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THE INTEGRATION OF ENGINEERED AND INSTITUTIONAL CONTROLS: A CASE STUDY APPROACH WITH LESSONS LEARNED FROM PREVIOUSLY CLOSED SITES

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ABSTRACT

Environmental remediation efforts that are underway at hundreds of contaminated sites in the United States will not be able to remediate large portions of those sites to conditions that would permit unrestricted access. Rather, large volumes of waste materials, contaminated soils and cleanup residuals will have to be isolated either in place or in new, often on-site, disposal cells with long term monitoring, maintenance and institutional control needs. The challenge continues to be to provide engineering systems and controls that can ensure the protection of public health and the environment over very long time horizons (hundreds to perhaps thousands of years) with minimal intervention.

Effective long term management of legacy hazardous and nuclear waste requires an integrated approach that addresses both the engineered containment and control system itself and the institutional controls and other responsibilities that are needed. Decisions concerning system design, monitoring and maintenance, and the institutional controls that will be employed are best done through a "risk-informed, performance-based" approach. Such an approach should incorporate an analysis of potential "failure" modes and consequences for all important system features, together with lessons learned from experience with systems already in place.

The authors will present the preliminary results of a case study approach that included several sites where contamination isolation systems including institutional controls have been implemented. The results are being used together with failure trees and logic diagrams that have been developed for both the engineered barriers and the institutional controls. The use of these analytical tools to evaluate the potential for different levels of failure and associated consequences will be discussed. Of special interest is the robustness of different approaches to providing long-term protection through redundancy and defense in depth.

INTRODUCTION

Technical and economic limitations associated with the inability to destroy various waste constituents have resulted in large volumes of hazardous, radioactive and other contaminated materials being isolated on-site in engineered containment systems. The time horizons over which these engineered contaminant isolation facilities (CIFs) must perform ranges from hundreds to, perhaps, thousands of years due to the long-lived nature of the contaminants [1].

The objective of effective containment is the prevention of adverse consequences, which may result from either migration of contaminants from the CIF to human and/or environmental receptors or intrusion into the contained materials. Consequently, we seek robust engineered system designs that can perform over long time periods with minimal intervention, together with effective approaches to institutional controls and long-term monitoring and maintenance.

In this paper, we report the preliminary results of a case study approach using previously closed sites. The case study selection criteria and lessons learned are discussed. Our ultimate goal is the development of an analytical framework that will permit questions concerning long-term performance, monitoring and the potential need for intervention to be evaluated in advance of final system design.

CONTAMINANT ISOLATION FACILITIES (CIF)

Contamination isolation can be performed through an in-situ approach that uses surface and subsurface barriers to prevent release and migration or through excavation of the material and emplacement in a new disposal cell, constructed with both a bottom liner system and a surface cover.

The primary objective of an engineered cover is to prevent potentially infiltrating rainwater from leaching contaminants and facilitating their transport through groundwater to potential receptors. The design approach to engineered covers has evolved over the years as information and experience were obtained. The current approach features a primary barrier of natural and/or synthetic materials to prevent infiltration. Other components are typically placed above the primary barrier to provide drainage, prevent biointrusion, and support vegetation. Depending upon the regulations driving the cleanup [e.g., CERCLA, RCRA, UMTRCA or the U.S. Nuclear Regulatory Commission's License Termination Rule (LTR)], the design may be prescriptive or "performance-based" [2-4].

The anticipated long-term performance of an engineered CIF is dependent upon the effectiveness and robustness of both the engineered containment facility itself and the institutional controls and other needed institutional responsibilities, such as monitoring and maintenance. The engineered system design has the objective of preventing the release and subsequent migration of hazardous constituents to human and environmental receptors, while the institutional controls have the design objective of influencing human behavior so as to keep them from contacting the hazardous constituents.

A CASE STUDY APPROACH TO PERFORMANCE EVALUATION

This research utilized a case study approach to investigate the performance of existing CIFs. Case studies have been shown to be a valuable research methodology. The case study approach can offer several advantages over other research techniques [5-8]. With respect to our objective of evaluating potential long-term CIF performance, the key advantages are that case studies:

- Can provide insight into the dynamics of a complex situation,
- Have been successful in tackling questions of "why" and "how",
- Provide the investigator an ability to retain a holistic view of individual cases while retaining the flexibility to explore embedded units of analysis across cases, and
- Can provide an all-inclusive approach including both quantitative and qualitative evidence.

Case studies do not represent a sample of a population, but rather, they are a form of empirical inquiry useful in generalizing and expanding a theory or hypothesis [7].

Cases were selected with the following characteristics:

- Operations/Remedial Action phases were completed,
- Known, persistent (i.e. half-lives > 100 years) contaminated material remains on-site in the shallow subsurface (i.e. in the top 10 meters of the earth’s surface),
- Engineered and Institutional Controls are included in the remediation action,
- System performance information is available, and
- Regulatory structure is defined e.g., CERCLA, UMTRCA.

This research selected and investigated a number of sites as case studies. A primary regulation governing the management of residual contaminants is CERCLA. Therefore, CERCLA-applicable sites were a major source of potential case studies. Three of the investigated case studies were Love Canal, Maxey Flats and the Anaconda/Old Works Smelter Site. Table I provides a regulatory summary of these sites.

Table I. Regulatory Summary of Three 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

Love Canal

The Love Canal site gained national notoriety in the late 1970's and is often recognized as a major contributor to the creation of CERCLA. The original Love Canal property was used by the Hooker Electrochemical Company (now Occidental), and possibly others, for chemical waste disposal from 1942 through 1953 [9]. The EPA estimates that approximately 21,000 tons of chemicals were disposed of in the canal [10]. Following World War II, a population growth spurred the housing market in the Niagara Falls area. In 1953, the entire Love Canal property was transferred to the Niagara Falls Board of Education for $1[11-14]. An elementary school and additional residential development occurred in this area from 1953 through the 1960's.

Public health concerns and questions began to surface in 1976 including suggested health problems such as miscarriages, birth defects and cancer. National attention began to focus on the neighborhood of Love Canal. With the enactment of CERCLA in December 1980, the Love Canal site was placed on the National Priority List (NPL). The site has undergone remediation, which included soil excavation, on-site solidification, and on-site disposal including a low-permeablity cover.

The USEPA "delisted" Love Canal from the NPL in 2004. This decision states that the USEPA has determined that all appropriate response actions under CERCLA have been implemented and that no additional response actions are required [15].

Maxey Flats

The Maxey Flats Disposal Site, was used for low-level radioactive waste (LLW) disposal from 1963 until 1977 by the Nuclear Engineering Company [16]. Approximately 4.8 million cubic feet of LLW, containing over 2.4 million curies of radioactivity, was deposited into 52 unlined earthen trenches at this facility [17], 18].

Operational problems began to arise in the early 1970's [18]. Repeated subsidence problems with the surface cover had resulted in preferential infiltration routes through the cap. Contaminated leachate resulting from the burial trenches ultimately prompted the site's closure in 1977 [19].

The Maxey Flats disposal site was placed on the NPL in 1986 [17]. The ROD was finalized in September 1991 [18]. The remedy included the solidification and on-site disposal of nearly a million gallons of contaminated leachate. A 'natural stabilization' remedy was also selected and implemented for the final remediation of Maxey Flats. This remedy required closure of the site, contouring of the site to reduce erosion and the subsequent capping of the site to prevent infiltration. The 'interim' geotextile cap, was completed in 2003 and covers approximately 60 acres. 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.

Anaconda/Old Works

The Anaconda/Old Works Smelter site was established in 1883 to process copper ore. Related operations continued at the site until 1980. In 1983, the USEPA placed the Anaconda site on the NPL, which initiated a series of site investigations. These investigations determined that the waste volumes associated with this site included 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. Human health risks resulting from the site are associated with five chemicals: arsenic, cadmium, lead, zinc, and copper [20].

The size and complexity of this site necessitated that it be subdivided into smaller, manageable Operable Units (OUs). One of the 15 OUs, the Old Works/East Anaconda Development Area (OW/EADA), was the primary focus of our research. The selected remedy for the OW/EADA OU requires both engineered and institutional controls. The remedial design also involved the economic revitalization of a portion of the impacted area. This re-use approach included the construction of a Jack Nicklaus Signature Golf Course on the OU. The Old Works Golf Course, which opened in 1997, incorporated innovative "irrigated mining caps" into its design, which supports the re-use of the property for recreational purposes [21], 22].

LESSONS LEARNED FROM THE CASE STUDIES

An analysis of the case studies investigated in this research illustrates variations used to isolate residual contaminants. While all three of these presented sites have an on-site CIF and use various institutional controls and engineered barriers to maintain isolation, which controls are used and how the controls are applied, tends to differ from site to site.

For example, Love Canal and Maxey Flats can be described as sacrifice zones that are fenced off to prevent human access onto the property. Site security is actively maintained. At both of these sites the States have acquired title to the property. In the case of Love Canal, agents of the primary responsible party maintain access control. At Maxey Flats the Commonwealth of Kentucky maintains access control for the site. Conversely, Anaconda maintains a controlled re-use potential and the landowner controls limited recreational access.

Although both Love Canal and Maxey Flats are similar in that no re-use of the site is presently planned they differ in their designation of site completion. As previously mentioned, Love Canal has been delisted meaning no further remedial action is required. This "final" solution approach appears similar to other program approaches such as UMTRCA. Maxey Flats has designated its condition as an interim custodial maintenance period, which is projected to last for 100 years. This approach may require more active maintenance in the near-term but it may also offer a more flexible and adaptive management strategy.

There are also notable differences with regard to stakeholder notification e.g., warning signs, Notice. At the Love Canal site the regulators have intentionally limited signage to contain emergency contacts only. This action was apparently taken to accommodate public concern regarding the notoriety of Love Canal. Conversely, the Maxey Flats site uses radiation-warning signs to inform the public. The Anaconda site relies on No Trespassing signage although the site also tends to advertise its heritage and "rebirth" through poster displays and brochures.

FAULT TREE ANALYSIS

A combination of selected controls is believed to offer increased protection against system failure. Through the application of multiple controls, the CIF is believed to be more robust and less likely to result in the re-exposure of receptors to the residual contaminants. This approach is often referred to as defense-in-depth or a layering of controls [1]. This research investigated this concept through the application of fault tree analysis (FTA).

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 in reliability engineering [23], 24]. The FTA process is initiated by first defining an undesired state of the system. For the purposes of this research the undesired state of the system was described as *Failure of Contaminant Isolation Facility Controls*. An analysis of the details of the system was then performed to determine logical ways in which the undesired event could occur [23].

Figure 1 illustrates the high-level system Fault Tree for the Failure of Contaminant Isolation Facility Controls. This figure illustrates that CIFs consist of two subsystems, Institutional Controls and Engineered Barriers. These two subsystems are comprised of 13 individual controls, labeled A through M.

These individual controls were further analyzed and most were found to be prone to failure e.g., single point errors. In other words a single implementation error could promulgate upward through the fault trees leading to control error. These errors could be latent errors resulting in no immediate adverse consequences but rather only become evident when combined with other factors [25].

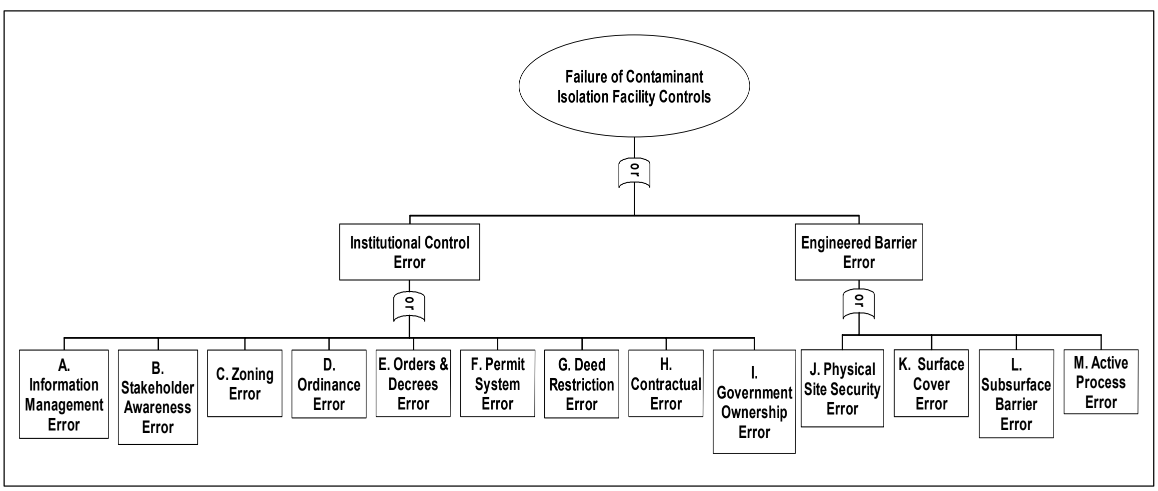

Fig. 1. High-level system Fault Tree for the Failure of Contaminant Isolation Facility Controls.

CONCLUSION

Various system configurations are being applied for the near-surface isolation of residual contaminants for long-term periods. These configurations utilize a series of mechanisms to achieve the isolation objective. These individual controls including engineered barriers and institutional controls.

Which controls are applied and how they are implemented varies from site to site. These variations appear intertwined with the site steward's roles and responsibilities. Multi-organizational involvement appears to be a routine component of CIF operations.

If roles and responsibilities are clearly defined and multi-organizational collaboration is achieved, an improved monitoring approach can result. If responsibilities are unclear or if conflicting objectives are present, multi-organizational involvement will complicate CIF operations.

Maintaining a site's performance should include actively monitoring both the engineered barriers as well as the institutional controls. Monitoring should include self-monitoring by the site stewards as well as transparent third party monitoring by regulators, stakeholders, and the general public.

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

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