the information is not properly analyzed.
2.1	No Analysis	Basic fault: indicating that no analysis is performed.
2.1.1	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
2.1.2	Lack of Incentives	Undeveloped event: indicates that there is no motive to perform the analysis.
2.1.3	Communication Error	Initiating event: indicates that information is not properly transmitted or received.
2.2	Analysis Incorrect	Basic fault: indicates that the analysis is not correct, it is inaccurate or it is wrong.
2.2.1	Lack of Integration	Initiating event: indicates that the data is not integrated.
2.2.2	Information Misinterpreted	Undeveloped event: indicates that the interpretation of the information is not correct, it is inaccurate or it is wrong.
3.	Output Error	Basic fault: indicates problems with regard to the output stream of information management.
3.1	No Output	Basic fault: indicates that there is no output from information management.
3.1.1	Communication Error	Initiating event: indicates that information is not properly transmitted or received.
3.1.2	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
3.2	Output Incorrect	Basic fault: indicates that the output is not correct.
3.2.1	Information Incorrect	Initiating event: indicates that the information is not correct, it is inaccurate or it is wrong.
3.2.2	Information Not Understandable	Undeveloped event: indicates that the information is not comprehendible.
3.2.3	Information Mishandled	Undeveloped event: indicates that the information is not managed properly.

Lack of Stakeholder Awareness

Figure 41 illustrates the complete fault tree for the *Lack of Stakeholder Awareness* (B) branch. All events within this tree are connected by Or-Gates, indicating that only one input event is needed to occur for the corresponding output event to occur. Contributing events leading to *Lack of Stakeholder Awareness* (B) include *Notice Error* (1) and *Lack of Stakeholder Involvement* (2). Further descriptions of these intermediate events and their subsequent faults, initiating events and undeveloped events are presented in Table 21. The transfer symbols indicate that the Information Management branches have been described previously.

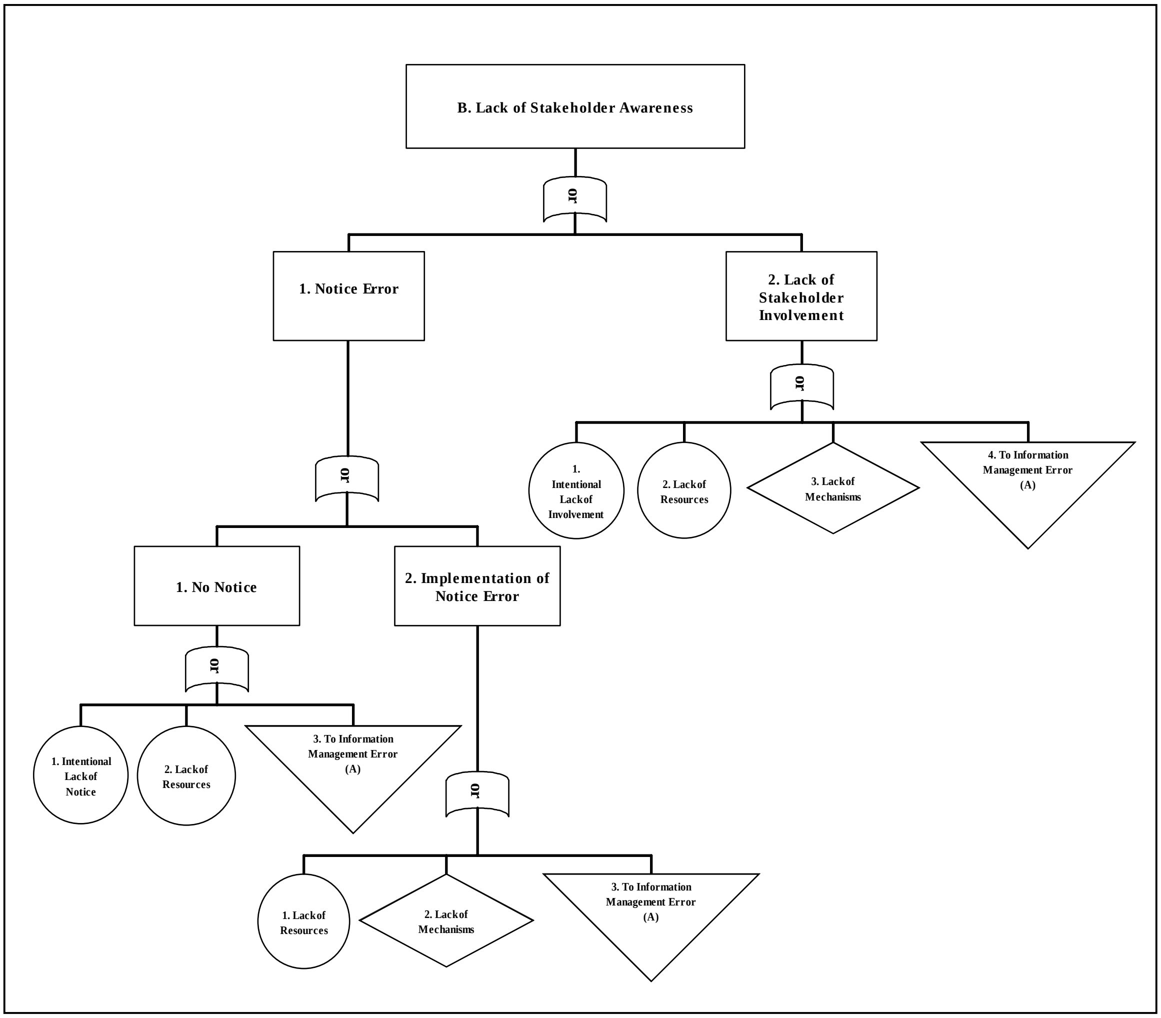

Figure 41. Lack of Stakeholder Awareness branch.

Table 21. Description of events contributing to the Lack of Stakeholder Awareness.

Label	Event	Description
B.	Lack of Stakeholder Awareness	Basic fault: contributes to Institutional Control Error via loss of knowledge.
1.	Notice Error	Basic fault: indicates an error with regard to the public disclosure of information.
1.1	No Notice	Basic fault: indicates no public disclosure of information.
1.1.1	Intentional Lack of Notice	Initiating event: indicates that no public disclosure of information is an intentional decision.
1.1.2	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
1.1.3	To Information Management Error	Transfer Symbol to A.
1.2	Implementation of Notice Error	Basic fault: indicates that the public disclosure of information is not properly conducted.
1.2.1	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
1.2.2	Lack of Mechanisms	Undeveloped event: indicates that the proper mechanisms are not available to properly achieve public disclosure of information.
1.2.3	To Information Management Error	Transfer Symbol to A.
2.	Lack of Stakeholder Involvement	Basic fault: indicates that stakeholders are not actively involved or engaged.
2.1	Intentional Lack of Involvement	Initiating event: indicates that the lack of stakeholder involvement is intentional.
2.2	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
2.3	Lack of Mechanisms	Undeveloped event: indicates that the proper mechanisms are not available to properly achieve stakeholder involvement.
2.4	To Information Management Error	Transfer Symbol to A.

Zoning Error

Figure 42 illustrates the complete fault tree for the *Zoning Error* (C) branch. Contributing events leading to *Zoning Error* (C) include *Monitoring Error* (1), *Zoning Changed* (2), *Current Zoning Enforcement Error* (3) and *Inadequate Zoning Defined* (4). Most of the events within this tree are connected by Or-Gates, although the *Zoning Changed* branch is controlled by an And-Gate. Further descriptions of the intermediate events and their subsequent faults, initiating events and undeveloped events are presented in Table 22. The transfer symbol indicates that a portion of this branch is described elsewhere in the tree.

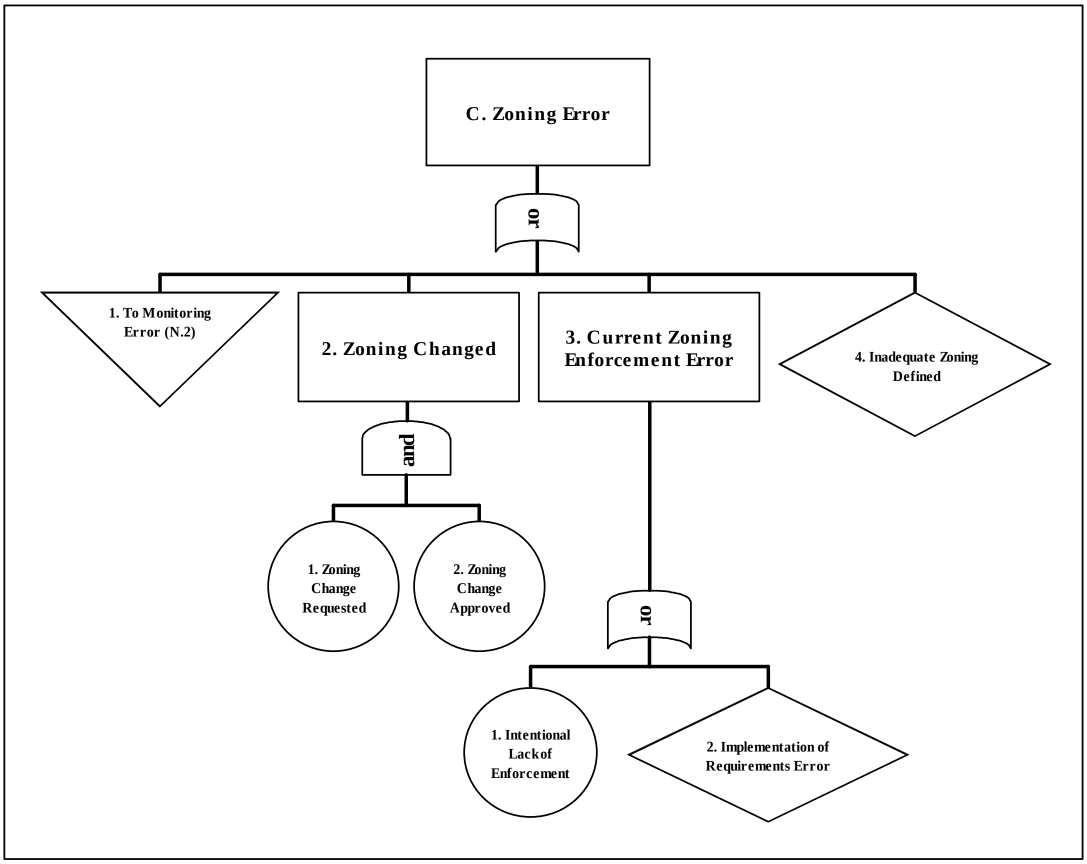

Figure 42. Zoning Error branch.

Table 22. Description of events contributing to Zoning Error.

Label	Event	Description
C.	Zoning Error	Basic fault: contributes to Institutional Control Error. One type of Government Control Error.
1.	To Monitoring Error	Transfer Symbol to N.2.
2.	Zoning Changed	Basic fault: indicates that the zoning classification of land was changed.
2.1	Zoning Change Requested	Initiating event: indicates that there was a request to change the zoning requirements.
2.2	Zoning Request Approved	Initiating event: indicates that the zoning change request was approved.
3.	Current Zoning Enforcement Error	Basic fault: indicates that the current zoning requirements have not been enforced.
3.1	Intentional Lack of Enforcement	Initiating event: indicates that the lack of enforcement was an intentional decision.
3.2	Implementation of Requirements Error	Undeveloped event: indicates that the requirements are not implemented properly.
4.	Inadequate Zoning Defined	Undeveloped event: indicates that the proper zoning requirements were not established given the site's condition.

Ordinance Error

Figure 43 illustrates the complete fault tree for the *Ordinance Error* (D) branch. Three contributing events lead to *Ordinance Error* (D). These events include *Monitoring Error* (1), *Enforcement of Ordinance Requirements Error* (2) and *Ordinance Voided* (3). All of the events within this tree are connected by Or-Gates indicating that only one input event is needed to occur for the corresponding output event to occur. Further descriptions of the intermediate events and their subsequent faults, initiating events and undeveloped events are presented in Table 23. The transfer symbols indicate that portions of this branch are described elsewhere in the tree.

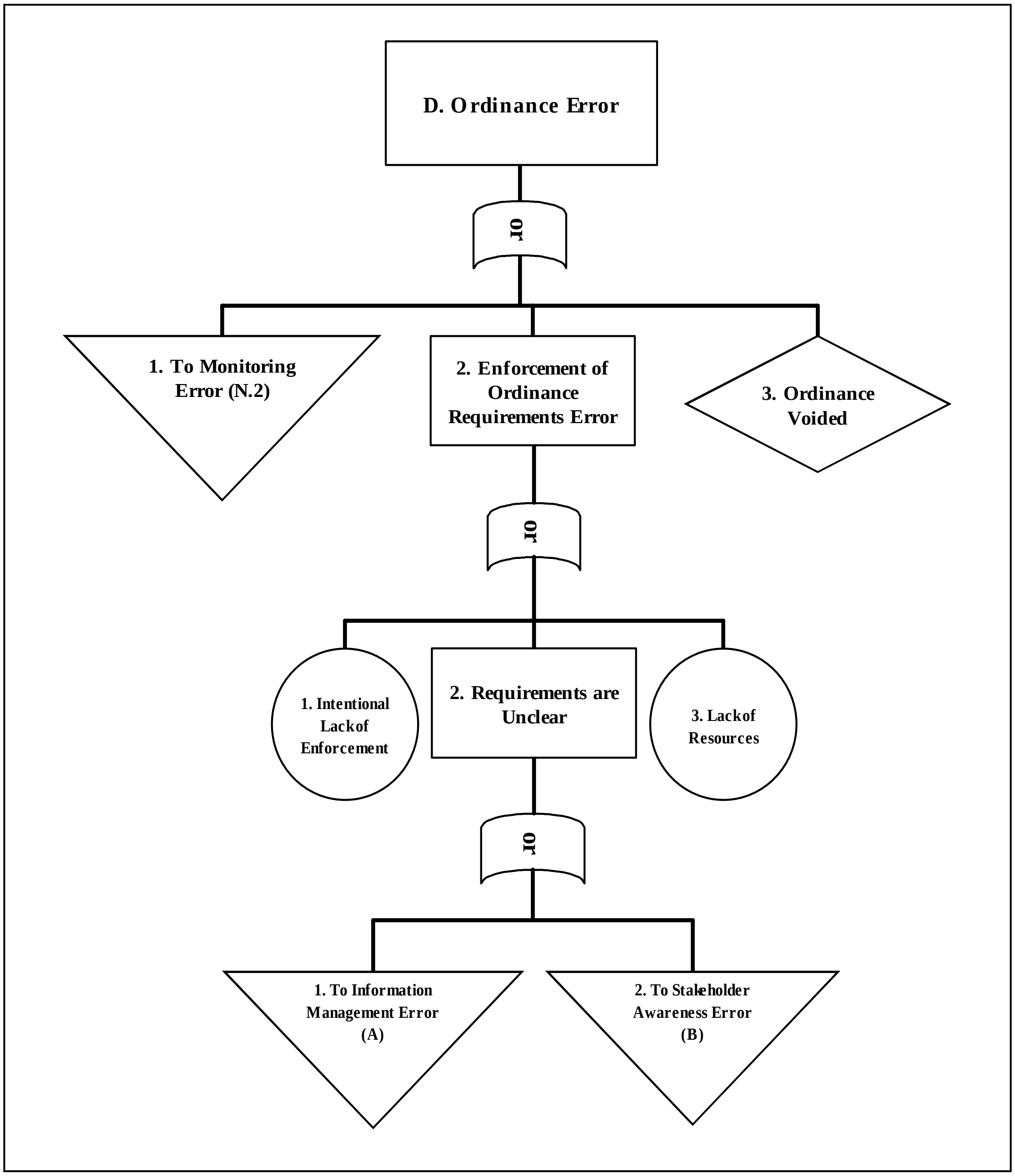

Figure 43. Ordinance Error branch.

Table 23. Description of events contributing to Ordinance Error.

Label	Event	Description
D.	Ordinance Error	Basic fault: contributes to Institutional Control Error. A type of Government Control Error.
1.	To Monitoring Error	Transfer Symbol to N.2.
2.	Enforcement of Ordinance Requirements Error	Basic fault: indicates that existing ordinance requirements are not being enforced.
2.1	Intentional Lack of Enforcement	Initiating event: indicates that the decision to not enforce requirements was an intentional decision.
2.2	Requirements are Unclear	Undeveloped event: indicates that the requirements are not understood.
2.2.1	To Information Management Error	Transfer Symbol to A.
2.2.2	To Stakeholder Awareness Error	Transfer Symbol to B.
2.3.1	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
3.	Ordinance Voided	Undeveloped Event: indicates that the ordinance was nullified or dismissed.

Orders and Decrees Error

Figure 44 illustrates the complete fault tree for the *Orders and Decrees Error* (E) branch. Two contributing events lead to *Orders and Decrees Error* (E). These events include *Monitoring Error* (1) and *Enforcement of Orders and Decree Requirements Error* (2). The events within this tree are all connected by Or-Gates indicating that only one input event is needed to occur for the corresponding output event to occur. Further descriptions of the intermediate events and their subsequent faults and initiating events are presented in Table 24. The transfer symbols indicate that portions of this branch are described elsewhere in the tree.

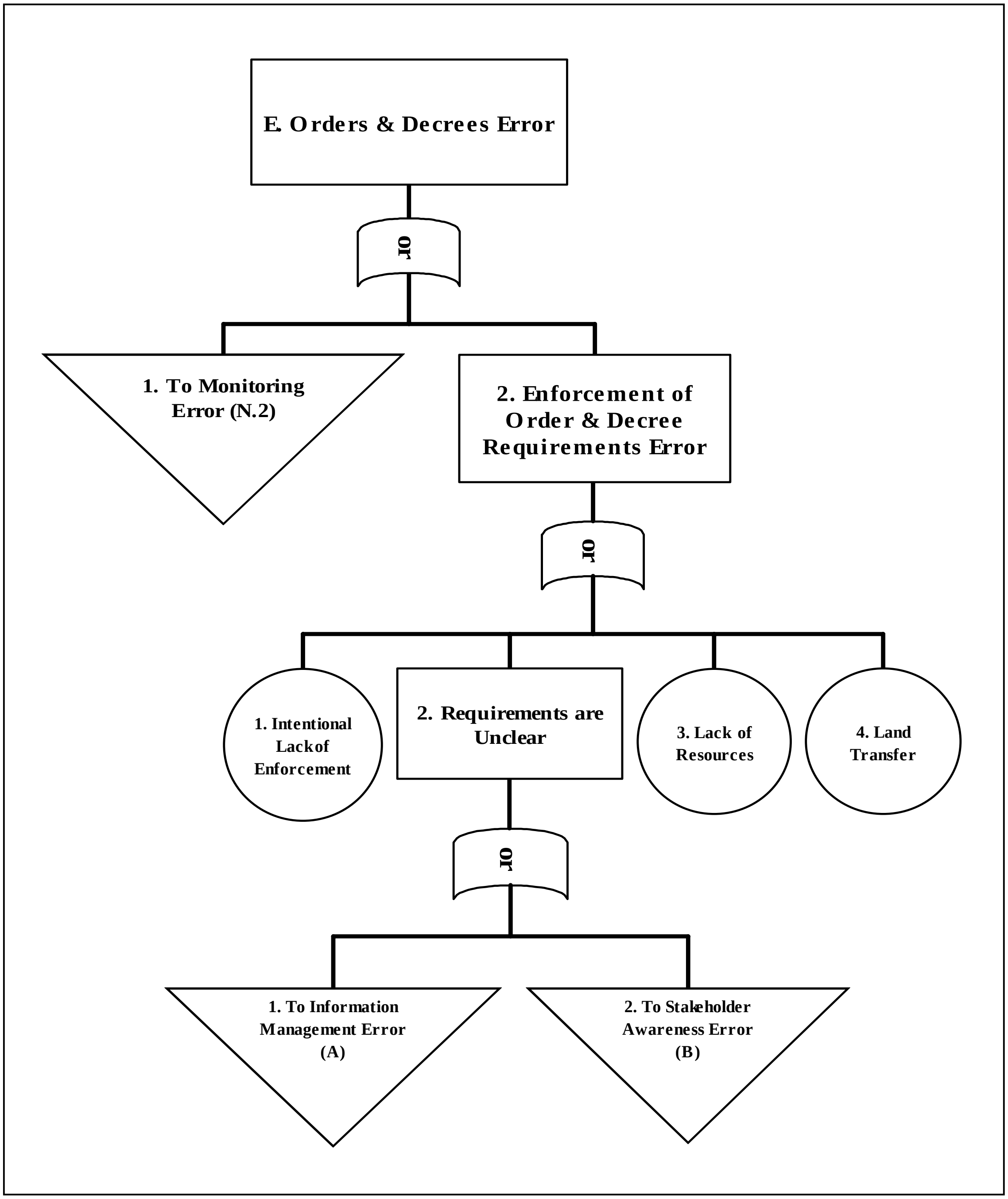

Figure 44. Orders and Decrees Error branch.

Table 24. Description of events contributing to Orders and Decrees Error.

Label	Event	Description
E.	Orders and Decrees Error	Basic fault: contributes to Institutional Control error. A type of Government Control Error.
1.	To Monitoring Error	Transfer Symbol to N.2.
2.	Enforcement of Order and Decree Requirements	Basic fault: indicates that existing order and decree requirements are not being enforced.
2.1	Intentional Lack of Enforcement	Initiating event: indicates that the decision to not enforce requirements was an intentional decision.
2.2	Requirements are Unclear	Undeveloped event: indicates that the requirements are not understood.
2.2.1	To Information Management Error	Transfer Symbol to A.
2.2.2	To Stakeholder Awareness Error	Transfer Symbol to B.
2.3.	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
2.4	Land Transfer	Initiating event: indicates that the land associated with the order and decree has been transferred from one owner to another.

Permit System Error

Figure 45 illustrates the complete fault tree for the *Permit System Error* (F) branch. Three contributing events lead to *Permit System Error* (F). These events include *Monitoring Error* (1), *Notice Error* (2) and *Enforcement of Permit Requirements Error* (3). Most of the events within this tree are connected by Or-Gates indicating that only one input event is needed to occur for the corresponding output event to occur. The event, *Permit Improperly Awarded*, is controlled by an And-Gate indicating that both contributing events must occur for this condition to occur. Further descriptions of the intermediate events and their subsequent faults and initiating events are presented in Table 25. The transfer symbols indicate that portions of this branch are described in other branches of the tree.

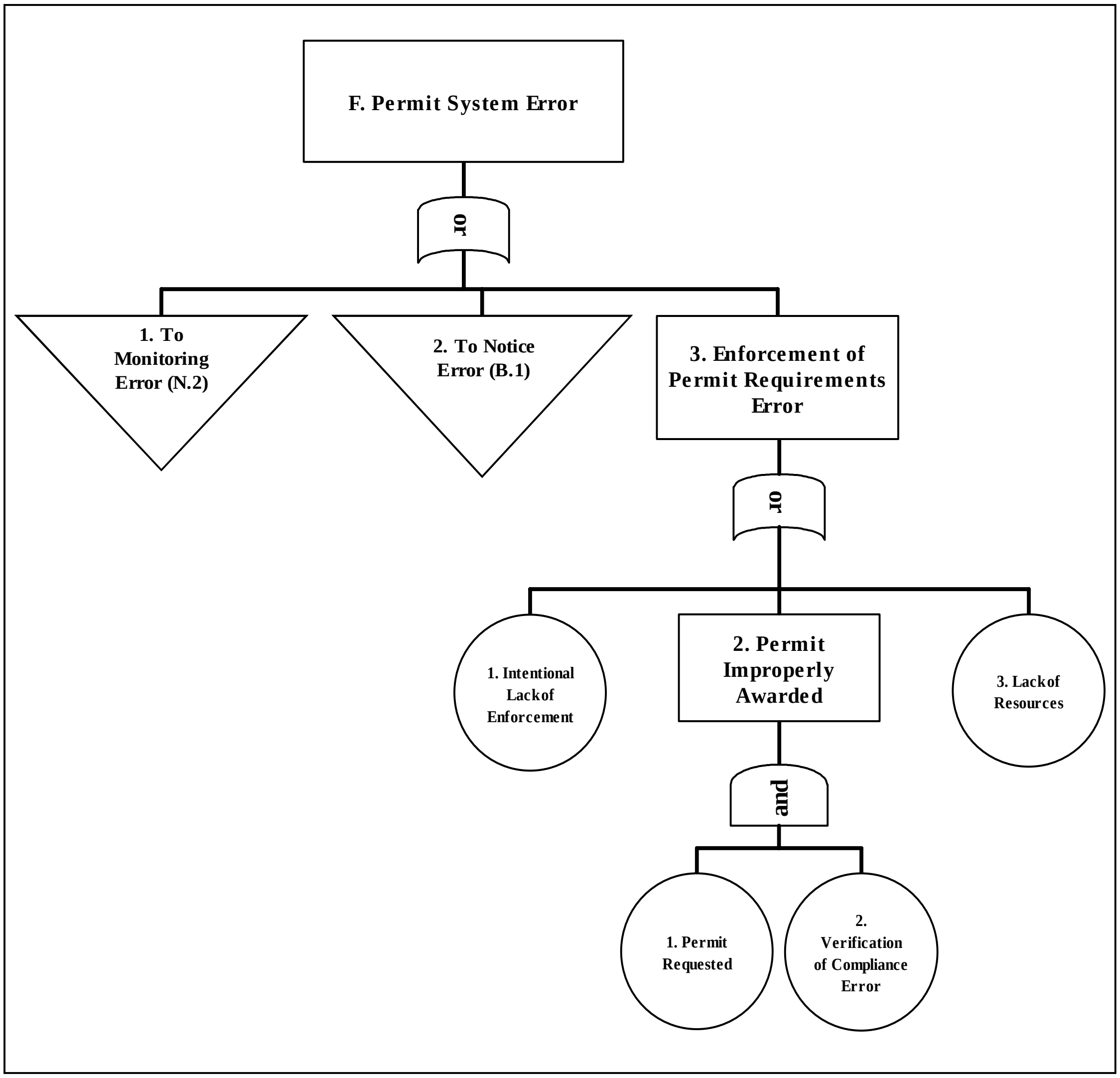

Figure 45. Permit System Error branch.

Table 25. Description of events contributing to Permit System Error.

Label	Event	Description
F.	Permit System Error	Basic fault: contributes to Institutional Control Error. A type of Government Control Error.
1.	To Monitoring Error	Transfer Symbol to N.2.
2.	To Notice Error	Transfer Symbol to B.1.
3.	Enforcement of Permit Requirements Error	Basic fault: indicates that existing permit system requirements are not being enforced.
3.1	Intentional Lack of Enforcement	Initiating event: indicates that the decision to not enforce requirements was an intentional decision.
3.2	Permit Improperly Awarded	Basic fault: indicates that the permit was incorrectly issued.
3.2.1	Permit Requested	Initiating event: indicates that a landowner requested a permit.
3.2.2	Verification of Compliance Error	Initiating event: indicates that compliance with established permit requirements was not verified. This could include the lack of verification of additional site remediation required to be consistent with the permit request.
3.3	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.

Deed Restriction Error

Figure 46 illustrates the complete fault tree for the *Deed Restriction Error* (G) branch. Three contributing events lead to *Deed Restriction Error* (G). These events include *Monitoring Error* (1), *Notice Error* (2) and *Enforcement of Deed Restriction Error* (3). All of the events within this tree are connected by Or-Gates indicating that only one input event is needed to occur for the corresponding output event to occur. Further descriptions of the intermediate events and their subsequent faults and initiating events are presented in Table 26. The transfer symbols indicate that portions of this branch are described elsewhere.

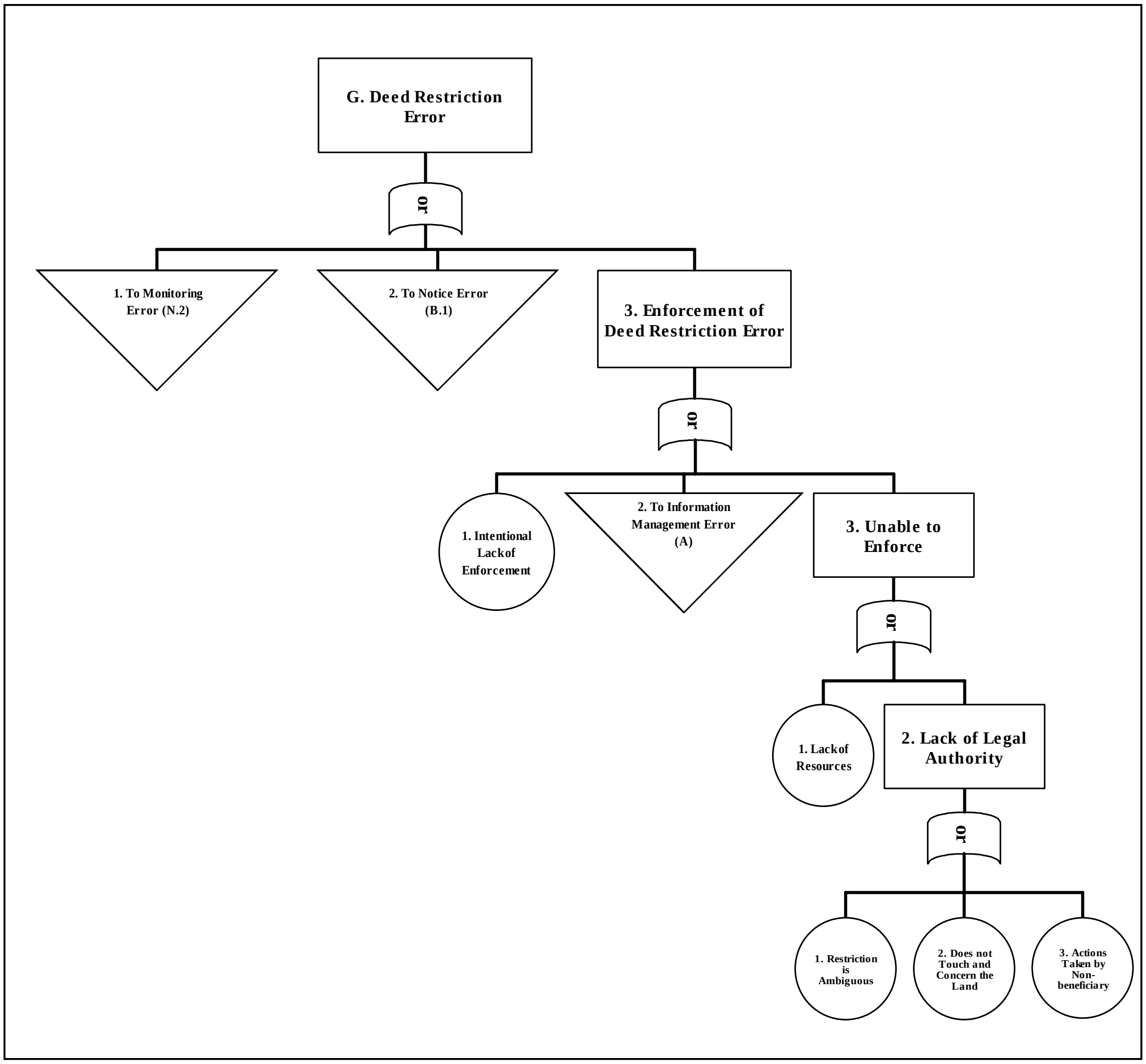

Figure 46. Deed Restriction Error branch.

Table 26. Description of events contributing to Deed Restriction Error.

Label	Event	Description
G.	Deed Restriction Error	Basic fault: contributes to Institutional Control Error. A type of Property-based Control Error.
1.	To Monitoring Error	Transfer Symbol to N.2.
2.	To Notice Error	Transfer Symbol to B.1.
3.	Enforcement of Deed Restriction Error	Basic fault: indicates that deed restrictions are not being enforced.
3.1	Intentional Lack of Enforcement	Initiating event: indicates that the decision to not enforce the restrictions was an intentional decision.
3.2	To Information Management Error	Transfer Symbol to A.
3.3	Unable to Enforce	Basic fault: indicates that the ability to enforce the requirements does not exist.
3.3.1	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
3.3.2	Lack of Legal Authority	Basic fault: indicates that deed restrictions cannot be legally enforced.
3.3.2.1	Restriction is Ambiguous	Initiating event: indicates that the restriction is not clearly defined in legal terms.
3.3.2.2	Does not Touch and Concern the Land	Initiating event: indicates that restrictions did not run with the title of the land as interpreted by common property law.
3.3.2.3	Actions Taken by Non-beneficiary	Initiating event: indicates that a third party rather than the covenanting parties or their successors took the legal action.

Contractual Error

Figure 47 illustrates the complete fault tree for the *Contractual Error* (H) branch. Two contributing events lead to *Contractual Error* (H). These events include *Monitoring Error* (1) and *Enforcement of Contract Requirements Error* (2). All of the events within this tree are connected by Or-Gates indicating that only one input event is needed to occur for the corresponding output event to occur. Further descriptions of the intermediate events and their subsequent faults and initiating events are presented in Table 27. The transfer symbols indicate that portions of this branch are described elsewhere.

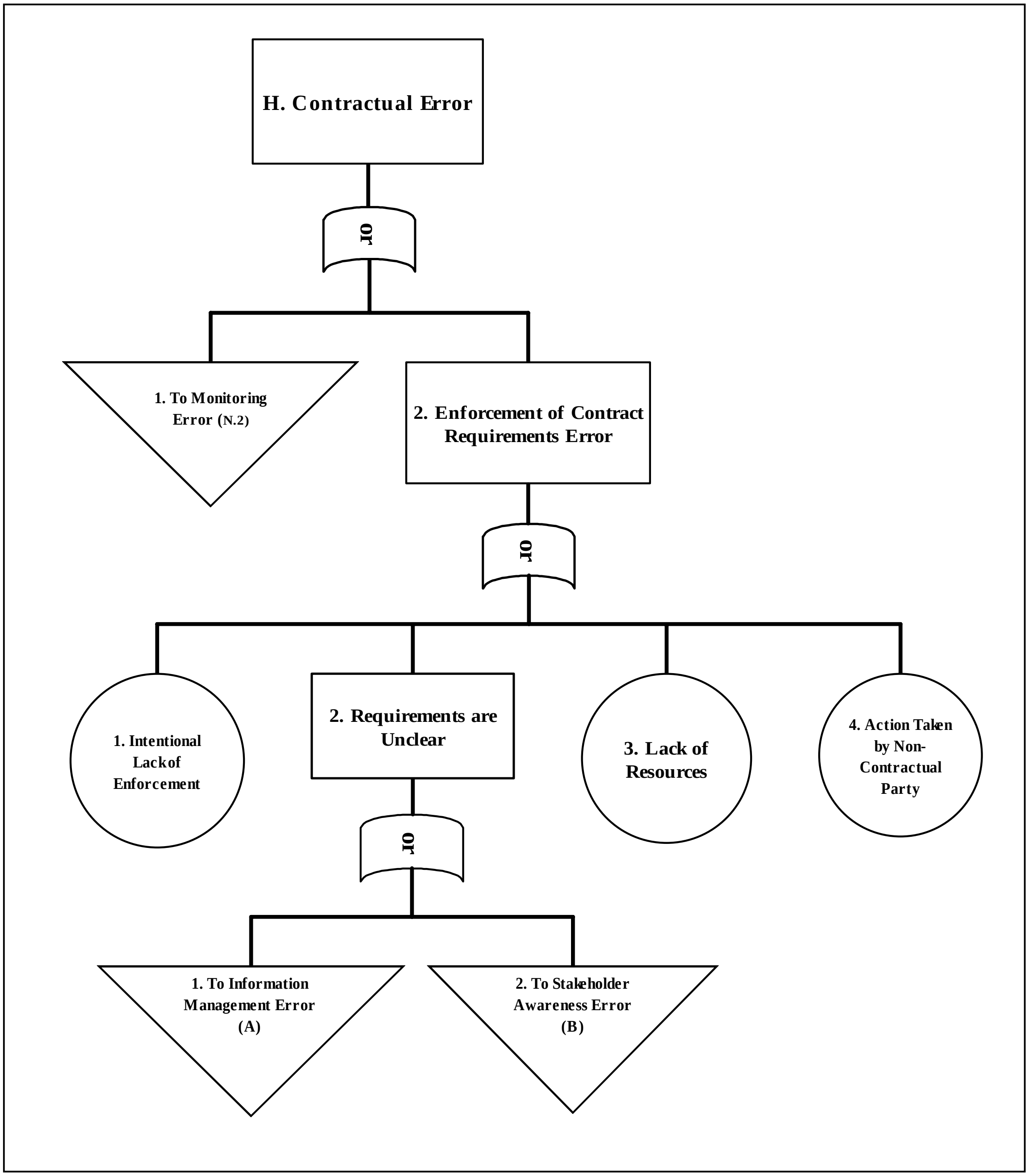

Figure 47. Contractual Error branch.

Table 27. Description of events contributing to Contractual Errors.

Label	Event	Description
H.	Contractual Error	Basic fault: contributes to Contractual Error. A type of Property-based Control Error.
1.	To Monitoring Error	Transfer Symbol to N.2.
2.	Enforcement of Contract Requirements Error	Basic fault: indicates that existing contract requirements are not being enforced.
2.1	Intentional Lack of Enforcement	Initiating event: indicates that the decision to not enforce requirements was an intentional decision.
2.2	Requirements are Unclear	Basic fault: indicates that the contractual requirements are not understood.
2.2.1	To Information Management Error	Transfer Symbol to A.
2.2.2	To Stakeholder Awareness Error	Transfer Symbol to B.
3.3	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
3.4	Actions taken by Non-contractual Party	Initiating event: indicates that a non-contractual, therefore a non-binding, party initiated the legal actions.

Government Ownership Error

Figure 48 illustrates the complete fault tree for the *Government Ownership Error* (I) branch. Two contributing events lead to *Government Ownership Error* (I). These events include *Land Transfer* (1) and *Lack of Alternative Controls* (2). These two events are connected to the *Government Ownership Error* (I) event via an And-Gate indicating that both of these events must occur for the output event (i.e., *Government Ownership Error*) to occur. The remaining events within this tree are governed by Or-Gates indicating that only one of the underlying events need occur for the above output event to occur. Further descriptions of the intermediate events and their subsequent faults and initiating events are presented in Table 28. The transfer symbols indicate that portions of this branch have been previously described.

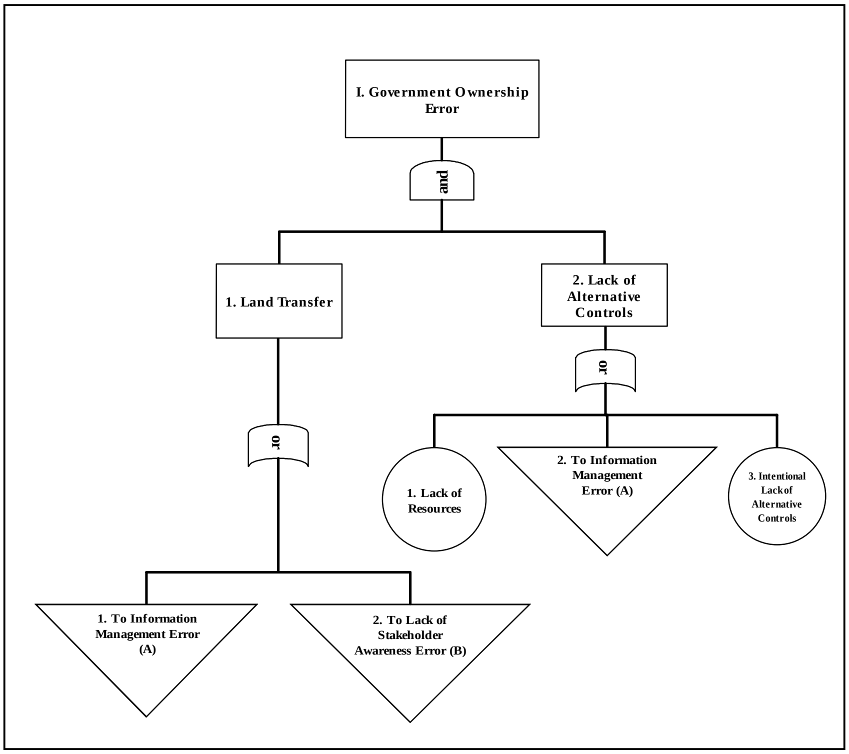

Figure 48. Government Ownership Error branch.

Table 28. Description of events contributing to Government Ownership Error.

Label	Event	Description
I.	Government Ownership Error	Basic fault: contributes to Institutional Control Error. A type of Property-based Control Error.
1.	Land Transfer	Basic fault: indicates that the land associated with the government ownership has been transferred to a non-government owner.
1.1.	To Information Management Error	Transfer Symbol to A.
1.2.	To Lack of Stakeholder Awareness Error	Transfer Symbol to B.
2.	Lack of Alternative Controls Error	Basic fault: indicates that new alternative controls have not been established.
2.1	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
2.2	To Information Management Error	Transfer Symbol to A.
2.3	Intentional Lack of Alternative Controls	Initiating event: indicates that the decision not to establish alternative controls was intentional.

Physical Site Security Error

Figure 49 illustrates the complete fault tree for the *Physical Site Security Error* (J) branch. Two contributing events lead to *Physical Site Security Error* (J). These events include *Physical Control Error* (1) and *Response Error* (2), which are connected by an And-Gate. All remaining events within this tree are connected by Or-Gates indicating that only one of the underlying events need occur for the above output event to occur. Further descriptions of the intermediate events and their subsequent faults, initiating events and undeveloped events are presented in Table 29. The transfer symbols indicate that portions of this branch are described elsewhere.

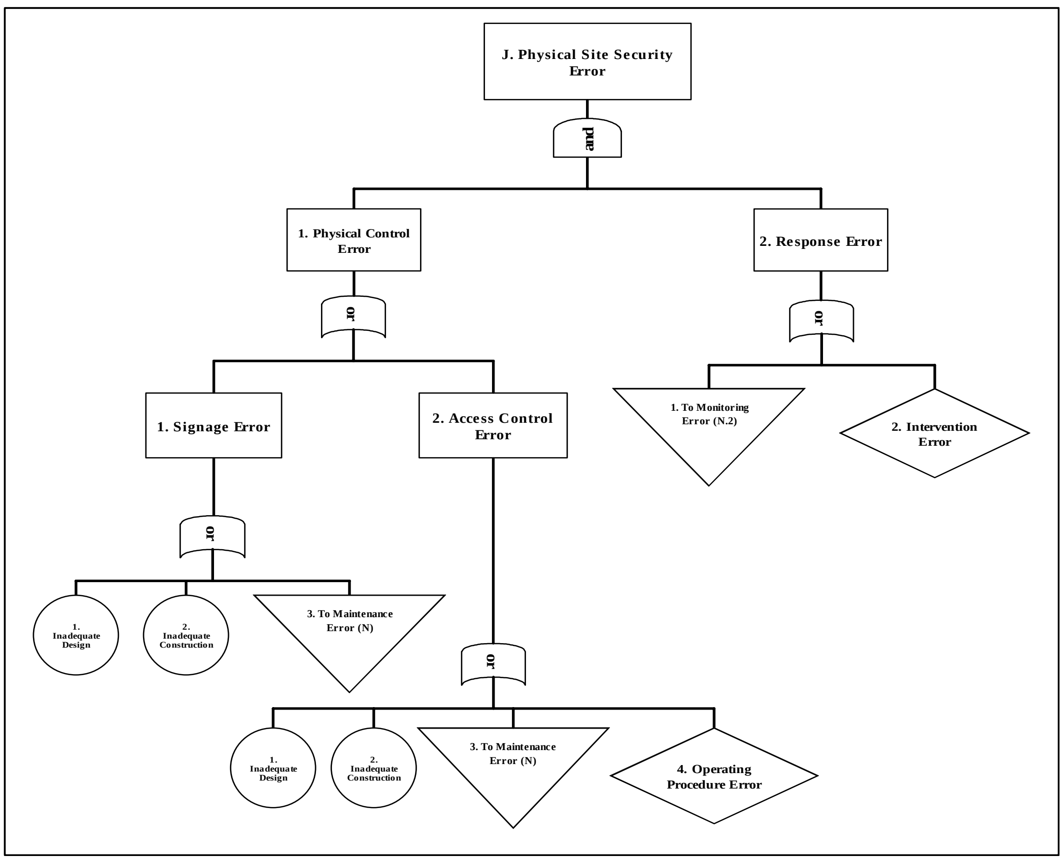

Figure 49. Physical Site Security Error branch.

Table 29. Description of events contributing to Physical Site Security Error.

Label	Event	Description
J.	Physical Site Security Error	Basic fault: contributes to Engineered Barrier Error.
1.	Physical Control Error	Basic fault: indicates that the physical controls have been breached.
1.1	Signage Error	Basic fault: indicates that the site's signs are inadequate in disseminating necessary information.
1.1.1	Inadequate Design	Initiating event: indicates that the signage design was inadequate, including the adequacy of the message.
1.1.2	Inadequate Construction	Initiating event: indicates that the signage construction was inadequate.
1.1.3	To Maintenance Error	Transfer Symbol to N.
1.2.	Access Control Error	Basic fault: indicates that the access controls have been breached.
1.2.1	Inadequate Design	Initiating event: indicates that the access control design was inadequate.
1.2.2	Inadequate Construction	Initiating event: indicates that the access control construction was inadequate.
1.2.3	To Maintenance Error	Transfer Symbol to N.
1.2.4	Operating Procedure Error	Undeveloped event: indicates that the operating procedures were inadequate.
2.	Response Error	Basic fault: indicates that physical site security breach was not adequately responded to.
2.1	To Monitoring Error	Transfer Symbol to N.2.
2.2	Intervention Error	Undeveloped event: indicates that the intervening response was unsuccessful in protecting the site's security.

Surface Control Error

Figure 50 illustrates the fault tree for the *Surface Control Error* (K) branch. Three contributing events lead to *Surface Control Error* (K). These events include *Inadequate Design* (1), *Inadequate Construction* (2) and *Maintenance Error* (3). The events within this tree are connected by Or-Gates indicating that only one of the underlying events need occur for the above output event to occur. Further descriptions of the initiating events are presented in Table 30. The transfer symbol indicates that the maintenance portion of this branch is described elsewhere.

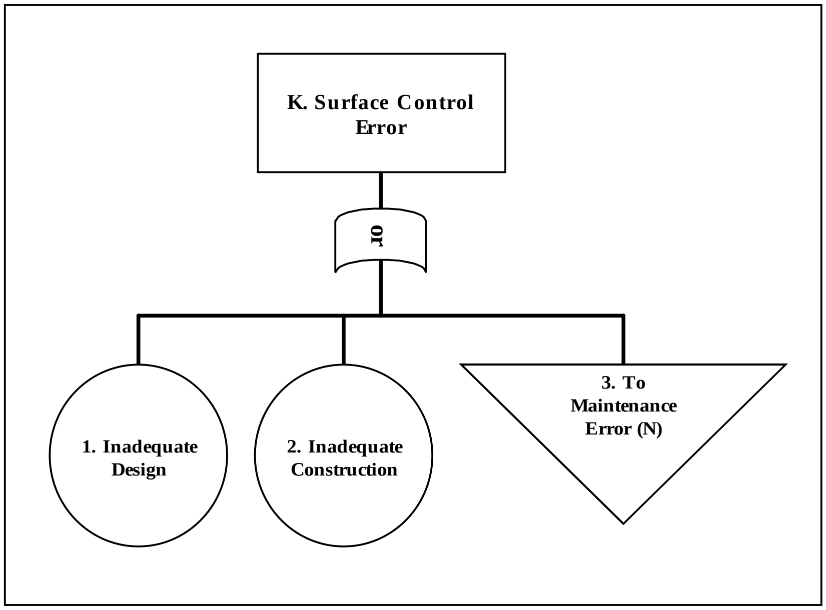

Figure 50. Surface Control Error branch.

Table 30. Description of events contributing to Surface Control Error.

Label	Event	Description
K.	Surface Control Error	Basic fault: contributes to Engineered Barrier Error. A type of Engineered Barrier Error.
1.	Inadequate Design	Initiating event: indicates that the design of the surface controls was inadequate.
2.	Inadequate Construction	Initiating event: indicates that the construction of the surface controls was inadequate.
3.	Maintenance Error	Transfer Symbol to N.

Subsurface Barrier Error

Figure 51 illustrates the fault tree for the *Subsurface Bartrier Error* (L) branch. Three contributing events lead to *Subsurface Barrier Error* (L). These events include

Inadequate Design (1), *Inadequate Construction* (2) and *Maintenance Error* (3). The events within this tree are connected by Or-Gates indicating that only one of the underlying events need occur for the above output event to occur. Further descriptions of the initiating events are presented in Table 31. The transfer symbol indicates that the maintenance portion of this branch is described elsewhere.

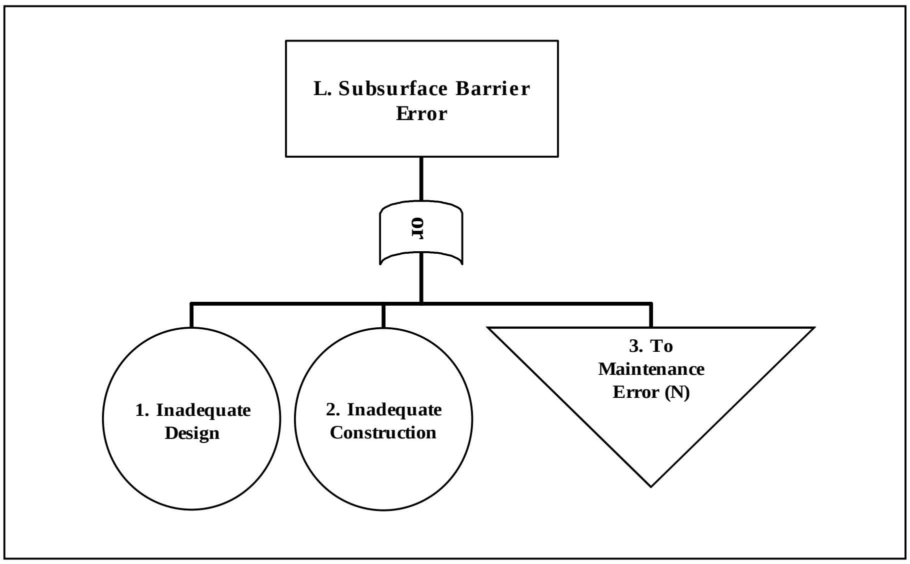

Figure 51. Subsurface Barrier Error branch.

Table 31. Description of events contributing to Subsurface Barrier Error.

Label	Event	Description
L.	Subsurface Barrier Error	Basic fault: contributes to Engineered Barrier Error.
1.	Inadequate Design	Initiating event: indicates that the design of the subsurface controls was inadequate.
2.	Inadequate Construction	Initiating event: indicates that the construction of the subsurface controls was inadequate.
3.	To Maintenance Error	Transfer Symbol to N.

Active Process Error

Figure 52 illustrates the fault tree for the *Active Process Error* (M) branch. Three contributing events lead to *Active Process Error* (M). These events include *Inadequate Design* (1), *Inadequate Construction* (2) and *Maintenance Error* (3). All of the events within this tree are connected by Or-Gates indicating that only one of the underlying events need occur for the above output event to occur. Further descriptions of the initiating events are presented in Table 32. The transfer symbol indicates that the maintenance portion of this branch is described elsewhere.

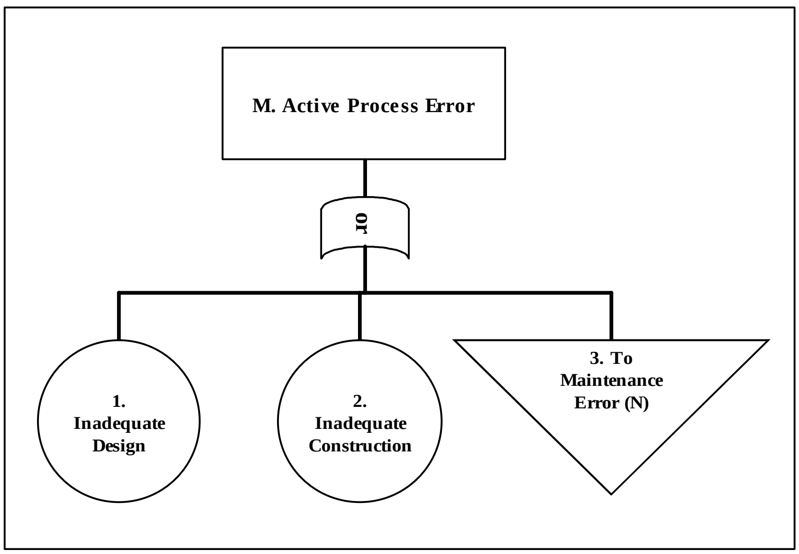

Figure 52. Active Process Error branch.

Table 32. Description of events contributing to Active Process Error.

Label	Event	Description
M.	Active Process Error	Basic fault: contributes to Engineered Barrier Error.
1.	Inadequate Design	Initiating event: indicates that the design of the active remediation processes was inadequate.
2.	Inadequate Construction	Initiating event: indicates that the construction of the active remediation processes was inadequate.
3.	To Maintenance Error	Transfer Symbol to N.

Review of Errors

The fault trees presented in this section illustrate how errors can occur for each of the defined controls. These fault trees when considered in relation to the previous case study discussion begin to illustrate why the potential implementation errors are prevalent at the selected case studies.

For example, the current Love Canal site was observed to have error characteristics for *Physical Site Security* and *Stakeholder Awareness*. The event contributing to the *Physical Site Security* error is described on Figure 49 as *Inadequate Design* (J.1.1.1). This initiating event involves an intentional decision by the regulators to limit the information present on the signs surrounding the disposal cell. Although this decision was made to accommodate local public concern it may not prove effective over the long-term.

The second implementation error noted for the current Love Canal site involved *Stakeholder Awareness*. The initiating event for this error appears to be *Intentional Lack of Stakeholder Involvement* (B.2.1) as shown on Figure 41. The intentional lack of involvement appears to be by the local stakeholders as evidence in their lack of participation in public meetings regarding the de-listing of the site.

The original Love Canal site was also observed to have error characteristics for *Stakeholder Awareness*. Although the property transfer deed contained information with regard to the chemical waste disposed of on the site, satisfying notice during this transaction, there was no evidence of further public notice or stakeholder involvement.

The Spring Valley case study identified four potential implementation errors. All four of these errors are related to the original disposal conditions at the site. These errors include Contractual *Requirements are Unclear* (H.2.2) as shown on Figure 47, *Inadequate Design* (J.1.2.1) with regard to access control as illustrated on Figure 49, *Inadequate Design* (K.1) with regard to surface controls as illustrated on Figure 50 and *Inadequate Design* (L.1) with regard to subsurface barriers as illustrated on Figure 51. The ramification of these errors is being addressed via the non-time critical and emergency actions at the current Site Valley site.

The Canonsburg case study identified two potential implementation errors. *Stakeholder Awareness* exhibited error characteristics with regard to the *Lack of Stakeholder Involvement* (B.2) as illustrated on Figure 41. The initiating events for this error appear to be local communication errors, which contribute to the *Information Management Error* event (B.2.4). The second potential implementation error was associated with *Government Ownership* (I.1.1) as shown on Figure 48. The initiating event for this error appears to be *Information Misinterpreted* (A.2.2.2) on Figure 41, which contributes to the *Information Management Error* (I.1.1) on Figure 48.

Finally, the Burrell case study was observed to have two potential implementation errors. The first error involves the Stakeholder Awareness functions and is similar to that described in the Canonsburg case. The second potential error at Burrell is associated with the Surface Controls. This error is best described as a *Maintenance Error* (K.3) as shown on Figure 50. This condition is described as an error because the control is not performing as designed. The vegetative growth on the surface cover was not originally anticipated. It is noted that the site stewards have completed a risk assessment and this deviation is not anticipated to increase risk to the public or the environment. Nonetheless, the situation is described as an error because a significant deviation from the planned objective has occurred.

Analysis of Maintenance and Monitoring

The previous analysis shows how deviations and errors can occur to each of the institutional controls and engineered barriers. Basic contributing faults and initiating events have been described. To mitigate these errors and events it is recognized that an active maintenance and monitoring program is required.

The following section provides an analysis of the maintenance and monitoring required for a contaminant isolation facility to remain effective. This analysis illustrates the cross-cutting nature of the maintenance function and links back to the individual control errors described on the previous branches (A through M). It is evident through this analysis that a complete maintenance and monitoring program should have integrated responsibilities with regard to engineered barriers and institutional controls.

Maintenance Error

Figure 53 illustrates the top levels of the *Maintenance Error* (N) branch. Three contributing events lead to *Maintenance Error* (N). The contributing events include *Site Security Error* (1), *Monitoring Error* (2) and *Implementation of Corrective Action Error* (3). The contributing errors are connected by an Or-Gate indicating that only one of the underlying events need occur for the above output event to occur. Further descriptions of the intermediate events and their subsequent faults, initiating events and undeveloped events are presented in Table 33. The transfer symbols indicate that portions of this branch are described elsewhere.

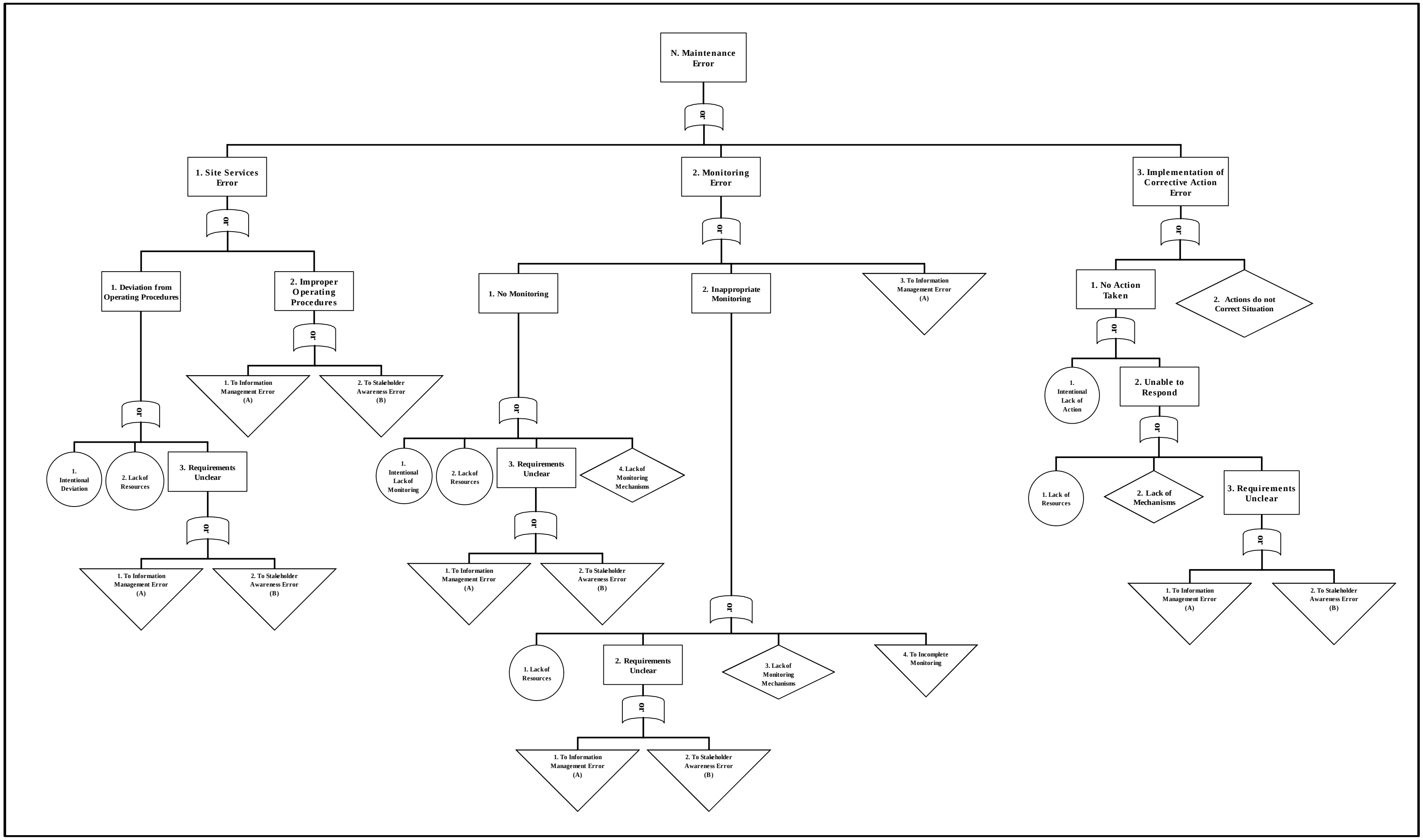

Figure 53. Maintenance Error branch.

Table 33. Description of events contributing to Maintenance Error.

Label	Event	Description
N.	Maintenance Error	Basic fault: contributes to Contaminant Isolation Facility Failure.
1.	Site Services Error	Basic fault: indicates that there was a deviation from approved operating procedures.
1.1	Deviation from Operating Procedures	Basic fault: indicates that the site's signs are inadequate in disseminating necessary information.
1.1.1	Intentional Deviation	Basic fault: indicates that the deviation from the approved operating procedures was intentional.
1.1.2	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
1.1.3	Requirements Unclear	Basic event: indicates that operating procedure requirements are not understood.
1.1.3.1	To Information Management Error	Transfer Symbol to A.
1.1.3.2	To Stakeholder Awareness Error	Transfer Symbol to B.
1.2	Improper Operating Procedures	Basic event: indicates that the operating procedures are inadequate for proper site services.
1.2.1	To Information Management Error	Transfer Symbol to A.
1.2.2	To Stakeholder Awareness Error	Transfer Symbol to B.
2.	Monitoring Error	Basic event: indicates that the monitoring efforts were inadequate for the maintenance functions.
2.1	No Monitoring	Basic event: indicates that no monitoring was conducted.
2.1.1	Intentional Lack of Monitoring	Initiating event: indicates that the lack of monitoring was intentional.
2.1.2	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
2.1.3	Requirements Unclear	Basic event: indicates that the monitoring requirements are not understood.
2.1.3.1	To Information Management Error	Transfer Symbol to A.
2.1.3.2	To Stakeholder Awareness Error	Transfer Symbol to B.
2.1.4	Lack of Monitoring Mechanisms	Undeveloped event: indicates that mechanisms are not in place for appropriate monitoring.
2.2	Inappropriate Monitoring	Basic event: indicates that the monitoring was not appropriate for the maintenance efforts.
2.2.1	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
2.2.2	Requirements Unclear	Basic event: indicates that the monitoring requirements are not understood.
2.2.2.1	To Information Management Error	Transfer Symbol to A.

Table 33, continued.

2.2.2.2	To Stakeholder Awareness Error	Transfer Symbol to B.
2.2.3	Lack of Monitoring Mechanisms	Undeveloped event: indicates that mechanisms are not in place for appropriate monitoring.
2.2.4	To Incomplete Monitoring	Transfer Symbol to N.2.2.4, Figure 54.
2.3	To Information Management Error	Transfer Symbol to A.
3.	Implementation of Corrective Action Error	Basic event: indicates that corrective actions were not implemented correctly to solve a problem.
3.1	No Action Taken	Basic event: indicates that no corrective action was taken.
3.1.1	Intentional Lack of Action	Initiating event: indicates that the decision to not take corrective actions was intentional.
3.1.2	Unable to Respond	Basic event: indicates that the site stewards were unable to take corrective actions.
3.1.2.1	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
3.1.2.2	Lack of Mechanisms	Undeveloped event: indicates that corrective action mechanisms were not available to solve the problem.
3.1.2.3	Requirements Unclear	Basic event: indicates that the corrective action requirements are not understood.
3.1.2.3.1	To Information Management Error	Transfer Symbol to A.
3.1.2.3.2	To Stakeholder Awareness Error	Transfer Symbol to B.
3.2	Actions do not Correct Situation	Undeveloped event: indicates that implemented actions did not correct the identified problems.

Incomplete Monitoring

A major branch of this tree, not previously analyzed, is illustrated by the transfer symbol N.2.2.4, *To Incomplete Monitoring*. This branch is expanded on to further evaluate the contributing events that could lead to *Inappropriate Monitoring* (N.2.2) and subsequently *Maintenance Error* (N).

The proper monitoring of a contaminant isolation facility involves five areas of monitoring. These five areas of monitoring, as illustrated in Figure 54, include in-system performance monitoring, vadose zone monitoring, groundwater sampling, site inspections and land use control monitoring. Further details of the intermediate events and their subsequent faults, initiating events and undeveloped events are presented in Table 34. The transfer symbols indicate that portions of this branch are described elsewhere.

A major branch of this tree is reflected by the transfer symbol *To Land Use Control Monitoring Error* (N.2.2.4.5). This branch is expanded on to further evaluate the contributing events that could lead to *Incomplete Monitoring* (N.2.2.4), *Inappropriate Monitoring* (N.2.2) and subsequently *Maintenance Error* (N).

Land Use Control Monitoring Error

The transfer symbol *To Land Use Control Monitoring Error* (N.2.2.4.5) in Figures 54 and 55 reflects a major branch in the *Maintenance Error* (N) branch. Three basic events, *No Land Use Control Monitoring* (1), *Inappropriate Land Use Control Monitoring* (2) and *Failure of Information Management* (3) contribute to the *Land Use Control Monitoring Error* (N.2.2.4.5). An important sub-branch to the *Inappropriate Land Use Control Monitoring* event is the *Inadequate Land Use Control Monitoring* branch. This branch reflects a major monitoring error that could directly relate back to the *Institutional Control Error* branches (C through I) illustrated in Figures 42 through 48.

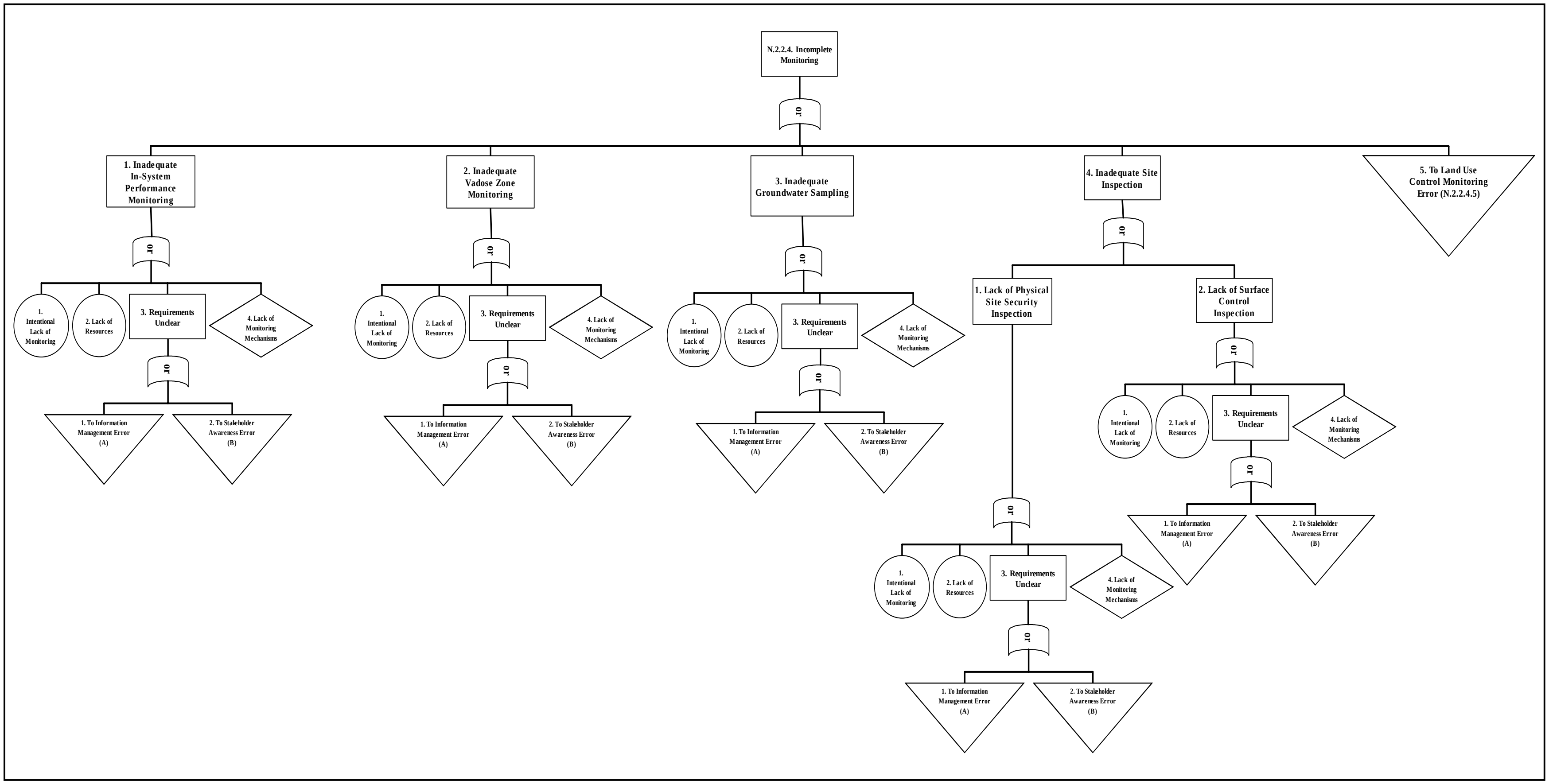

Figure 54. Incomplete Monitoring branch.

Table 34. Description of events contributing to Incomplete Monitoring.

Label	Event	Description
N.2.2.4	Incomplete Monitoring	Basic event: contributes to Inappropriate Monitoring (N.2.2).
1.	Inadequate In-System Performance Monitoring	Basic event: indicates that the performance of the internal components (moisture content, material properties, radon emanation, etc.) of the contaminant isolation facility is not adequately monitored.
1.1	Intentional Lack of Monitoring	Basic event: indicates that the lack of monitoring was an intentional decision.
1.2	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
1.3	Requirements Unclear	Basic event: indicates that monitoring requirements are not understood.
1.3.1	To Information Management Error	Transfer Symbol to A.
1.3.2	To Stakeholder Awareness Error	Transfer Symbol to B.
1.4	Lack of Monitoring Mechanisms	Undeveloped event: indicates that mechanisms are not in place for appropriate monitoring.
2.	Inadequate Vadose Zone Monitoring	Basic event: indicates that the monitoring of the vadose zone is not adequate with respect to moisture content, contaminant concentrations, etc.
2.1	Intentional Lack of Monitoring	Basic event: indicates that the lack of monitoring was an intentional decision.
2.2	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
2.3	Requirements Unclear	Basic event: indicates that monitoring requirements are not understood.
2.3.1	To Information Management Error	Transfer Symbol to A.
2.3.2	To Stakeholder Awareness Error	Transfer Symbol to B.
2.4	Lack of Monitoring Mechanisms	Undeveloped event: indicates that mechanisms are not in place for appropriate monitoring.
3.	Inadequate Groundwater Sampling	Basic event: indicates that the sampling of groundwater is inadequate (frequency, constituents, etc.).
3.1	Intentional Lack of Monitoring	Basic event: indicates that the lack of monitoring was an intentional decision.
3.2	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
3.3	Requirements Unclear	Basic event: indicates that monitoring requirements are not understood.
3.3.1	To Information Management Error	Transfer Symbol to A.
3.3.2	To Stakeholder Awareness Error	Transfer Symbol to B.

Table 34, continued.

3.4	Lack of Monitoring Mechanisms	Undeveloped event: indicates that mechanisms are not in place for appropriate monitoring.
4.	Inadequate Site Inspection	Basic event: indicates that site inspections are inadequate.
4.1	Lack of Physical Site Security Inspection	Basic event: indicates that the physical site inspections were inadequate with respect to fences, gates, wells, signs, etc.
4.1.1	Intentional Lack of Monitoring	Basic event: indicates that the lack of inspection was an intentional decision.
4.1.2	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
4.1.3	Requirements Unclear	Basic event: indicates that inspection requirements are not understood.
4.1.3.1	To Information Management Error	Transfer Symbol to A.
4.1.3.2	To Stakeholder Awareness Error	Transfer Symbol to B.
4.1.4	Lack of Monitoring Mechanisms	Undeveloped event: indicates that mechanisms are not in place for appropriate monitoring.
4.2	Lack of Surface Control Inspection	Basic event: indicates that the surface control inspections were inadequate with respect to cover material (geo-membranes, riprap, etc.), vegetation, drainage systems, etc.
4.2.1	Intentional Lack of Monitoring	Basic event: indicates that the lack of inspection was an intentional decision.
4.2.2	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
4.2.3	Requirements Unclear	Basic event: indicates that inspection requirements are not understood.
4.2.3.1	To Information Management Error	Transfer Symbol to A.
4.2.3.2	To Stakeholder Awareness Error	Transfer Symbol to B.
4.2.4	Lack of Monitoring Mechanisms	Undeveloped event: indicates that mechanisms are not in place for appropriate inspection.
5.	To Land Use Control Monitoring Error	Transfer Symbol to N.2.2.4.5

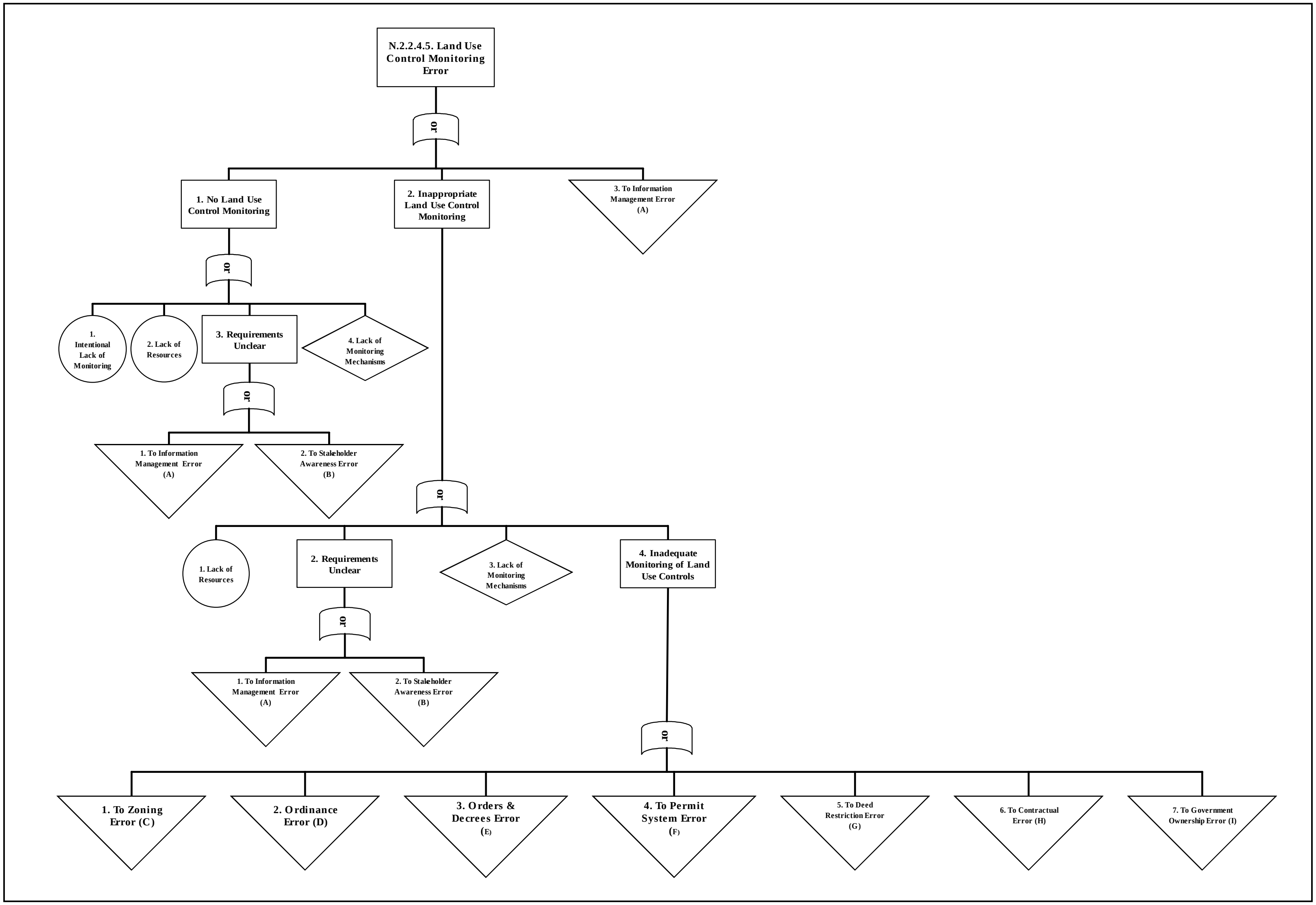

Figure 55. Land Use Control Monitoring Error branch.

Table 35. Description of events contributing to Land Use Control Monitoring Error.

Label	Event	Description
N.2.2.4.5	Land Use Control Monitoring Error	Basic event: contributes to Incomplete Monitoring (N.2.2.4).
1.	No Land Use Control Monitoring	Basic event: indicates that there is a lack of Land Use Control monitoring.
1.1	Intentional Lack of Monitoring	Basic event: indicates that the lack of monitoring was an intentional decision.
1.2	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
1.3	Requirements Unclear	Basic event: indicates that monitoring requirements are not understood.
1.3.1	To Information Management Error	Transfer Symbol to A.
1.3.2	To Stakeholder Awareness Error	Transfer Symbol to B.
1.4	Lack of Monitoring Mechanisms	Undeveloped event: indicates that mechanisms are not in place for appropriate monitoring.
2.	Inappropriate Land Use Control Monitoring	Basic event: indicates that the monitoring of the land use controls is not adequate.
2.1	Lack of Resources	Initiating event: indicates that there is inadequate funding or personnel.
2.2	Requirements Unclear	Basic event: indicates that monitoring requirements are not understood.
2.2.1	To Information Management Error	Transfer Symbol to A.
2.2.2	To Stakeholder Awareness Error	Transfer Symbol to B.
2.3	Lack of Monitoring Mechanisms	Undeveloped event: indicates that mechanisms are not in place for appropriate monitoring.
2.4	Inadequate Monitoring of Land Use Controls	Basic event: indicates that the monitoring of land use controls is inadequate.
2.4.1	To Zoning Error	Transfer Symbol to C with respect to monitoring Zoning Change Requests, Zoning Requirements and Zoning Definitions.
2.4.2	To Ordinance Error	Transfer Symbol to D with respect to Ordinance Requirements, Enforcement Resource Requirements and Related Legislative Actions.
2.4.3	To Orders & Decrees Error	Transfer Symbol to E with respect to Order & Decree Requirements, Enforcement Resource Requirements, Related Legislative & Judicial Actions and Property Transfer Records.
2.4.4	To Permit System Error	Transfer Symbol to F with respect to Permit Requirements, Permit Requests, Permit Compliance Requirements and Enforcement Resource Requirements.

Table 35, continued.

2.4.5	To Deed Restriction Error	Transfer Symbol to G with respect to Deed Restriction Requirements, Enforcement Resource Requirements and Property Transfer Records.
2.4.6	To Contractual Error	Transfer Symbol to H with respect to Contractual Requirements and Resource Requirements
2.4.7	To Government Ownership Error	Transfer Symbol to I with respect to Ownership Requirements and Resource Requirements.
3.	To Information Management Error	Transfer Symbol to A.

Management Responsibilities

The management of a contaminant isolation facility is a complex dynamic process. Temporal changes require site stewards to adjust their management approach accordingly. Maintenance and monitoring are key mitigating actions that are necessary to prevent precursor errors and system failure.

Additional institutional management responsibilities of site stewards include properly managing and disseminating information about the site and the contaminant isolation facility's performance, maintaining a multi-generational awareness of the site within the local community, maintaining financial security for the site and for the associated maintenance functions and continually assessing the performance of the system as well as the components of the system.

CHAPTER VII

CONCLUSIONS

Contaminant isolation facilities are designed to maintain isolation of known contaminants until such time that they are no longer a risk to humans or the environment. Contaminant isolation facility configurations involve a collection of individual controls to achieve the contaminant isolation objective. These individual controls include a combination of engineered barriers and institutional controls. Operating experience with modern contaminant isolation techniques shows that contaminant isolation facilities and associated management techniques do not always perform as expected. The results of this research show that precursor errors can occur to both institutional controls and engineered barriers. This research has also shown how these errors can lead to system failure. Without continued human intervention to correct these errors, contaminant isolation facilities will fail, given the longevity of the contaminants.

Case Studies

The selected case studies, Anaconda, Burrell, Canonsburg, Love Canal, Maxey Flats, Rocky Mountain Arsenal and Spring Valley, illustrate several variations in system configurations being applied for the near-surface isolation of residual contaminants for long-term periods. These configurations include sacrifice zones such as those found at Burrell, Canonsburg, Love Canal and Maxey Flats that are not being re-used for purposes other than contaminant isolation. The three other selected sites, Anaconda, Rocky Mountain Arsenal and Spring Valley, are examples of sites with portions of their property actively being re-used for other applications in addition to contaminant isolation.

The contaminant isolation facility configurations investigated through this case study research involved the following 13 individual controls:

- Information Management,
- Stakeholder Awareness,
- Zoning,
- Ordinances,
- Orders and Decrees,
- Permit Systems,
- Deed Restrictions,
- Contracts,
- Government Ownership,
- Physical Site Security,
- Surface Covers,
- Subsurface Barriers, and
- Active Processes.

The number of individual controls employed as part of the contaminant isolation strategies at the selected cases ranged from six to 12 controls per site with the average being 10 individual controls per site. Information management, stakeholder awareness, ordinances and physical site security were found to be the most frequently applied controls having been applied at all investigated sites.

The performance of implemented controls varied from site to site. Not all controls were performing as expected. Four of the seven investigated cases exhibited error characteristics at the individual control level. The Spring Valley site exhibited the most control implementation errors with four. Canonsburg, Burrell and Love Canal each exhibited two control implementation errors.

Stakeholder awareness was the control that most frequently exhibited error characteristics. Three of the seven sites showed implementation errors with regard to stakeholder awareness.

Maintenance and monitoring, although not a defined control, was found to be a critical institutional responsibility for ensuring the long-term performance of contaminant isolation facilities. Active maintenance and monitoring was evident at all investigated sites. Reduced monitoring strategies were applied at several sites within a few years of the isolation cell's completion.

Monitoring is shown to be an important component of site maintenance. Current site monitoring programs are structured to satisfy regulatory compliance in a confirmatory manner. Monitoring efforts are designed to confirm contaminant release and thus system failure. In other words, current management efforts operate in the fix-as-fail mode rather than in a more predictive and preventative mode.

Multi-organizational involvement was found to be a routine component of contaminant isolation facility operations. Independent regulatory oversight was observed at both UMTRCA and CERCLA sites. The USNRC, operating as a licensing body, provides federal oversight of operations consistent with USEPA regulations at UMTRCA sites while state involvement was observed to be minimal. For the CERCLA sites, the operations were again performed consistent with the federal regulations although the regulatory lead varied between state and federal oversight.

Contaminant Isolation Facility Failure Analysis

The evaluation of the performance of the individual controls and their associated errors supported the development of logical fault trees. Fault trees are cause-and-effect diagrams useful for evaluating the root causes of failure modes. These trees were developed to illustrate the major potential failure pathways for each of the contaminant isolation facility controls. This analysis provided a graphical means of displaying the qualitative information included in the case studies.

This analysis focused on unintentional precursors and events that could contribute to failure. Intentional violations, catastrophic natural events and deliberate acts with the intent to destroy or damage the contaminant isolation facility, such as sabotage, fraud or other illegal actions, present unique concerns and were not included in this analysis.

This fault tree taxonomy was useful for organizing and analyzing both institutional controls and engineered barriers. Fault trees provided a logical approach for clarifying how the undesired event (i.e., control error and system failure) could occur and, likewise, how mitigation efforts can reduce implementation errors and subsequent system failure.

Individual isolation controls were found to contain many single point errors. Controls with single point errors can be described as *non-robust* in that one single event could potentially result in a significant error rendering the control incapable of fulfilling its intended objective.

Contaminant isolation facility failure, as defined in this research, was found to require the breach of an engineered barrier. Engineered barriers include the passive physical components (i.e., the stabilized wasteform, surface controls and subsurface barriers) as well as the active processes (i.e., groundwater and leachate treatments). The completed failure analysis shows that for an engineered barrier error to occur an institutional control error must first occur. Institutional control errors, therefore, should be viewed as precursors to potential system failure. This research also showed that institutional control error alone does not directly lead to system failure.

Figure 56 illustrates the layering relationship of engineered barriers and institutional controls. Two distinct layers of protection are formed via the collection of implemented engineered barriers and institutional controls. Individual controls represent integral but independent pieces of these two layers. Additional controls are not necessarily redundant and therefore do not always reduce the likelihood of system failure.

Institutional control errors could be described as an erosion of protection. If uncorrected, these gaps in protection could negatively contribute to engineered barrier error via both the ingress or egress scenarios and ultimately system failure. Figure 57 illustrates this potential erosion of protection. This concept is similar to the “Swiss cheese model of defenses” suggested by Reason (1997).

Inadequate information management, stakeholder awareness and available resources were found to be key initiating events potentially leading to individual control error. These initiating events could be latent errors resulting in no immediate impact to the system performance. The consequences resulting from these latent errors may not be realized until additional events occur.

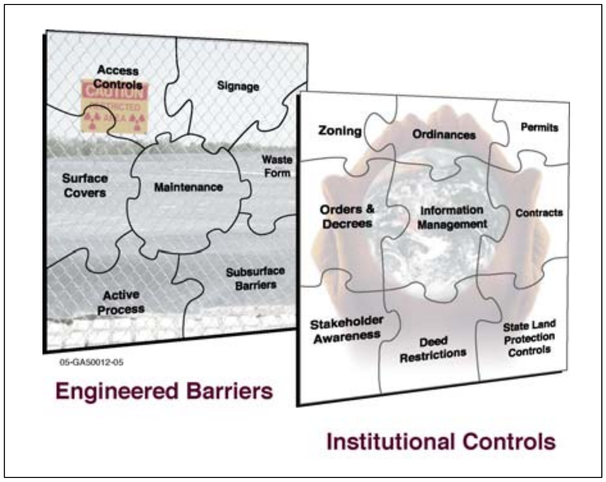

Figure 56. An illustration of the layering of engineered barriers and institutional controls.

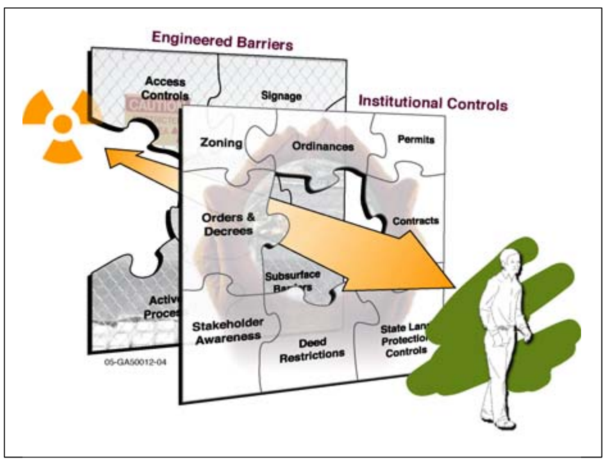

Figure 57. An illustration of the erosion of protection.

An analysis of the maintenance and monitoring functions of a contaminant isolation facility found that such functions are designed to validate and detect system failure. Current monitoring techniques do not necessarily provide site stewards with timely information sufficient to intervene and prevent failure.

Recommendations

To mitigate the potential errors and events illustrated through this research an expanded maintenance and monitoring program is required. Such a program must be designed to address the potential individual control errors so that system failure can be prevented.

Maintenance and Monitoring

More sustainable approaches are needed that should involve pro-active system monitoring focused on the detection of system changes prior to failure. Monitoring efforts should include identifying precursors to failure, thus providing more timely information that permits the implementation of corrective action before system failure occurs. In this manner, monitoring should be used as a guide to drive system maintenance rather than simply a strategy designed to satisfy compliance.

Maintenance and monitoring programs need to include the ability and the incentive to site stewards to make complete use of all existing information and monitoring data. Site stewards need to not only collect the required monitoring data but they also need to actively integrate this information and interpret and translate it into active site knowledge. This knowledge management should be the responsibility of the site steward who has an inherent interest in the site and the associated success of the contaminant isolation facility. Additional incentives may be required to motivate site stewards to maintain this site knowledge for future generations.

Monitoring should include self-monitoring by the site stewards as well as independent third party monitoring by regulators, stakeholders and the general public.

The transparency of monitoring, including independent oversight, could be a valuable technique for identifying significant operational errors. Third party oversight could also serve to strengthen the overall monitoring process and could in essence shift a number of FTA logic gates from or-gates to and-gates. This would result in more robust controls.

A risk-informed approach could be useful for establishing appropriate monitoring strategies for individual sites. Such a strategy could incorporate expanded monitoring of a site's performance including appropriate initiating events, which could potentially contribute to institutional control and engineered barrier errors. Sites that pose a high risk of negative consequences should failure occur may warrant this expanded monitoring.

Expanded monitoring in support of institutional control maintenance could include: zoning change requests, legislative and judicial actions, permit requests, property transfer records, enforcement resource requirements and specific control requirements. Expanded monitoring in support of engineered barrier maintenance could include: in-system performance monitoring (in-cell moisture content, material properties and barrier integrity measurements, radon emanation, etc.), vadose zone monitoring (moisture content, contaminant concentrations, etc.), groundwater sampling (sampling frequency, contaminant concentrations, etc.), site inspections (signs, fences, wells, etc.) and surface cover inspections (geo-membranes, riprap, vegetation, drainage systems, etc.).

The results of this research should also be useful during the design phase of new contaminant isolation facilities. These results suggest, that at a minimum, contaminant isolation facilities should utilize the following appropriate controls: physical site security, surface covers, subsurface barriers, information management, stakeholder awareness and ordinances. State land control ordinances, which are consistent with the UECA, are also recommended. Additionally, buffer zones incorporated into the facility design can reduce the likelihood of human ingress. Buffer zones can be incorporated into both sacrifice sites such as illustrated in the Maxey Flats case as well as into reuse sites such as the Rocky Mountain Arsenal.

Finally, new facility design should embrace information management. This research highlights the significant role that information management plays throughout the facility's existence. The objective of information management should be to maintain an adequate knowledge of the site so as to support not only current but future generations.

Follow-on Research

In addition to the above recommendations the results of this research suggest the need for follow-on research in several areas.

First, the potential failure pathways were determined using the case study approach. Further investigation using a representative sample of applicable sites should be performed to validate the proposed fault trees identified through this research. An appropriate sample of sites could readily be obtained from the approximately 900 completed CERCLA sites to perform this validation (USEPA, 2004f). Such a study could potentially determine probabilities for each of the identified pathways to failure. This analysis would support development of future mitigation measures applicable to the most probable pathways.

In addition to investigating sites with on-site contaminant isolation facilities, other types of residual waste sites (i.e., sites with contaminated groundwater) should be investigated using the same fault tree approach. Such an analysis would identify the unique characteristics of these sites, which are also a significant national and international problem.

Third, additional analysis of contaminant isolation facilities should be performed with regard to the various levels of risk posed by these sites. For example, CERCLA sites with high risk (i.e., high potential for negative consequences) could be evaluated to determine if unique management strategies are being applied at these sites or whether the potential failure pathways identified in this research are still prevalent. Results from such research could support resource planners in that limited management resources could be directed towards the more high-risk sites to minimize potential negative consequences.

Further analysis is warranted in the area of organizational responsibilities. This analysis should include an investigation of organizational mission with regard to the long-term management of contaminant isolation facilities. An analysis of the role of collective federal ownership as a management strategy should be conducted. Such a management strategy could potentially achieve an economy of scale through the consolidation of management efforts for a collection of residual waste sites. This analysis should also investigate the relationship of organizational mission as a means of shifting from the current strategy of monitoring for compliance (e.g., failure) to the recommended expanded monitoring of error precursors.

Finally, additional considerations should be given to the potential impact that natural resource damage claims may play with regard to current and future long-term contaminant isolation facilities. For example, future sacrifice zones may in particular be subject to significant litigation and damage claims.

The research of Dr. James Clarke and other members of the Consortium for Risk

Evaluation with Stakeholder Participation (CRESP) continues to improve the long-term management of residual contaminants. CRESP, in partnership with the USDOE, USEPA, USNRC, national laboratories and universities should continue collaborative research projects to investigate and implement the recommendations of this research.

APPENDIX A

GLOSSARY OF TERMS

Action Memorandum

An official document describing the actions that need to be taken to remediate a site as part of a removal action.

Activity and Use Limitations (AULs)

Legal or physical restrictions or limitations on the use of, or access to, a site or facility to eliminate or minimize potential exposures to chemicals of concern, or to prevent activities that could interfere with the effectiveness of a response action, to ensure maintenance of a condition of "acceptable risk" or "no significant risk" to human health and the environment (ASTM, 2000b).

Administrative Order

A legal agreement (between the USEPA and the potentially responsible parties [PRP]) through which the PRP agrees to pay for or take the required corrective action or refrain from an activity (USEPA, 2004i).

Baseline Risk Assessment

An evaluation of the potential threat to human health and the environment in the absence of any remedial action (USEPA, 1992).

Best Practices

Standard, published operating methods found to produce the best performance and results in a given industry or organization (Bridgefield, 2004).

Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980, commonly known as Superfund, establishes the framework for the federal response to the release of hazardous substances that endanger public health or the environment (CERCLA 1994).

Consent Decree

A legal document (approved by a judge, that formalizes an agreement between the USEPA and PRP) that describes the actions that the PRP will take (USEPA, 2004i).

Conservation Easement

A legal agreement authorized by a property owner that limits the type and amount of development that can take place on their property.

Contaminant

Any physical, chemical, biological, or radiological substance found in air, water, soil or biological matter that has a harmful effect on plants or animals; harmful or hazardous matter introduced into the environment (USEPA, 2004c).

Contaminant Isolation Facility (CIF)

A near-surface, engineered structure suitable for the permanent disposal of hazardous, radioactive, or toxic materials.

Contaminant of Concern (COC)

Any contaminant that is shown to pose possible risk to a site; also known as Contaminants of Concern, Contaminants of Potential Concern, or Contaminants of Interest [modified from (USEPA, 2004c)].

Covenant

A promise made by one landowner to another in connection with the conveyance of property (USEPA, 2004i).

Decree

A decision or order of the court. A final decree is one that fully and finally disposes of the litigation.

Deed

A signed legal instrument defining a transfer, bargain, or contract (Webster, 1977).

Deed Notice

A non-enforceable, informational document generally filed in public land records (USEPA, 2004i).

Deed Restriction

A restriction or limitation on an interest in real property, created in conveyance from one party to another (ASTM, 2000b).

Easement

A property right conveyed by a landowner to another party that gives the second party rights with regard to the first party's land (USEPA, 2004i).

Enforcement

The ability to compel compliance with a use restriction, or such other injunctive relief as may be necessary to protect human health and the environment (Miller, 2003).

Engineered Barrier (EB) or Engineered Control (EC)

Physical modification to the natural setting, including the site, facility and/or the residual materials themselves, in order to reduce or eliminate the potential for exposure to contaminants of concern (COCs).

Environmental Use Restriction

A prohibition of one or more uses of or activities on specified real property; or a requirement to perform certain acts; or both, where such prohibitions or requirements are relied on in the remedial decision for the purpose of protecting human health or the environment (Miller, 2003).

Equitable Servitudes

Building restrictions and restrictions on the use of land which may be enforced in equity (ASTM, 2000b).

Error

Unwanted actions or inactions that arise from problems in sequencing, timing, knowledge, interfaces and/or procedures that result in deviations from expected standards or norms that places people, equipment and systems at risk (Gertman and Blackman, 1994).

Errors are events in which a planned sequence of activities do not achieve the intended outcome. In the context of this research, errors are potential precursors to contaminant isolation facility failure.

Failure

Inability to achieve an objective. In the context of this research, failure refers to a contaminant isolation facility's inability of maintaining contaminant isolation.

Fault Tree Analysis (FTA)

An analytical technique, whereby an undesired state of the system is specified and the system is then analyzed in the context of its environment and operation to find all credible ways in which the undesired event can occur (Vesely et al., 1981).

Fault

Higher order event (Vesely et al., 1981).

Government Controls or Government-based Controls

Controls using the regulatory authority of a government entity to impose restrictions on citizens or sites under its jurisdiction (USEPA, 2004i).

Hazard

The inherent danger a material possesses for causing harm to human health, the environment, physical property and/or business continuity (Abkowitz, 2003).

Institutional Controls (IC)

Non-engineered instruments such as administrative and/or legal controls that minimize the potential for human exposure to contamination by limiting land or resource use (USEPA, 2000).

Institutional controls can be viewed as processes, instruments and mechanisms designed to influence human behavior and activity.

Institutional Responsibilities

All of the necessary functions that need to be conducted by the site stewards to ensure the long-term integrity of a waste isolation facility; these include all conventional institutional controls as well as site security, financial security, community involvement, information management and emergency preparedness.

Land Disposal Facility

The land, building, structures and equipment that are intended to be used for the disposal of radioactive wastes (10-CFR-61, 1982).

Near-surface Disposal Facility

A land disposal facility in which radioactive waste is disposed of in or within the upper 30 meters of the earth’s surface (10-CFR-61, 1982).

Notice

The public disclosure of information.

Order

A decision of a judge that is put in writing and filed in the court case. An order often requires action and, if not complied with, can result in contempt charges.

Ordinance

A written law enacted by the legislative body of a county, city or town.

Permits

Permits are land use control mechanisms that authorize specific limitations and requirements. For example, permits may be required before building construction or groundwater well installation.

Potentially Responsible Party (PRP)

A person or company who is or who could be liable and therefore responsible for the remediation of a site under federal or state laws (USEPA, 2004i).

Property-based Controls

Controls based on private property law used to restrict or affect the use of a property; also referred to as Proprietary Controls (USEPA, 2004i).

Proprietary Controls

Controls based on private, real property law used to restrict or affect the use of a property; also referred to as Property-based Controls (USEPA, 2004i).

Record Of Decision (ROD)

Official CERCLA documentation describing the selected remedy and associated rationale for a site’s remediation.

Remediation

Cleanup or other methods used to remove or contain a toxic spill or hazardous materials from a Superfund site (USEPA, 2004c).

Residual Hazards

Hazards arising from on-site residual waste/contaminants.

Residual Hazards Management

The collective use of engineered and institutional controls to isolate residual contaminants from the biosphere to minimize the associated hazards.

Residual Waste

Hazardous/contaminated material remaining on-site following remedial action.

Restrictive Covenant

A covenant acknowledged in a deed or lease that restricts the use of a property.

Reversionary Interest

A real estate interest created when a landowner deeds property to another, which specifies that the property will revert to the original owner under specified conditions (USEPA, 2004i).

Risk

The potential for realization of unwanted, adverse consequences to human life, health, property, or the environment; risk is usually based on the expected value of the conditional probability of the event occurring times the consequence of the event given that it has occurred (SRA, 2004).

Servitude

A burden resting on one estate for the benefit or advantage of another. An agreement granting limited permission to use the property.

State Land Use Controls

State statutes providing owners of contaminated property with the authority to establish use restrictions specifically for contaminated property (USEPA, 2000).

Statute

A law enacted by the legislative branch of the national or state government. Statutory law is distinguished from case law (i.e., law made by courts).

Success

Adherence to Best Practices to ensure the continued isolation of known residual contaminants.

System

A deterministic entity comprising an interacting collection of discrete elements (Vesely et al., 1981).

Waste

Hazardous, radioactive and other toxic substances resulting from energy production, mineral extraction, national defense programs, industrial operations and manufacturing operations.

Zoning

A local government land use control instrument used to regulate activity and development on private property located within its jurisdiction.

APPENDIX B

CASE STUDY CHECKLISTS

Anaconda Checklist

Case Study Name:	Anaconda Smelter NPL Site, Old Works/East Anaconda Development Area Operable Unit
Site Location:	Anaconda, MT
Site Point of Contact(s):	Milo Manning, USEPA Technical Assistance Group (TAG) 406-563-5538 mmaeei00@in-tch.com
Location of Information:	Anaconda Environmental Education Institute
Date of Site Visit:	October 2-3, 2003
Participants in Visit:	Kevin Kostelnik
Background	The Anaconda site was established in 1883, by the Anaconda Mineral Company, to process copper ore that was being mined at Butte, MT some 30 miles away. The site was selected because of the dependable water supply provided by Warm Springs Creek. Construction of the Upper Works area was completed from 1883-1884. The Lower Works, constructed in 1888, expanded the processing capacity. The two Works also operated two copper smelters. The smelters were connected to brick stacks atop adjacent hills by masonry flues. The Old Works and the two smelters operated from 1884 to 1901. Operations included separating ore with copper concentration greater than 6%. Ore of this concentration was sent to the smelters and processed. Slag and flue ash were the residual waste. Ore with concentration less than 6% was first crushed, segregated, concentrated and then processed. This process produced additional waste streams jig tailings, which were discharged onto the floodplain. Operations at the Old Works ended in 1901. A newer smelting operation, known as the Washoe Works or the Anaconda Reduction Works, started operating across the valley. This facility operated from 1902 through 1980. During the 1930s and 1940s portions of the residual waste were reworked. From 1940 to 1943 approximately 26 million pounds of copper and more than 1 million pounds of silver were retrieved from the reworking of the Red Sands. The Atlantic Richfield Company (ARCO) acquired the Anaconda Mineral Company in 1977 and continued operation until 1980. In 1983, the USEPA placed the Anaconda site on the National Priority List (NPL) as part of the recently enacted Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) program. In October

	1984, ARCO entered into an Administrative Order Consent and began to conduct a Remedial Investigation of the site. An expedited Remedial Investigation/Feasibility Study (RI/FS) was entered into in July 1986 for the Mill Creek area of the site. Young children were temporarily relocated due to the elevated arsenic levels in soil. A 1987-ROD determined that permanent relocation was warranted. A second Administrative Order Consent was established in September 1988 for the Flue Dust and Smelter Hill OUs. A 1991-ROD was finalized for these sites. An Action Memorandum was signed in July 1991 for the Old Works area. This Action included stabilization of the Red Sands, repairs to Warm Springs Creek levees and access control fencing. The March 1994 ROD refers to this area as the Old Works/East Anaconda Development Area (OW/EADA) OU. Additional OUs are currently being investigated and remediated. The final OU to be resolved will be the Anaconda Soils, Community Soils, and Regional Water and Wastes OU.	
Site Characteristics		
	Annual Precipitation	The average annual precipitation for the area is 13.7 inches.
	Surface Waters	Warm Springs Creek flows east across the site of the OW/EADA OU. This perennial stream is a tributary to the upper Clark Fork River and is the principle drainage of the Deer Lodge Valley. Approximately 2.8 miles of stream lie within this OU. Warm Springs Creek was channeled by levees in the 1880s to support the smelter operations.
	Aquifer/Ground Water	Residents in the area are on public water supplies. An alluvial aquifer underlies the site. This aquifer ranges in thickness from 20 feet in the western portion of the site to 100 feet along the eastern boundary. Groundwater flow is from west to east. Groundwater measurements of arsenic, cadmium, copper and zinc exceed the Federal Safe Drinking Water Act (FSDWA) maximum contaminant levels (MCL).
	Biological Indicators	Vegetation within the OU consists of secondary growth of weedy forbs, grasses and shrubs. Large portions of the site were bare before remedial operations.
	Annual Freeze/Thaw Cycles	Mean maximum temperature 81^{o}F is observed in the summer, while the mean minimum temperature of 15^{o}F is observed in winter.
	Ecosystem "Value"	The site is not consider a critical habitat although endangered species such as bald eagles, peregrine falcons and Rocky Mountain wolfs have been observed in the general vicinity. Regional wildlife includes mule and white-tailed deer, elk, moose, antelope, mice, voles, rabbit, small birds, brown trout, insects and other invertebrate organisms.

	Size	The Anaconda Smelter NPL site encompasses approximately 300 square mile area. This site involves 15 Remedial Design Units (i.e., Operable Units). Waste volumes are estimated to be approximately 230 million cubic yards of concentrated mine tailings, 30 million cubic yards of furnace slag, 500,000 cubic yards of flue dust, 20,000 acres of contaminated soil and millions of gallons of contaminated groundwater. The OW/EADA OU encompasses approximately 1300 acres. Approximately 1.4 million cubic yards of waste material (jig tailings, “heap roast” slag, Red Sands and other wastes) were associated with this OU. The site is bounded by Highway 1 on the south, Highway 273 to the east, Stuckey Ridge to the north and Cedar Street to the west. The OW/EADA OU is further divided into 6 subareas: the Old Works Structural area, the Heap Roast Slag and Waste Piles, the Warm Springs Creek floodplain, Red Sands, East Anaconda yard and the Drag Strip.
	Site Geology	The Anaconda site is described as three distinct soil areas. The floodplain area involving silt and clay loam soils, the lowland area involving broad alluvial fans with silt loam soils and the foothills, which are characterized as steeply sloping alluvial fans, colluvium and bedrock of sedimentary and volcanic rock.
Waste Characteristics		
	Primary Contaminants of Concern	Human health risks are associated with five chemicals: arsenic, cadmium, lead, zinc and copper.
	Primary Exposure Routes	The historical release and transport mechanisms for the contaminants of concern at this site include discarded waste materials, aerial deposition form stack emissions, in situ leaching from waste material, fluvial erosion and redeposition of wastes and demolition of structures. Pathways for potential migration were determined to be air, surface water, infiltration of precipitation and groundwater. The 1994 Record Of Decision (ROD) determined that the most plausible routes of human exposure for this OU were direct ingestion of dust, soil or surface wastes, inhalation exposure to respirable particulate matter and ingestion of contaminants in ground water.

		This determination was made because no human populations live within the OU. Current and future land use is assumed to remain recreational and commercial. Therefore, the exposed population is assumed to be recreational visitors and on-site workers. Residential development is considered to be low and therefore on-site residential scenarios were not considered.
	Primary Risk	The theoretical Reasonable Maximum Exposure cancer risk for on-site workers was determined to be greater than 1×10^{-4}. The range was 2×10^{-5} to 4×10^{-4}.
Societal Characteristics		
	Population Density within 1 mi.	Approximately 10,000 persons lived within 1 mile of the site as of 1990.
	Population Density within 3 mi.	The surrounding population increases only slightly due to the rural nature of the site.
	Demographic Pattern	The current surrounding population appears to be stable. When operations stopped in 1980, thousands of workers lost their jobs. The regional economics were difficult resulting in a demographic shift away from this area. The site is immediately adjacent to the town of Anaconda. The surrounding area is characterized as rural lands.
	Current Regional Land Use	The current regional land use is a combination of residential and rural.
	Historic Regional Land Use	The historical regional land use is ranchland and agricultural.
	Current Site Land Use	The OU has been remediated consistent with the 1994 ROD. This OU now contains a Championship Golf Course that incorporates the institutional and engineered controls required under this ROD. Waste materials are contained beneath this golf course.
	Potential Alternative Land Use(s)	None foreseen as long as the Golf Course remains economically viable. Surrounding areas are beginning to promote residential development.
Regulatory Characteristics		
	Principle Regulation	The response actions are performed under the CERCLA.
	Current Land Owner	US Army, US Fish and Wildlife Service
	Land Transfers	Anaconda Minerals Company operated ore processing facilities on the site from 1884 through 1977. Atlantic Richfield Company purchased AMC

		in 1977 and continued operations on site until 1980. Portions of the remediated OW/EADA OU were transferred to Anaconda-Deer Lodge County May 5, 1994.
	Former Land Owner(s)	Anaconda Minerals Company
	Potentially Responsible Parties	Atlantic Richfield Company (ARCO)
System Characteristics		
	Engineered Barriers (EB) Description	The remedial actions for Anaconda fall under CERCLA. The selected remedy for the OW/EADA OU requires: - Construction of engineered covers of waste materials exceeding arsenic levels of 1000 parts per million for areas designated as recreational and potentially commercial, - Treatment of soils exceeding arsenic levels of 1000 parts per million (ppm) for areas designated as recreational and potentially commercial, - Cover or treat soils exceeding arsenic level of 500 ppm in current commercial areas, - Construction of surface controls to manage surface water runoff, - Repair and upgrade levees to Warm Springs Creek.
	Institutional Controls (IC) Description	The remedial actions for Anaconda fall under CERCLA. The selected remedy for the OW/EADA OU require that institutional controls: - Assure that future land and water use is consistent with residual risks, - Preserve and maintain the remedial structures, - Assure that future construction be performed consistent with the remedial actions, - As development occurs, ensure that future remediation is conducted. To achieve these objectives four layers of ICs are envisioned. The first layer is the Community Protective Measures Program (CPMP). CPMP is primarily an informational process including deed notices, warning signs, maps, remedial status reports and public health advisories. The second layer of IC is the Anaconda Deer Lodge County Master Plan and Anaconda-Deer Lodge County Development Permit System. All new development in the impacted area will require a County Permit. This permit system provides for identification of potential future remediation of proposed residential or commercial development at the time of development to the appropriate arsenic

		levels. The final two layers are not in existence at the time of this writing. It is anticipated that the final set of ICs will be defined in the last Regional OU. The third protective layer is control of groundwater. It is envisioned that the State of Montana or the local water district will establish procedures for managing groundwater use. The fourth layer of control envisioned is specific to the area of the site were waste has been left in-place. Restrictive covenants, conservation easements and dedicated development areas are anticipated to serve the foundation for these controls. It is anticipated that these restrictive techniques will be designed to: - Protect the engineered controls and manage land and water use; - Implement long-term monitoring; - Preserve, to the extent practicable, historic features in the Old Works Historic District; and - Conduct five-year reviews of selected remedy.
	Date of Site Closure	This OU is covered under the 1994 ROD. The USEPA issued a Unilateral Administrative Order to ARCO in April 1994 to implement the preferred alternative remedy. Construction of the Golf Course sub-area began in June 1994 and was completed in 1996. The course was opened for business in May 1997. Construction in the last sub-area of the OU was completed in 2001. The OU is considered to be in an Interim Status because the remediation of groundwater in this area has been deferred to the Anaconda Regional Water, Waste, & Soils OU.
	State of Practice at that time	1994 ROD. Active remedial operations completed in 2001.
	Repair Actions to Date	None noted.
Graphics		
	Photographs	Obtained
	Maps	Obtained
	Timeline	Attached

Functions	Activities	Comments
Maintain the Engineered Contaminant Control System		
	Verify Engineered System Construction (i.e., Construction QA/QC)	Construction QA/QC Plan was in place during construction.
	Establish System Monitoring Plan	Yes

	Perform System Monitoring (i.e., after release or integrated system)	Yes
	Analyze and Report Data (i.e., monthly, quarterly, annually)	Yes
	Maintain Active Processes (pump & treat, biorem., etc.)	Yes
	Conduct Active Repairs	Yes
Monitor the Environment & Ecosystem		
	Define Environmental, Ecological & Bioindicators	Yes, Baseline Risk Assessment evaluated ecological risk.
	Establish Monitoring Plan	Yes
	Perform Active Monitoring	Yes, bio-monitoring was performed by USFW, USEPA and Texas Tech in 1999-2001. But it does not to appear to be an on-going process.
	Analyze and Report Data	Yes
Maintain Site Security		
	Establish Security Plan	Limited access and signs posted.
	Maintain Security Mechanisms (i.e., Access Controls)	Limited access and signs posted.
	Detect Security Violations	Informal
	Deter Security Violations	No
Enforce Legal Controls		
	Define Legal Responsibility (i.e., local, state, fed, multiple)	Yes
	Establish Property-based Controls (i.e., Real Estate Provisions, easements, covenants, restrictions)	Yes, County Permit System
	Maintain Reporting Requirements	Yes
Maintain Financial Security		
	Establish Financial Requirements (for monitoring, repair, replace, emergency actions, etc.)	Yes, via terms of land transfer. Appears to exclude Golf Course parcel due to its economic benefits.
	Establish Funding Mechanisms (i.e., insurance, tax, trust, appropriations)	Yes, ARCO funds O&M costs of County for lands transferred to County unless County obtains an economic benefit from the land.
	Maintain Funding (i.e., long-term financial security)	Yes, but only as long as ARCO exists.
Maintain Community Awareness		
	Identify Site Stakeholders	Yes. Local involvement. Local USEPA TAG.
	Establish Community Awareness Program	Yes, local repository, frequent public meetings because operations are still active. Some information available

		through golf course.
	Define Community Awareness procedures and schedule	Yes
	Maintain Community Awareness Program	Yes, local repository houses Administrative Record. Includes information up to ROD. Periodic fact sheets published.
Perform Information Management		
	Define Information Users	No
	Define Information Requirements	Administrative Record is very complete. First two 5-year reviews were obtained.
	Establish Information Management System	None evident.
	Integrate all monitoring and other relevant data	None evident.
	Maintain Information Management System	None evident.
	Maintain data current with information technology platforms	None evident.
Perform Emergency Actions		
	Establish Emergency Preparedness Plans	Still have on-going remedial operations
	Obtain Emergency Response equipment	Still have on-going remedial operations.
	Train Emergency Response Teams	Operation & Management (O&M) staff located at the site.
	Maintain Emergency Response Equipment & Team	O&M staff located at the site.
Continuous Improvement of System Operations		
	Integrate all Residual Hazards Management System Functions	Still have on-going remedial operations.
	Define Best Available Technology	Based on results of 1994 ROD.
	Analyze Cost-Effectiveness of Repair versus Replace versus Re-remediate	Still active remediation in other areas of NPL site.

Love Canal Checklist

Case Study Name:	Love Canal Waste Disposal Facility	
Site Location:	Niagara Falls, NY	
Site Point of Contact(s):	Mr. Michael Basile Public Affairs Officer USEPA Public Information Office Carborundum Center, Niagara Falls, NY (716) 285-8842	
Location of Information:	University at Buffalo, The State University of New York	
Date of Site Visit:	June 10, 2003	
Participants in Visit:	Kevin Kostelnik Dr. James Clarke	
Background	The origins of Love Canal date back more than 100 years. In the 1890s, William T. Love had a vision to create a "model city" in the Niagara Falls region of New York State. Love's plan was to construct a canal between the upper and lower reaches of the Falls. Love acquired property rights in the La Salle region of the City of Niagara Falls. The clay soils of the area made them suitable for construction of the canal. In 1894, construction of the canal began with both state and private financial backing. A portion of the canal, measuring between ½ to 1 mile was constructed. The canal, however, was never finished. The canal unfinished, subsequently served as a swimming hole for local residents for some 40 years until another entrepreneur arrived on the scene. Elon H. Hooker began the Hooker Electrochemical Company in the early 1900s. Hooker established a very successful company by generating chlorine and caustic soda. Hooker's enterprise grew to be one of the largest chemical corporations in America (later known as Occidental Chemical Corporation). With this growth came the need to dispose of residues and waste. Hooker disposed of waste in the former canal from 1942 through 1953.	
Site Characteristics		
	Annual Precipitation	The 30-year average annual precipitation for the area is 36 inches. For the years 1976 and 1977, the average annual precipitation was 47 and 50 inches respectively. These levels were significantly higher than the average.
	Surface Waters	The site is within ¼ mile of the Niagara River
	Aquifer/Ground Water	Residents in the area are on public water supplies. Groundwater resources in the area are minimal.
	Biological Indicators	The region is classified as a deciduous mixed forest. Vegetation is primarily hickory, oak, ash and maple. Due to the residential nature of the site the primary wildlife include small animals such as squirrel, birds and waterfowl.

	Annual Freeze/Thaw Cycles	Temperatures can range from approximately –10F ^{o} to 90 ^{o} F.
	Ecosystem "Value"	No threatened or endangered species are known to exist near this site.
	Size	The landfill measures approximately 16 acres. The dimensions of the canal at the time of waste disposal measured 3000 feet long and varied from 60 to 80 feet wide. The depth varied from 8 to 16 feet. Hooker conducted disposal operations in the northern section of the canal from 1943 through 1946. The southern portion of the canal served the period from 1946 through 1953. In addition, Hooker dug a number of disposal pits outside of the canal. These pits measured approximately 40 feet by 40 feet and were 25 feet in depth. After reaching capacity in 1953, Hooker filled the site with layers of dirt. Following remediation the size of the site consists of 70 acres fenced with a 40-acre clay/synthetic liner cap.
	Site Geology	The impermeable clay soils that made the site suitable for holding the canal water were also appealing to Hooker for containing the hazardous waste.
Waste Characteristics		
	Primary Contaminants of Concern	22,000 tons of chemical waste materials were disposed of in the canal. Chlorides, chlorobenzenes, sulfides, dioxin, metals, pesticides, phenols, toluenes, xylenes, arsenic, chromium, lead and VOCs.
	Primary Exposure Routes	The 1988-ROD determined that the most plausible routes of exposure were inhalation or inadvertent ingestion of contaminated soil, most likely occurring with children playing on the site.
	Primary Risk	The theoretical cumulative cancer risk for the no-action alternative was determined to be 2.4×10^{-4}. If the site were disturbed without implementing direct contact or dust control measures, the cumulative cancer risk was estimated to increase to 1.3×10^{-3}.
Societal Characteristics		
	Population Density within 1 mi.	Approximately 10,000 persons lived within 1 mile of the site as of 2003.
	Population Density within 3 mi.	Approximately 70,000 persons lived within 3 miles of the site as of 2003.
	Demographic Pattern	Beginning as early as 1942, the LaSalle Housing Development was established one block from Love Canal. By the early 1950s, small single-family homes began to surround the rectangular canal site. In 1954 the Niagara Falls Board of Education built the 99th Street School on the acquired Love Canal property (see Land Transfer section). During the initial excavation

		for the school waste was encountered. Construction continued and the 99th Street School opened in 1955. In addition to this construction project, the Board sold portions of the former Love Canal property for residential development. Additionally, in 1955, portions of the property were used for the construction of streets and sidewalks. Storm sewers were installed at a ten-foot depth under sections of Wheatfield and Read Avenue. All of these construction activities involved disturbances to the clay soils that served as the containment system for the original Love Canal disposal cell.
	Current Regional Land Use	The current regional land use remains primarily residential.
	Historic Regional Land Use	Residential. See demographic section.
	Current Site Land Use	Waste disposal, surrounded by residential areas.
	Potential Alternative Land Use(s)	Portions of the area surrounding the disposal facility are now vacant. Alternative uses of these areas are potential (i.e., parks and recreation).
Regulatory Characteristics		
	Principle Regulation	The initial response actions were performed under both state and federal emergency actions. The U.S. federal government enacted new legislation, the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), commonly known as Superfund, on December 11, 1980. Enactment of this Act was a direct result of the attention raised by the Love Canal disaster. The Resource Conservation and Recovery Act (RCRA) was also critical in determining alternative treatments and land disposal.
	Current Land Owner	Multiple landowners. Need further information.
	Land Transfers	As the city's population increased its infrastructure continued to expand to accommodate the demand. In the early 1950s the Niagara Falls Board of Education approached Hooker with regard to its interest in acquiring a portion of the canal lot. The Board was interested in acquiring a suitable property for a new school. Hooker informed the Board of the type of waste disposed of in the canal and suggested that this site was not suitable for excavation or construction. The Board continued its pursuit of the site. On at least two occasions Hooker appeared at Board meetings to again present their warnings. Finally, on April 28, 1953, after further discussions, the entire Love Canal property was transferred to the Niagara Falls Board of Education for $1. Language in the Deed acknowledged that waste was buried on the site and released Hooker of all liability and risk associated with the site.
	Former Land Owner(s)	Hooker Chemical Co. (Occidental Chemical Co.) City of Niagara Falls (Board of Education)

		Private Land Owners State of New York
	Potentially Responsible Parties	Occidental Chemical Corporation (OCC), formerly Hooker; US Army
System Characteristics		
	Engineered Barriers Description	The site consisted of several operable units resulting in several RODS, seven remedial stages and three Explanation of Significant Differences (ESD). The 1987 ROD considered six remedial alternatives for the remediation of this site. The selected remedy called for soils excavation, on-site solidification and a low permeable cover. Specifically, the selected remedy required: 1. Excavation of approximately 7500 cubic yards of contaminated soil. 2. On-site solidification of the excavated material. 3. Re-disposal of the solidified material back into the same unit of contamination. 4. Treatability studies to evaluate the effectiveness of the solidification process. 5. A low permeability cap installed over the unit of contamination. OCC, USEPA, NY entered into a Partial Consent Decree in 1989 to implement portions of the 1987 ROD. In 1990, USEPA determined that the excavated materials should be classified as RCRA F039 wastes (i.e., wastes containing dioxin). This waste needed to be treated to meet the Universal Treatment Standards (UTS) for dioxin 1 ppb. This treatment was first considered to be conducted at the OCC Buffalo Plant. This was later changed and treatment was performed by commercial facilities. Residues from the treatment were disposed of at a RCRA Subtitle C Landfill outside of the State of New York. In addition, contaminated sewer and creek sediments were analyzed, segregated, treated and disposed of.
	Institutional Controls Description	Groundwater monitoring program will be established in accordance with RCRA. The remedy will be reviewed at least every five years in accordance with CERCLA. O&M are required for maintaining the groundwater-monitoring program and maintaining the low permeable cover.
	Date of Site Closure	The landfill cover and leachate collection system was completed in 1985. The site was deemed construction complete on September 29, 1999. The sewer, sediment and other waste materials were shipped off-site for disposal in 2000.
	State of Practice at that time	1985-1993
	Repair Actions to Date	Portions of the canal cover required the liner to be repaired and replaced. Also, portions of the cap required

		regrading. These short-term remedial actions were completed in September 1993.
Graphics		
	Photographs	Obtained
	Maps	Obtained
	Timeline	In 1978, New York State Department of Environmental Conservation (NYSDEC) installed a system to collect leachate from the Site. The landfill area was covered and fenced and a leachate treatment plant was constructed. In 1981, the USEPA erected a fence around Black Creek and conducted environmental studies. In 1982, the USEPA selected a remedy to contain the landfill by constructing a barrier drain and a leachate collection system; covering the temporary clay cap with a synthetic material to prevent rain from coming into contact with the buried wastes; demolishing the contaminated houses adjacent to the landfill and nearby school; conducting studies to determine the best way to proceed with further site cleanup; and, monitoring to ensure the cleanup activities are effective. In 1985, NYSDEC installed the 40-acre cap and improved the leachate collection and treatment system. With the first Record of Decision (ROD) in May 1985, the USEPA implemented a remedy to remediate the sewers and the creeks that included 1) hydraulically cleaning the sewers; 2) removal and disposal of the contaminated sediments; 3) inspecting the sewers for defects that could allow contaminants to migrate; 4) limiting access, dredging and hydraulically cleaning the Black Creek culverts; and, 5) removing and storing Black and Bergholtz creeks' contaminated sediments. In 1986 the state cleaned 62,000 linear feet of storm and sanitary sewers. An additional 6,000 feet were cleaned in 1987. In 1989, Black and Bergholtz creeks were dredged of approximately 14,000 cubic yards of sediments. Clean riprap was placed in the creek beds, and the banks were replanted with grass. Prior to final disposal, the sewer and creek sediments and other wastes (33,500 cubic yards) were stored at OCC’s Niagara Falls RCRA-permitted facilities. In October 1987, as identified in a second ROD, the USEPA selected a remedy to address the destruction and disposal of the dioxin-contaminated sediments from the sewers and creeks: 1) construction of an onsite facility to dewater and contain the sediments; 2) construction of a separate facility to treat the dewatered contaminants through high temperature thermal destruction; 3) thermal treatment of the residuals stored at the site from the leachate treatment facility and other associated Love Canal waste materials; and, 4) on-site disposal of any nonhazardous residuals from the thermal treatment or incineration process.

		In 1989, OCC, USEPA and the State of New York entered into a partial consent decree (PCD) to address some of the required remedial actions, i.e., the processing, bagging and storage of the creek sediments, as well as other Love Canal wastes, including the sewer sediments. Also, in 1989, the USEPA published an Explanation of Significant Differences (ESD), which provided for these sediments and other remedial wastes to be thermally treated at OCC's facilities rather than at the site. In November 1996, a second ESD was issued to address a further modification of the 1987-ROD to include off-site USEPA-approved thermal treatment and/or land disposal of the stored Love Canal waste materials. In December 1998, a third ESD was issued to announce a 10-ppb treatability variance for dioxin for the stored Love Canal waste materials. The sewer and creek sediments and other waste materials were subsequently shipped off-site for final disposal; this remedial action was deemed complete in March 2000. A 1988 ROD selected a remedy for the 93rd Street School property including the excavation of approximately 7500 cubic yards of contaminated soil adjacent to the school followed by on-site solidification and stabilization. This remedy was reevaluated as a result of concerns raised by the NFBE, regarding the future reuse of the property. An amendment to the original 1988 ROD was issued in May 1991; the subsequent selected remedy was excavation and off-site disposal of the contaminated soils. This remedial action was completed in September 1992. Subsequently, Love Canal Area Revitalization Agency (LCARA) purchased the 93rd Street School property from the NFBE and demolished the building. (Region 2 Summary)

Functions	Activities	Comments
Maintain the Engineered Contaminant Control System		
	Verify Engineered System Construction (i.e., Construction QA/QC)	Construction QA/QC Plan was in place during construction.
	Establish System Monitoring Plan	Yes
	Perform System Monitoring (i.e., after release or integrated system)	GW monitoring
	Analyze and Report Data (i.e., monthly, quarterly, annually)	GW monitoring. State Rehabilitation Study
	Maintain Active Processes (pump & treat, biorem., etc.)	Yes
	Conduct Active Repairs	Yes
Monitor the Environment & Ecosystem		
	Define Environmental, Ecological & Bioindicators	None observed

	Establish Monitoring Plan	NA
	Perform Active Monitoring	NA
	Analyze and Report Data	NA
Maintain Site Security		
	Establish Security Plan	Yes
	Maintain Security Mechanisms (i.e., Access Controls)	Physical access is limited by locked fence. Project staff is located at site during work hours.
	Detect Security Violations	NA
	Deter Security Violations	NA
Enforce Legal Controls		
	Define Legal Responsibility (i.e., local, state, fed, multiple)	Yes
	Establish Property-based Controls (i.e., Real Estate Provisions, easements, covenants, restrictions)	The federal government and the State of New York purchased the affected properties. LCARA is the coordinating New York State agency in charge of maintaining, rehabilitating and selling the affected properties. Pursuant to Section 312 of CERCLA, as amended, the USEPA has been providing funds to LCARA for the maintenance of those properties and for the technical assistance. The USEPA awards these funds to LCARA directly through an USEPA cooperative agreement for home maintenance and technical assistance. The rehabilitation and sale of these homes have been completed. Since the rehabilitation program began, approximately 260 homes have been sold. Also, a new senior citizen housing development has been constructed on vacant property in the habitable portion of the area. (Region 2 Summary)
	Maintain Reporting Requirements	OCC performs monitoring and reports to State of New York and USEPA.
Maintain Financial Security		
	Establish Financial Requirements (for monitoring, repair, replace, emergency actions, etc.)	OCC is performing active maintenance. But likely does not include emergency contingency.
	Establish Funding Mechanisms (i.e., insurance, tax, trust, appropriations)	Corporate budget for O&M. This has not yet been verified.
	Maintain Funding (i.e., long-term financial security)	OCC funds operations and maintenance efforts.
Maintain Community Awareness		
	Identify Site Stakeholders	High profile site. Very active local

		involvement in 70s and 80s. Major participants have left the area. Little local interest/excitement observed. Currently celebrating the 25th anniversary.
	Establish Community Awareness Program	No information obtained concerning current local involvement.
	Define Community Awareness procedures and schedule	No
	Maintain Community Awareness Program	Local public reading rooms house Administrative Record. Includes information up to ROD.
Perform Information Management		
	Define Information Users	No
	Define Information Requirements	Information appears limited to that defined in the ROD. No 5-year reviews obtained yet.
	Establish Information Management System	No defined system was identified.
	Integrate all monitoring and other relevant data	No
	Maintain Information Management System	No defined system was identified.
	Maintain data current with information technology platforms	No historic data located yet.
Perform Emergency Actions		
	Establish Emergency Preparedness Plans	None observed on site.
	Obtain Emergency Response equipment	None observed on site.
	Train Emergency Response Teams	Operation & Management (O&M) staff located at the site.
	Maintain Emergency Response Equipment & Team	O&M staff located at the site.
Continuous Improvement of System Operations		
	Integrate all Residual Hazards Management System Functions	Appears OCC has this responsibility.
	Define Best Available Technology	Based on results of 1988 ROD
	Analyze Cost-Effectiveness of Repair versus Replace versus Re-remediate	Not obvious.

Maxey Flats Checklist

Case Study Name:	Maxey Flats Disposal Site	
Site Location:	Hillsboro, KY; Fleming County	
Site Point of Contact(s):	Omar Heath, Department for Environmental Protection, Division of Waste Management, Maxey Flats Project, Commonwealth of Kentucky, Route 2, Box 238A Hillsboro, KY 41049 (606) 784-6612 (606) 784-7862 fax	
Location of Information:	Morehead State University Library and Maxey Flats Project Office	
Date of Site Visit:	June 6, 2003	
Participants in Visit:	Kevin Kostelnik Dr. James Clarke Dr. Ann Clarke	
Background	Maxey Flats was used for low-level radioactive waste disposal from 1963 until December 1977. Approximately 4.8 million cubic feet of Low Level Waste containing more than 2.4 million curies of activity was disposed of in 52 trenches on site. Trenches were unlined and measured 15 to 670 feet long, 10 to 70 feet wide and 10 to 35 feet deep. Problems began to arise in the early 1970s. The site has a low permeability. Continuous subsidence in the soil cap, which was ~3 feet in depth, produced infiltration routes. Water accumulation in the trenches was observed. Subsequently, this leachate migrated from the trenches. Contamination was detected 300 feet from source trenches prompting site closure.	
Site Characteristics		
	Annual Precipitation	Average annual precipitation measured 44.3 inches for the period 1941-1970.
	Surface Waters	The site is located on a large terrace some 280-350 feet above the valley floor. Two perennial streams are located adjacent to the site. Rock Lick Creek runs to the south of the site. Crane Creek runs along the north.
	Aquifer/Ground Water	Groundwater resources in the area are very limited. Groundwater quality is considered poor. Since 1985, residents in the area are on public supplies. Prior to 1985, residents used shallow wells.

	Biological Indicators	The region is classified as deciduous, evergreen and mixed forest. Vegetation is primarily hickory, oak, ash and maple. Wildlife include deer, turkey, squirrel, waterfowl, etc.
	Annual Freeze/Thaw Cycles	The area is classified as temperate continental. Temperatures can range from 100^o F to –22^o F.
	Ecosystem "Value"	No threatened or endangered species are known to exist near this site.
	Size	The site originally involved approximately 40 acres of disposal trenches and 280 acres of land. Following remediation the size of the site consists of 55 acres of disposal trenches and a total of 800 acres (expanded buffer zone).
	Site Geology	Clay-rich soils range from 1- to 15-feet deep. The underlying geology consists of shale interbedded with lenses of fine-grained sandstone and siltstone.
Waste Characteristics		
	Primary Contaminants of Concern	Radionuclides: plutonium-238, plutonium-239/240, strontium-90, tritium, uranium-235, uranium-238, cobalt-60, carbon-14. Chemicals: benzene, toluene, xylenes, arsenic, cyanide
	Primary Exposure Routes	Groundwater (i.e., the off-site exposure Well Water pathway in the dominant pathway as determined in the baseline risk assessment.) Tritium is the critical radionuclide.
	Primary Risk	Off-Site The total dose equivalent from all combined off-site pathways (in the no action scenario) would be 75 mrem per year for the average case. The upper bound estimate from such a scenario would be 4300 mrem. The average lifetime risk of cancer from prolonged exposure from off-site pathways would be approximately 1 x 10^{-3}. The upper bound is 6 x 10^{-2}. On-Site Various intruder/trespasser scenarios were considered in the ROD. The direct exposure pathway was most critical if the cap is disturbed. The

		lifetime risk of cancer approaches 1 for prolonged exposures. This risk is reduced by a factor of 3 if the 100-year institutional control period is assumed to be successful.
Societal Characteristics		
	Population Density within 1 mi.	Approximately 152 persons lived within 1 mile of the site as of 1991.
	Population Density within 2.5 mi.	Approximately 663 persons lived within 2.5 miles of the site as of 1991.
	Demographic Pattern	The regional population is projected to increase by 15% through 2020. The estimated population living within 2.5 miles of the site by 2020 is 767. Nearest municipality is Morehead, KY located 10 miles southeast of the site.
	Current Regional Land Use	The area is primarily mixed woodlands, open farmland, agriculture and rural residential.
	Historic Regional Land Use	Agriculture, rural residential
	Current Site Land Use	Waste disposal. Surrounding forested area serves as a buffer zone.
	Potential Alternative Land Use(s)	None
Regulatory Characteristics		
	Principle Regulation	The site was placed on the NPL in 1986 to be remediated under CERCLA. The Record of Decision was finalized September 1991. A Consent Decree was signed July 1995 by the settling private parties, the settling federal agencies, the Commonwealth of Kentucky and USEPA.
	Current Land Owner	Commonwealth of Kentucky
	Land Transfers	The Commonwealth of Kentucky owned the property since disposal practices began. During the operational phase the Commonwealth leased (25 year lease with options for 25 more years) the property (January 1963) to Nuclear Engineering Company, Inc. In 1977, the State of Kentucky repurchased the leasehold estate.
	Former Land Owner(s)	Owned by State of Kentucky. Leased to Nuclear Engineering Company, Inc. for original waste disposal.
	Potentially Responsible Parties	823 potentially responsible parties (PRPs). In 1987, 82 PRPs formed the Maxey Flats Steering Committee to perform the RI/FS.

System Characteristics		
	Engineered Barriers Description	The selected remedy calls for "natural stabilization." The initial closure of the site includes grading the site then capping it to prevent infiltration. The initial cap consists of a layer of compacted clay (21 inches) and a 40-mm synthetic liner. Monitoring wells are located under the cap in the trenches to detect the degree of infiltration. Additional monitoring wells are located around the perimeter of the site.
	Institutional Controls Description	Following the initial site closure, the selected remedy has a 100-year "interim maintenance period," which is then followed by the final closure and custodial maintenance (in perpetuity). The interim maintenance period involves the establishment of a buffer zone around the site, posting of signs and fences, active maintenance, groundwater monitoring.
	Date of Site Closure	Interim cap completed 2003.
	State of Practice at that time	Current
	Repair Actions to Date	QA check done on cap integrity and cap sealed. No major repairs required to date.
Graphics		
	Photographs	Obtained
	Maps	Obtained
	Timeline	See five-year review.

Functions	Activities	Comments
Maintain the Engineered Contaminant Control System		
	Verify Engineered System Construction (i.e., Construction Quality Assurance/Quality Control).	Construction QA/QC Plan was in place during construction.
	Establish System Monitoring Plan	Yes
	Perform System Monitoring (i.e., after release or integrated system)	GW monitoring
	Analyze and Report Data (i.e., monthly, quarterly, annually)	For GW monitoring only.
	Maintain Active Processes (pump & treat, biorem., etc.)	None
	Conduct Active Repairs	As needed, no major post-ROD repairs required to date.

Monitor the Environment & Ecosystem		
	Define Environmental, Ecological & Bioindicators	None being monitored. Since no contamination is observed in streams fish monitoring is no longer performed.
	Establish Monitoring Plan	NA
	Perform Active Monitoring	NA
	Analyze and Report Data	NA
Maintain Site Security		
	Establish Security Plan	Yes
	Maintain Security Mechanisms (i.e., Access Controls)	Physical access is limited by locked fence. Project staff is located at site during work hours.
	Detect Security Violations	NA
	Deter Security Violations	NA
Enforce Legal Controls		
	Define Legal Responsibility (i.e., local, state, fed, multiple)	Yes
	Establish Property-based Controls (i.e., Real Estate Provisions, easements, covenants, restrictions)	Property ownership is under the direct control of the Commonwealth of Kentucky. Five-year review notes that Deed Restrictions are in place.
	Maintain Reporting Requirements	Property ownership is under the direct control of the Commonwealth of Kentucky.
Maintain Financial Security		
	Establish Financial Requirements (for monitoring, repair, replace, emergency actions, etc.)	Annual maintenance budget. But likely does not include emergency contingency.
	Establish Funding Mechanisms (i.e., insurance, tax, trust, appropriations)	State Trust Fund has been established per discussion with Omar Heath.
	Maintain Funding (i.e., long-term financial security)	State Trust Fund has been established per discussion with Omar Heath.
Maintain Community Awareness		
	Identify Site Stakeholders	Local interest group formed during RI/FS.
	Establish Community Awareness Program	Involved group during RI/FS through Initial Closure Period. No information available concerning involvement during Interim Maintenance Period.
	Define Community Awareness procedures and schedule	No
	Maintain Community Awareness Program	Local public reading rooms house Administrative Record. Includes information up to ROD. Periodic USEPA fact sheets published.
Perform Information Management		
	Define Information Users	No

	Define Information Requirements	Information is limited to that defined in the ROD.
	Establish Information Management System	No defined system was identified.
	Integrate all monitoring and other relevant data	No
	Maintain Information Management System	No defined system was identified.
	Maintain data current with information technology platforms	No historic information yet.
Perform Emergency Actions		
	Establish Emergency Preparedness Plans	Staff located at the site.
	Obtain Emergency Response equipment	Site is currently adjusting its infrastructure for maintenance and operations.
	Train Emergency Response Teams	Staff located at the site.
	Maintain Emergency Response Equipment & Team	Staff located at the site.
Continuous Improvement of System Operations		
	Integrate all Residual Hazards Management System Functions	Maxey Flats Project Office appears to have the responsibility for total site management.
	Define Best Available Technology	Based on results of 1991 ROD.
	Analyze Cost-Effectiveness of Repair versus Replace versus Re-remediate	No

Rocky Mountain Arsenal Checklist

Case Study Name:	Rocky Mountain Arsenal
Site Location:	Commerce City, (Denver) CO
Site Point of Contact(s):	Mr. Tom Jackson U.S. Fish and Wildlife Agency Rocky Mountain Arsenal Commerce City, CO (303) 289-0232
Location of Information:	Rocky Mountain Arsenal Technical Information Center (Ms. Amira Hamdy) Commerce City, CO (303) 289-0342
Date of Site Visit:	September 10, 2003
Participants in Visit:	Kevin Kostelnik
Background	An Act of Congress created the Rocky Mountain Arsenal (RMA) in 1942. RMA was established to manufacture chemical warfare agents for use in World War II. Manufacturing operations began in 1942 at the South Plants complex. Initial products included mustard gas, lewisite and chlorine gas. In 1952, the Army initiated operations at the North Plants complex. North Plants manufactured the nerve agent GB (i.e., Sarin) from 1953 until 1957. Demilitarization of GB munitions began at the North Plants in the early 1970s. Various incendiary munitions were also manufactured at RMA. These included M-47 bombs filled with napalm gel and M-74 bomblets filled with a mixture of agents. Munitions were manufactured at RMA in support of WWII, the Korean War and the Vietnam War. Following WWII, portions of the South Plants complex were leased to private industry for the manufacture of chemicals and pesticides. Nine companies operated manufacturing operations at the South Plants between 1946 and 1982 including three primary leases. These included the Julius Hyman and Company from 1947-1952, the Shell Chemical Company from 1952-1982 and Colorado Fuel and Iron from 1946 to 1948. Waste generated at RMA throughout the 40s, 50s and 60s was disposed on on-site in basins, pits, trenches and burn pits. Liquid waste from RMA was often treated and discharged into catch basins. In 1961, the Army drilled a 12,045-foot-deep injection well. From 1961 until 1966 approximately 165 million gallons of treated effluent waste was disposed of in this manner. The USEPA, Army, Shell and the Colorado Department of Health signed a Memorandum of Agreement on December 6, 1982 to investigate the decontamination of RMA. Throughout the 80s and

	into the 90s numerous legal actions and lawsuits were pursued. In 1992, Congress enacted the Rocky Mountain Arsenal National Wildlife Refuge Act of 1992. This Public Law #102-402 designated the transfer of RMA from the Army to the Department of Interior and designated the site as a unit within our National Wildlife Refuge system.	
Site Characteristics		
	Annual Precipitation	The average annual precipitation for the area is 15 inches.
	Surface Waters	The site has a network of streams, lakes and canals. Four drainage basins are recognized. These include First Creek, Irondale Gulch, Sand Creek and Second Creek. Streamflow is variable but is generally intermittent. Note: With development of Denver International Airport and surroundings, First Creek is expected to change from an intermittent stream to a perennial stream. This will complicate RMA management strategies.
	Aquifer/Ground Water	Residents in the area are on public water supplies. Groundwater flow within the uppermost weathered, alluvium portion of the Denver Formation has been designated as the Unconfined Flow System (UFS). This system is separated from deeper water-bearing units that are designated as the Confined Flow System (CFS). Some interchange between systems is possible.
	Biological Indicators	RMA is classified as a temperate grassland region. This area is considered as a transition zone between mountain and plains habitat. As of 1996, 88% of RMA was vegetated. Vegetation is a combination of early successional plant communities (41%), crested wheatgrass (19%) and a mix (28%) of shrubland, riparian woodland, marshes, wetlands and deciduous tree groves. RMA has a large wildlife community and is designated as a U.S. Wildlife Refuge. Wildlife is

		dominated by species of prairie, steppe and savanna communities. 26 species of mammals and 176 species of birds have been observed on RMA. Included are populations of deer, bald eagles, hawks, waterfowl and the rare Cassin's and Brewer's sparrows.
	Annual Freeze/Thaw Cycles	Mean maximum temperature (88°F) are observed in July while the mean minimum temperature (16°F) is observed in January.
	Ecosystem "Value"	RMA has a large wildlife community and is designated as a U.S. Wildlife Refuge. Wildlife is dominated by species of prairie, steppe and savanna communities. 26 species of mammals and 176 species of birds have been observed on RMA. Included are populations of deer, bald eagles, hawks, waterfowl and the rare Cassin's and Brewer's sparrows.
	Size	The RMA encompasses a 27 square mile area (17,000 acres). Upon closure 2000 acres will be contained within an inner fence and USDOD will be responsible. The surrounding 15,000 acres will be managed by USDOI as a wildlife refuge controlled at outer fence.
	Site Geology	RMA lies within the Denver Basin. The entire site is covered with unconsolidated alluvial and windblown sediments. Depth of these materials is approximately 130 feet.
Waste Characteristics		
	Primary Contaminants of Concern	More than 600 chemicals have been associated with activities at RMA. Principal contaminants include: organochlorine pesticides, metals (arsenic, mercury) and chlorinated and aromatic solvents. Human health risks are associated with four chemicals: aldrin, dieldrin, DBCP and arsenic.
	Primary Exposure Routes	The 1996 ROD determined that the most plausible routes of human exposure were consumption, dermal contact and inhalation. The highest risks are associated with the central portions of RMA where chemical processing and disposal occurred.

	Primary Risk	The theoretical cumulative cancer risk for the no-action alternative was determined to be greater than 1 x 10^{-4}.
Societal Characteristics		
	Population Density within 1 mi.	Approximately 21,000 people lived within 1 mile (e.g., Commerce City) of the site as of 2000.
	Population Density within 10 mi.	Approximately 555,000 people lived within 10 miles (e.g., Denver) of the site as of 2000.
	Demographic Pattern	The surrounding population is increasing. RMA is located approximately 8 miles from the City of Denver. Directly adjacent to RMA is Commerce City. East of RMA is the new Denver International Airport. Conversion of rural lands to urban areas is expected to increase surface runoff and thereby transform intermittent streams to perennial streams. Also as the result of Commerce City's growth (i.e., population expansion north of RMA), original plans to locate the visitor center in the southwest portion of RMA are being reconsidered.
	Current Regional Land Use	The current regional land use is a combination of industrial, residential and rural. RMA proper has been retained in federal ownership since 1942. Therefore RMA has retained a degree of separation from the surrounding influences.
	Historic Regional Land Use	The historical regional land use in the direct vicinity of RMA has been ranchland and agricultural. Although the site has always been in close proximity to the City of Denver (i.e., 8 miles) and Commerce City (i.e., immediate).
	Current Site Land Use	Waste disposal in the central portion of RMA. Wildlife refuge in the surrounding portions (i.e., doughnut configuration).
	Potential Alternative Land Use(s)	None foreseen as a result of the Rocky Mountain Arsenal National Wildlife Refuge Act of 1992.
Regulatory Characteristics		
	Principle Regulation	The response actions are performed

		under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). The Rocky Mountain Arsenal National Wildlife Refuge Act of 1992, Public Law 102-402, was also enacted to govern this site. The Resource Conservation and Recovery Act (RCRA) plays a role in determining alternative treatments and land disposal practices.
	Current Land Owner	US Army, US Fish and Wildlife Service
	Land Transfers	None, although several companies (i.e., Julius Hyman and Company 1947-52, Shell Chemical 1952-82, Colorado Fuel and Iron 1952-82) leased property for their operations.
	Former Land Owner(s)	US Army
	Potentially Responsible Parties	US Army, Shell Oil Company
System Characteristics		
	Engineered Barriers Description	The remedial actions for RMA fall under CERCLA and are incorporated into two operable units. The On-post OU addresses contamination within the fenced in 27 square miles of RMA proper. The Off-post OU addresses contamination outside of the RMA site. The On-post OU addresses 3000 acres of soil, 15 groundwater plumes and 798 structures. The selected remedy requires: continued operation of groundwater treatment systems, maintaining lake surface water levels to support aquatic ecosystems, continued monitoring of surface and groundwater, construction of a Toxic Substances Control Act (TSCA) compliant landfill, demolition and disposal on-site of contaminated structures, in situ stabilization of contaminated soils at Former Basin F, in situ thermal treatment of Hex Pit waste, and excavation and on-site disposal

		of contaminated soils and debris in a triple-lined RCRA-compliant landfill.
	Institutional Controls (IC) Description	Final Interim Institutional Plan was published February 2003. Plan defines the following ICs: Land Use Controls: residential development is prohibited, groundwater and surface water use as a potable source is prohibited, fish and game consumption is prohibited. Preservation: wildlife habitats are to be preserved, hydrogeologic characteristics are to be protected. Access Control via multiple and redundant layers. Perimeter fence with controlled access points. Second inner layer is the Central Remediation Area (CRA) restricted to workers. (A third inner layer is the exclusion zones established for worker protection.). GW monitoring wells are protected via signs. Army is responsible for ongoing operations and maintenance. A Wildlife Management Plan will be developed by USFW. This will include protective measures for caps and covers. Off-site ICs include notices of well restrictions. Additional institutional responsibilities include: Acquisition and delivery of 4000 acre-feet of potable water to the South Adams County Water and Sanitation District (SACWSD), Establishment of a Trust Fund to cover an RMA Medical Monitoring Program (as of 2003 this was not yet established), Five-year reviews.
	Date of Site Closure	1996 ROD. Active remedial operations expected through 2011.
	State of Practice at that time	1996 ROD. Active remedial operations expected through 2011.
	Repair Actions to Date	Still active operations.
Graphics		
	Photographs	Obtained
	Maps	Obtained
	Timeline	Developed

Functions	Activities	Comments
Maintain the Engineered Contaminant Control System		
	Verify Engineered System Construction (i.e., Construction QA/QC)	Construction QA/QC Plan was in place during construction.
	Establish System Monitoring Plan	Yes
	Perform System Monitoring (i.e., after release or integrated system)	Yes
	Analyze and Report Data (i.e., monthly, quarterly, annually)	Yes
	Maintain Active Processes (pump & treat, biorem., etc.)	Yes
	Conduct Active Repairs	Yes
Monitor the Environment & Ecosystem		
	Define Environmental, Ecological & Bioindicators	Yes
	Establish Monitoring Plan	Yes
	Perform Active Monitoring	Yes
	Analyze and Report Data	Yes
Maintain Site Security		
	Establish Security Plan	Yes
	Maintain Security Mechanisms (i.e., Access Controls)	Yes
	Detect Security Violations	Yes
	Deter Security Violations	Yes
Enforce Legal Controls		
	Define Legal Responsibility (i.e., local, state, fed, multiple)	Yes
	Establish Property-based Controls (i.e., Real Estate Provisions, easements, covenants, restrictions)	Yes
	Maintain Reporting Requirements	Yes
Maintain Financial Security		
	Establish Financial Requirements (for monitoring, repair, replace, emergency actions, etc.)	Yes
	Establish Funding Mechanisms (i.e., insurance, tax, trust, appropriations)	Yes, appropriations.
	Maintain Funding (i.e., long-term financial security)	Annual appropriations.
Maintain Community Awareness		
	Identify Site Stakeholders	High profile site. Active local involvement.

	Establish Community Awareness Program	Yes, visitor center and active visitor program.
	Define Community Awareness procedures and schedule	Yes
	Maintain Community Awareness Program	Yes, visitor center and active visitor program. Local public reading rooms house AR.
Perform Information Management		
	Define Information Users	Yes
	Define Information Requirements	Administrative record is very complete. First 5-year review was obtained.
	Establish Information Management System	Yes
	Integrate all monitoring and other relevant data	Yes
	Maintain Information Management System	Yes
	Maintain data current with information technology platforms	Yes
Perform Emergency Actions		
	Establish Emergency Preparedness Plans	Yes
	Obtain Emergency Response equipment	Yes, but still have on-going remedial operations.
	Train Emergency Response Teams	O&M staff located at the site.
	Maintain Emergency Response Equipment & Team	O&M staff located at the site.
Continuous Improvement of System Operations		
	Integrate all Residual Hazards Management System Functions	USDOI will have this responsibility after final remediation.
	Define Best Available Technology	Based on results of 1996 ROD.
	Analyze Cost-Effectiveness of Repair versus Replace versus Re-remediate	Still active remediation.

Spring Valley Checklist

Case Study Name:	Spring Valley	
Site Location:	Washington, D.C.	
Site Point of Contact(s):	George Arnold American University, University Archivist 202-885-3255	
Location of Information:	American University Bender Library	
Date of Site Visit:	April 17, 2002	
Participants in Visit:	Kevin Kostelnik Dr. Jerry Harbour	
Site Characteristics		
	Annual Precipitation	The average annual precipitation for the area is 39 inches.
	Surface Waters	The site is located in a residential/university suburb of Washington, D.C. Much of the area has been modified to control surface runoff. Drainage is to storm drains although a number of small intermittent streams still cross the area.
	Aquifer/Groundwater	Residents in the area are on public water supplies.
	Biological Indicators	The site is located in a residential/university suburb of Washington, D.C. Wildlife is limited to various species of birds and small mammals.
	Annual Freeze/Thaw Cycles	Temperatures range from approximately 87^{o}F to 27^{o}F.
	Ecosystem "Value"	The site is located in a residential/university suburb of Washington, D.C. Wildlife is limited to various species of birds and small mammals.
	Size	The Spring Valley area encompasses a 660-acre area. American University encompasses approximately 90 acres.
	Site Geology	The Spring Valley site involves four geologic formations, the Sykeville Formation, the Dalecarlia Intrusive Suite, the Anctinolite Schist and the Coastal Plain Terrace Formation.
Waste Characteristics		
	Primary Contaminants of Concern	The primary health risks are associated with the presence of unexploded, leaking ordnance and containers of chemical warfare agents. Additional risk is associated with soils contaminated from chemical warfare agents. Arsenic is the predominant contaminant, although health risk studies are ongoing.
	Primary Exposure Routes	Health risk studies are ongoing. Plausible routes of human exposure could be consumption, dermal contact and inhalation. The highest risks should be associated with areas of ordnance/chemical disposal.

	Primary Risk	Health risk studies are ongoing.
Societal Characteristics		
	Population Density within 1 mi.	Approximately 13,000 people live within the Spring Valley neighborhood.
	Demographic Pattern	The surrounding population is increasing. Spring Valley is within the District of Columbia.
	Current Regional Land Use	The current regional land use is residential, commercial and urban. Small pockets of woodlots remain within the neighborhood.
	Historic Regional Land Use	At the time American University was established (i.e., 1890) the area was predominantly rural farmland. This area later began to develop into residential land use.
	Current Site Land Use	The current regional land use is residential, commercial and urban. Small pockets of woodlots remain within the neighborhood.
	Potential Alternative Land Use(s)	None foreseen.
Regulatory Characteristics		
	Principle Regulation	Response actions at Spring Valley are being performed by the Army Corps of Engineers under their Defense Environmental Restoration Program (DERP). DERP was established under the Superfund Amendments and Reauthorization Act (SARA) of 1986 to identify, investigate and clean-up environmental contamination at formerly used defense sites (FUDS). The Corps coordinates its efforts with the USEPA, which has authority to act at the site via Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980. The District of Columbia, where Spring Valley is located, also plays a key role in making recommendations.
	Current Land Owner	American University, individual homeowners.
	Land Transfers	The Methodist Episcopal Church acquired 90 acres in 1889 to establish American University. The University properties, and surrounding lands, were leased to the U.S. government from 1917-1921. Portions of the properties were again leased to the U.S. government from 1937-1941. Areas surrounding the university were developed over the past century and approximately 1200 homes now occupy the property around American University.
	Former Land Owner(s)	Davis Farms American University
	Potentially Responsible Parties	US Army
System Characteristics		
	Engineered Barriers Description	Shallow land disposal.
	Institutional Controls Description	None

	Date of Site Closure	The properties were returned to the University in 1921. Active remedial operations are still occurring today.
	State of Practice at that time	Disposal in 1920 consisted of shallow land disposal. Active remedial operations are still occurring today.
	Repair Actions to Date	Still active remediation, investigations and operations.
Graphics		
	Photographs	Obtained
	Maps	Obtained
	Timeline	Completed

Functions	Activities	Comments
Maintain the Engineered Contaminant Control System		
	Verify Engineered System Construction (i.e., QA/QC)	No
	Establish System Monitoring Plan	No, broad area survey of 1483 properties initiated in 2002.
	Perform System Monitoring (i.e., after release or integrated system)	No
	Analyze and Report Data (i.e., monthly, quarterly, annually)	No
	Maintain Active Processes (pump & treat, biorem., etc.)	No
	Conduct Active Repairs	Yes, active remediations.
Monitor the Environment & Ecosystem		
	Define Environmental, Ecological & Bioindicators	No
	Establish Monitoring Plan	Yes
	Perform Active Monitoring	Yes
	Analyze and Report Data	Yes
Maintain Site Security		
	Establish Security Plan	Yes, at active remediation sites.
	Maintain Security Mechanisms (i.e., Access Controls)	Yes, at active remediation sites.
	Detect Security Violations	Yes, at active remediation sites.
	Deter Security Violations	Yes, at active remediation sites.
Enforce Legal Controls		
	Define Legal Responsibility (i.e., local, state, fed, multiple)	On-going through legal actions.
	Establish Property-based Controls (i.e., Real Estate Provisions, easements, covenants, restrictions)	No
	Maintain Reporting Requirements	No

Maintain Financial Security		
	Establish Financial Requirements (for monitoring, repair, replace, emergency actions, etc.)	On-going through legal actions.
	Establish Funding Mechanisms (i.e., insurance, tax, trust, appropriations)	On-going through legal actions.
	Maintain Funding (i.e., long-term financial security)	Remediation appears to be funded through annual appropriations of Corps.
Maintain Community Awareness		
	Identify Site Stakeholders	High profile site. Active local involvement.
	Establish Community Awareness Program	Yes, local reading rooms, newsletters and public meetings.
	Define Community Awareness procedures and schedule	None obvious.
	Maintain Community Awareness Program	Yes, local reading rooms, newsletters and public meetings.
Perform Information Management		
	Define Information Users	No
	Define Information Requirements	Historically no; a lot of information surfaced through families of men serving at AUES.
	Establish Information Management System	None obvious, although assume Corps has ongoing Administrative Record.
	Integrate all monitoring and other relevant data	None obvious, although assume Corps has ongoing Administrative Record.
	Maintain Information Management System	None obvious, although assume Corps has ongoing Administrative Record.
	Maintain data current with information technology platforms	None obvious, although assume Corps has ongoing Administrative Record.
Perform Emergency Actions		
	Establish Emergency Preparedness Plans	Site is being remediated under non-time critical removal actions.
	Obtain Emergency Response equipment	None obvious
	Train Emergency Response Teams	None obvious
	Maintain Emergency Response Equipment & Team	None obvious
Continuous Improvement of System Operations		
	Integrate all Residual Hazards Management System Functions	None obvious
	Define Best Available Technology	Still active remediation.
	Analyze Cost-Effectiveness of Repair versus Replace versus Re-remediate	Still active remediation.

Canonsburg Checklist

Case Study Name:	Canonsburg Uranium Mill Tailing Disposal Site	
Site Location:	Canonsburg, PA	
Site Point of Contact(s):	Carl Jacobson, Grand Junction Project Office, Department for Energy, S.M. Stoller, Grand Junction, CO, 81503 970-248-6040	
Location of Information:	Grand Junction Project Office	
Date of Site Visit:	June 13, 2003	
Participants in Visit:	Kevin Kostelnik	
Background	The Canonsburg disposal cell was used for disposal of residual radioactive material (RRM) resulting from the processing of uranium ore. The cell contains 376,100 cubic yards (i.e., 226,000 tons) of RRM. The average radioactivity of the tailings is 2315 pCi/g ^{226}Ra. The total cell radioactivity is 100 Ci ^{226}Ra.	
Site Characteristics		
	Annual Precipitation	Average annual precipitation for the Canonsburg, PA area is 37 inches.
	Surface Waters	The Canonsburg Disposal cell is directly bordered by Chartiers Creek (i.e., perennial stream) on the north, east and west. The water quality of the stream is considered poor in the vicinity of the site. Residents in the area are on public supplies. These public supplies rely on surface water upstream from the site.
	Aquifer/Ground Water	Groundwater occurs in the unconsolidated fill at a depth of 3 to 14 feet at the site. Groundwater resources in the area are minimal. Residents in the area are on public supplies. These public supplies rely on surface water upstream from the site.
	Biological Indicators	Vegetation is generally deciduous mixed forest consisting of primarily mixed oak, ash and maple. Wildlife include deer, squirrel, waterfowl, etc. There are no known threatened or endangered species in the area.

	Annual Freeze/Thaw Cycles	The region is classified as a humid continental climate. Temperatures generally range from 100°F to 0°F.
	Ecosystem "Value"	No threatened or endangered species are known to exist near this site.
	Size	The original site involved approximately 18.6 acres. Contaminated material from this site, as well as 163 vicinity properties (i.e., 30 acres), was consolidated and stabilized into a 6-acre on-site disposal cell.
	Site Geology	The geology of the site consists of approximately 30 feet of unconsolidated alluvium that overlies claystone and shales of the Pennsylvanian Casselman Formation.
Waste Characteristics		
	Primary Contaminants of Concern	Uranium tailings contain small concentrations of naturally occurring materials that radioactively decays to radium and produces radon, a radioactive gas. In addition, trace metals associated with the ore and chemicals used during the milling process are present.
	Primary Exposure Routes	Groundwater contamination of surface water.
	Primary Risk	A copy of the Baseline Risk Assessment has been requested from Grand Junction.
Societal Characteristics		
	Population Density within 1 mi.	As of 1990 the population of the Borough of Canonsburg was approximately 9200.
	Demographic Pattern	The immediate population appears stable. The site lies is the Borough of Canonsburg, 20 miles southwest from Pittsburgh, PA. The regional population is also stable.
	Current Regional Land Use	The immediate area is primarily residential.
	Historic Regional Land Use	The immediate area was industrial and residential.
	Current Site Land Use	Waste disposal, surrounded by residential.
	Potential Alternative Land Use(s)	None
Regulatory Characteristics		
	Principle Regulation	The principle regulation is the Uranium Mill Tailings Radiation Control Act. The Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978 was designed to clean up 24 abandoned mill tailing sites that had processed uranium and related ores for the federal government. Under the UMTRCA, the USEPA was directed to set general standards for the cleanup at these sites and vicinity properties. These are contained in the Code of Federal Regulations, Title 40, Part 192.

		UMTRCA authorized the USDOE to clean up the sites to meet USEPA standards. UMTRCA also authorized the U.S. Nuclear Regulatory Commission (USNRC) to oversee and certify the cleanup and license the completed disposal cell. Remedial actions at UMTRCA sites must also comply with the USEPA ground water protection standards published in the *Federal Register* in January 1995.
	Current Land Owner	U.S. federal government (USDOE) is the current landowner. The site is currently managed within the US DOE Long-term Surveillance and Monitoring Program by the DOE Grand Junction Project Office (DOE-GJO) under license (1996) to the USNRC. Site C was donated to the Borough of Canonsburg by the State of Pennsylvania.
	Land Transfers	The Canonsburg site was owned and operated as a radium extraction plant by Standard Chemical from 1911 to 1922. During the period of 1930-1942 operations continued at this location for the extraction of uranium and radium salts. Vitro Corporation of America acquired the property and processed ore from 1942 until 1957 under contract to the federal government. In 1956 and 1957, approximately 54,000 cubic yards of material was moved from the Canonsburg site to the Burrell site. In 1957 the Vitro plant closed. From 1957 through 1966 the site was used for storage under an Atomic Energy Commission contract. In 1967, the property was purchased by the Canon Development Company and was leased to tenant companies for light industrial use. Remedial action began in 1983. In accordance with UMTRCA, the Commonwealth of Pennsylvania was responsible for acquiring the designated properties. The site consisted of three parcels. The Commonwealth acquired these parcels through its Department of Environmental Resources. In addition to these parcels, approximately 163 vicinity properties were identified as potentially contaminated. The US Army Corps of Engineers (USACE) acquired these adjacent properties on behalf of the USDOE to complete the remedial action. Upon completion of the remedial action and following the USNRC's concurrence, the Commonwealth transferred the ownership of these properties to the United States of America. Site C was transferred to the Borough of Canonsburg for public use. These transfers were completed in 1995.

	Former Land Owner(s)	See Land Transfers section.
	Potentially Responsible Parties	US DOE
System Characteristics		
	Engineered Barriers Description	The size of the Canonsburg Disposal Cell is approximately 6 acres. The cell involves a compacted clay bottom liner. The radioactive tailings were then emplaced on the liner and the material was covered with a 3-foot radon barrier consisting of a clay-and-soil mixture. The radon barrier was covered with layers of rock and soil, which was seeded with grass.
	Institutional Controls Description	The DOE-GJO manages the site through its Long-Term Surveillance and Maintenance Program (LTSM) and in accordance with a long-term surveillance plan prepared specifically for the Canonsburg site. Under provisions of the LTSP, the LTSM Program: conducts annual inspections of this site to evaluate the condition of surface features, cuts the grass at least once each year and controls other vegetation, performs other maintenance as necessary, and continues to monitor groundwater. Specific Institutional Controls present at this site include: access controls/fencing, warning signs, site markers and monuments, erosion control markers along Chartiers Creek, annual inspections, routine maintenance and groundwater monitoring wells. The LTSM Program monitors groundwater and surface water at the site as a best management practice to evaluate potential contaminant trends within the unconsolidated materials underlying the disposal site and to ensure that the creek is not contaminated.
	Date of Site Closure	The date of the cell closure is December 1985.
	State of Practice at that time	Current
	Repair Actions to Date	In 2001, the southern bank of Chartier Creek was stabilized to prevent further erosion. Stream erosion had been a concern for several years prior to this corrective action. Erosion markers and groundwater wells were impacted. The corrective action has been successful to date.
Graphics		
	Photographs	Obtained
	Maps	Obtained
	Timeline	See Land Transfer Section.

Functions	Activities	Comments
Maintain the Engineered Contaminant Control System		
	Verify Engineered System Construction (i.e., Construction Quality Assurance/Quality Control.	Construction QA/QC Plan was in place during construction.
	Establish System Monitoring Plan	Yes, LTSM Plan from DOE-GJO.
	Perform System Monitoring (i.e., after release or integrated system)	GW monitoring and site inspections.
	Analyze and Report Data (i.e., monthly, quarterly, annually)	Annual inspection reports summarize findings. Only data available is for GW monitoring.
	Maintain Active Processes (pump & treat, bioremediate, etc.)	None
	Conduct Active Repairs	Yes
Monitor the Environment & Ecosystem		
	Define Environmental, Ecological & Bioindicators	NA
	Establish Monitoring Plan	NA
	Perform Active Monitoring	NA
	Analyze and Report Data	NA
Maintain Site Security		
	Establish Security Plan	Yes
	Maintain Security Mechanisms (i.e., Access Controls)	Physical access is limited by locked fence.
	Detect Security Violations	NA
	Deter Security Violations	NA
Enforce Legal Controls		
	Define Legal Responsibility (i.e., local, state, fed, multiple)	Yes
	Establish Property-based Controls (i.e., Real Estate Provisions, easements, covenants, restrictions)	Yes, but have not yet obtained copies of deeds.
	Maintain Reporting Requirements	Yes
Maintain Financial Security		
	Establish Financial Requirements (for monitoring, repair, replace, emergency actions, etc.)	Annual LTSM maintenance budget, but does not include emergency contingency.
	Establish Funding Mechanisms (i.e., insurance, tax, trust, appropriations)	Annual USDOE appropriations.
	Maintain Funding (i.e., long-term financial security)	Annual USDOE appropriations.

Maintain Community Awareness		
	Identify Site Stakeholders	No local interest groups identified.
	Establish Community Awareness Program	No information available concerning local community involvement.
	Define Community Awareness procedures and schedule	No
	Maintain Community Awareness Program	Annual inspection reports available from DOE-GJO. No information on local involvement.
Perform Information Management		
	Define Information Users	Only know users appear to be DOE-GJO.
	Define Information Requirements	Information IS included in annual inspection reports (i.e., groundwater data).
	Establish Information Management System	DOE-GJO has responsibility for maintaining information. DOE-GJO conducts trending analysis. Information is available via internet.
	Integrate all monitoring and other relevant data	Yes, but appears limited to groundwater data.
	Maintain Information Management System	No defined system was identified although trending data is presented in annual reports.
	Maintain data current with information technology platforms	DOE-GJO maintains paper copies of records.
Perform Emergency Actions		
	Establish Emergency Preparedness Plans	Emergency procedures and verification procedures appear to be in place between DOE-GJO and local and state authorities.
	Obtain Emergency Response equipment	No emergency equipment is located at the site. Places will rely on local and state support.
	Train Emergency Response Teams	NA
	Maintain Emergency Response Equipment & Team	NA
Continuous Improvement of System Operations		
	Integrate all Residual Hazards Management System Functions	The DOE-GJO has the responsibility for all management functions.
	Define Best Available Technology	NA
	Analyze Cost-Effectiveness of Repair versus Replace versus Re-remediate	NA

Burrell Checklist

Case Study Name:	Burrell Uranium Mill Tailing Disposal Site	
Site Location:	Blairsville, PA; Indiana County, PA	
Site Point of Contact(s):	Carl Jacobson, Grand Junction Project Office, Department for Energy, S.M. Stoller, Grand Junction, CO, 81503 970-248-6040	
Location of Information:	Grand Junction Project Office	
Date of Site Visit:	June 12, 2003	
Participants in Visit:	Kevin Kostelnik	
Background	The Burrell site is considered a vicinity property of the Canonsburg UMTRA site. As a result of the amount of residual radioactive material (RRM) as well as the distance to the Canonsburg site, the Burrell disposal cell was constructed on-site rather than relocating all RRM back to Canonsburg. The cell contains 86,000 tons of RRM. The total cell radioactivity is 4 Ci ^{226}Ra.	
Site Characteristics		
	Annual Precipitation	Average annual precipitation for the Blairsville, PA area is 44 inches, which is fairly evenly distributed throughout the year.
	Surface Waters	The Burrell Disposal cell is located approximately 1 mile from the Borough of Blairsville. The Conemaugh River directly borders the site on the south. The railroad tracks of the Norfolk Southern Rail Corporation directly border the site on the north. This river is recharged by groundwater flowing south-west through unconsolidated material.
	Aquifer/Groundwater	Groundwater occurs in the unconsolidated material at a depth of 30 feet at the site. Groundwater flows south-west through unconsolidated material below the site and discharges into the Conemaugh River. Residents in the area are on public supplies.
	Biological Indicators	Vegetation is generally deciduous mixed forest consisting of primarily mixed oak, ash and maple. Wildlife include deer, squirrel, waterfowl, etc. There are no known threatened or endangered species in the area.
	Annual Freeze/Thaw Cycles	The region is classified as a humid continental climate. Temperatures generally range from 100^{o}F to 0^{o}F.
	Ecosystem "Value"	No threatened or endangered species are known to exist near this site.
	Size	The Burrell site involves approximately 72 acres. Contaminated material was consolidated and stabilized into a 5-acre on-site disposal cell.
	Site Geology	The Burrell site is located upon a man-made plateau. Fill material, measuring 50 to 60 feet in depth, were

		landfilled to level the area for the rail service. The fill material consists of gravelly loam, cinders, gravel, sandstone, construction debris, etc. The site is underlain by claystone and shales of the Pennsylvanian Casselman Formation.
Waste Characteristics		
	Primary Contaminants of Concern	Uranium tailings contain small concentrations of naturally occurring materials that radioactively decays to radium and produces radon, a radioactive gas. In addition, trace metals associated with the ore and chemicals used during the milling process are present.
	Primary Exposure Routes	Groundwater contamination.
	Primary Risk	Groundwater water contamination. Initially 10 monitoring wells and 2 seeps were monitored for standard water quality indicators and 20 analytes including: gross alpha, lead, molybdenum, radium-226, radium-228, nitrate, selenium and uranium.
Societal Characteristics		
	Population Density within 1 mi.	The population within 1 mile of the site is very low (~<100). Residential sites are expanding into the area and the population within 2 miles of the site has been increasing. As of 1990 the population of the Borough of Blairsville was approximately 3595.
	Demographic Pattern	The immediate population appears to be increasing. Residential sites are expanding into the area and the population within 2 miles of the site has been increasing. The site lies within the Borough of Blairsville, 40 miles west from Pittsburgh, PA. The regional population is stable.
	Current Regional Land Use	The immediate area is wooded. A railroad is directly adjacent to the disposal site.
	Historic Regional Land Use	The immediate area is wooded. A railroad is directly adjacent to the disposal site.
	Current Site Land Use	Waste disposal, surrounded by wooded areas. Area residents access the railroad area for recreation and unofficial waste disposal.
	Potential Alternative Land Use(s)	None
Regulatory Characteristics		
	Principle Regulation	The principle regulation is the Uranium Mill Tailings Radiation Control Act. The Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978 was designed to clean up 24 abandoned mill tailing sites that had processed uranium and related ores for the federal government. Under the UMTRCA, the USEPA was directed to set general standards for the cleanup at these sites and vicinity properties. These are contained in the Code of Federal Regulations, Title 40, Part 192.

		UMTRCA authorized the USDOE to clean up the sites to meet USEPA standards. UMTRCA also authorized the USNRC to oversee and certify the cleanup and license the completed disposal cell. Remedial actions at UMTRCA sites must also comply with the USEPA ground water protection standards published in the *Federal Register* in January 1995.
	Current Land Owner	U.S. federal government (USDOE) is the current landowner. The site is currently managed within the US DOE Long-term Surveillance and Monitoring Program under license (1996) to the USNRC.
	Land Transfers	The Burrell site was previously owned by the Western Pennsylvania Railroad Company for the purposes of supporting rail operations as far back as 1882. The property changed ownerships several times but always to subsequent railroads. The Pennsylvania Railroad Company acquired portions of the property in 1937. Later the Consolidated Rail Corporation acquired the property in 1976. Resolution of the federal government's acquisition of the property occurred December 27, 1988.
	Former Land Owner(s)	See Land Transfers section.
	Potentially Responsible Parties	US DOE.
System Characteristics		
	Engineered Barriers Description	The size of the Burrell Disposal Cell is approximately 5 acres. The cell involves a multi-layer cap above the RRM found at the site. This RRM was originally transported to the Burrell site to serve as fill material at the site to level it for the railroad. This RRM, measuring approximately 74,400 tons, was left in place. In addition to this RRM, approximately 11,600 tons of additional RRM was relocated from the Canonsburg UMTRA site from 1956 through 1957. As part of the Burrell remedial action, this RRM was placed on top of the other RRM. The cap was then placed on top of this total 86,000 tons of RRM. The cap consists of three layers. Directly above the RRM a 3-foot-thick radon barrier was installed which consisting of a compacted clay. The purpose of this clay layer is to prevent the escape of radon gas and prevent the infiltration of precipitation. Above the radon barrier a 1-foot-thick soil-bedding layer was installed. The purpose of this layer was to promote precipitation runoff. The third layer consists of 1-foot-thick riprap. This layer was designed to prevent surface erosion.
	Institutional Controls Description	The DOE Grand Junction Office (DOE-GJO) manages the site through its Long-Term Surveillance and Maintenance Program (LTSM) and in accordance

		with a long-term surveillance plan prepared specifically for the Burrell site. Under provisions of the LTSP, the LTSM Program: conducts annual inspections of this site to evaluate the condition of site features, performs other maintenance as necessary, continues to monitor groundwater and maintains emergency response capabilities in the event of a catastrophe. Specific Institutional Controls present at this site include: access controls/fencing, warning signs, site markers and monuments, erosion control markers, annual inspections, routine maintenance and groundwater monitoring wells. The LTSM Program initially monitored both groundwater and surface water at the site as a best management practice to evaluate potential contaminant trends. Changes to this monitoring plan have been noted in the 2002 Annual Compliance Report. These modifications include: discontinuing vegetation control on the cell cover, reducing groundwater monitoring frequency to once every 5 years, elimination of 2 wells for groundwater monitoring, eliminating surface water monitoring on the Conemough River, discontinuing analyses for ammonia, cyanide, gross alpha, radium-226, radium-228 and vanadium, and removing reference to a site marker that was never installed.
	Date of Site Closure	The date of the cell closure is December 1987.
	State of Practice at that time	Current
	Repair Actions to Date	Vegetation removal from the cap riprap has been an ongoing problem. A July 1999 GJO report documents this issue and recommends the elimination of maintenance/vegetation removal.
Graphics		
	Photographs	Obtained
	Maps	Obtained
	Timeline	Developed

Functions	Activities	Comments
Maintain the Engineered Contaminant Control System		
	Verify Engineered System Construction (i.e., Construction Quality Assurance/Quality Control)	Construction QA/QC Plan was in place during construction.
	Establish System Monitoring Plan	Yes, LTSM Plan from DOE-GJO.
	Perform System Monitoring (i.e., after release or integrated system)	GW monitoring and site inspections.
	Analyze and Report Data (i.e., monthly, quarterly, annually)	Annual inspection reports summarize findings. In addition, a Plant

		Encroachment analysis report documents the projected effects of vegetation growing on the cap. Report includes additional data.
	Maintain Active Processes (pump & treat, biorem., etc.)	None
	Conduct Active Repairs	Yes, vegetation on cap sprayed until the requirement was eliminated.
Monitor the Environment & Ecosystem		
	Define Environmental, Ecological & Bioindicators	NA
	Establish Monitoring Plan	NA
	Perform Active Monitoring	NA
	Analyze and Report Data	NA
Maintain Site Security		
	Establish Security Plan	Yes
	Maintain Security Mechanisms (i.e., Access Controls)	Physical access is limited by locked fence.
	Detect Security Violations	NA
	Deter Security Violations	NA
Enforce Legal Controls		
	Define Legal Responsibility (i.e., local, state, fed, multiple)	Yes
	Establish Property-based Controls (i.e., Real Estate Provisions, easements, covenants, restrictions)	Yes
	Maintain Reporting Requirements	Yes
Maintain Financial Security		
	Establish Financial Requirements (for monitoring, repair, replace, emergency actions, etc.)	Annual LTSM maintenance budget, but does not include emergency contingency.
	Establish Funding Mechanisms (i.e., insurance, tax, trust, appropriations)	Yes, annual USDOE appropriations.
	Maintain Funding (i.e., long-term financial security)	Requires annual appropriations.
Maintain Community Awareness		
	Identify Site Stakeholders	No local interest groups identified.
	Establish Community Awareness Program	DOE-GJO LTSM website established and maintained. No information available concerning local community involvement.
	Define Community Awareness procedures and schedule	No
	Maintain Community Awareness Program	Annual inspection reports available from DOE-GJO. No information on local involvement.

Perform Information Management		
	Define Information Users	Only known users appear to be DOE-GJO and the Nuclear Regulatory Commission (USNRC).
	Define Information Requirements	Information appears to be limited to that included in annual inspection reports (i.e., groundwater data).
	Establish Information Management System	No defined system was identified although trending data is presented in annual reports. Some information is available via DOE-GJO webpage.
	Integrate all monitoring and other relevant data	Yes, but appears limited to groundwater data.
	Maintain Information Management System	No defined system was identified although trending data is presented in annual reports.
	Maintain data current with information technology platforms	DOE-GJO maintains paper copies of records.
Perform Emergency Actions		
	Establish Emergency Preparedness Plans	Emergency procedures and verification procedures appear to be in place between DOE-GJO and local and state authorities.
	Obtain Emergency Response equipment	No emergency equipment is located at the site. Response will rely on local and state support.
	Train Emergency Response Teams	NA
	Maintain Emergency Response Equipment & Team	NA
Continuous Improvement of System Operations		
	Integrate all Residual Hazards Management System Functions	The DOE-GJO has the responsibility for all management functions.
	Define Best Available Technology	NA
	Analyze Cost-Effectiveness of Repair versus Replace versus Re-remediate	NA

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