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The Use of Protective Barriers to Deter Inadvertent Human Intrusion Into a Mined Geologic Facility for the Disposal of Radioactive Waste: A Review of Previous Investigations and Potential Concepts

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ABSTRACT

Sandia National Laboratories is evaluating the feasibility of developing a protective barrier system for the Waste Isolation Pilot Plant (WIPP) to thwart inadvertent human intrusion into this radioactive-waste disposal system for a period of 9,900 years after assumed loss of active institutional controls. The protective barrier system would be part of a series of enduring passive institutional controls whose long-term function will be to reduce the likelihood of inadvertent human activities (e.g., exploratory drilling for resources) that could disrupt the WIPP disposal system.

Literature addressing the topic of inadvertent human intrusion into mined, geologic repositories (like the WIPP) generally acknowledge the importance of a protective barrier system as part of a "defense-in-depth" strategy against inadvertent human activities that could potentially disrupt a repository system. Yet, none of these studies developed the concept of protective barriers beyond this stage. The only conceptual design for a multipurpose barrier mound system being assessed is for a near-surface, radioactive-waste disposal site. Because the WIPP is a deep, mined geologic disposal system, however, the feasibility of adopting this barrier mound system design for use at the WIPP is questionable.

Several observations and concepts regarding the development of a potential protective barrier system for the WIPP have been identified and may be worthy of additional consideration: (1) reducing the deposit-site area requiring protective barriers to the volumes encompassed by the waste panels and the area above it; (2) if practical, incorporating a "defense-in-depth" strategy into the design of a protective barrier system for the WIPP; and (3) designing small, durable subsurface markers to enhance the effectiveness of the protective barrier system by conveying a warning to the intruder.

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1 INTRODUCTION

Rationale and Purpose

The safe disposal of radioactive waste within the Waste Isolation Pilot Plant (WIPP) requires that such waste be isolated in this disposal system until it no longer poses an excessive hazard to humans. Regulations and guidelines promulgated by the United States Environmental Protection Agency (EPA) define this period of time to be as long as 10,000 years (40 CFR Part 191, U.S. EPA, 1985 [to be referred to as the Standard]). The Standard requires that the long-term performance of the disposal system be analyzed and evaluated to identify all conditions or events, natural or human-induced, that might compromise or disrupt its long-term performance.

One such aspect that must be considered is the threat posed by future human activities at, or near, the WIPP. Past studies of both hypothetical and proposed mined, geologic disposal systems (e.g., Claiborne and Gera, 1974; Lee et al., 1978; Davis et al., 1983; ONWI [Office of Nuclear Waste Isolation], 1984; Cranwell et al., 1990; Guzowski, 1990; Hora et al., 1991) indicate that certain types of human activity pose a post-closure risk to disposal systems. Examples of potentially disruptive human activities include drilling, mining, archaeological exhumation, development of injection wells, waste recovery, weapons testing, and war (Claiborne and Gera, 1974; Lee et al., 1978; ONWI, 1984; Hora et al., 1991). However, guidance set forth in Appendix B of the Standard identifies exploratory drilling for resources as the most severe inadvertent human-intrusion event(s) that needs to be considered at the location of a disposal facility. The Standard further requires the development and emplacement of passive measures to reduce the likelihood of inadvertent intrusion. Such passive measures include a combination of widespread records detailing the location and hazards of disturbing the WIPP, enduring surface monuments (markers) inscribed with warnings about the hazards of disturbing the WIPP, and may include other measures such as a protective barrier system that would thwart the inadvertent intruder. This approach relies on a defense-in-depth strategy in which the record system and marker system, if they endure and their message is understood, deter the initiation of inadvertent exploratory drilling; if, for whatever reason, the records and markers fail to prevent human activity at the WIPP, a protective barrier system would represent a final defensive measure that could prevent inadvertent intrusion into the disposal system.

The purpose of this report is to present a background review of available information regarding the use of protective barriers to thwart inadvertent human intrusion into disposal systems. Topics covered within this report include the physical setting and description of the WIPP, a brief overview of

pertinent regulatory guidance, definition of barrier terminology as employed in this report, a summary of previous studies that addressed this topic and their findings, and a discussion of some additional observations and concepts regarding the potential design and placement of barrier systems.

2 PHYSICAL SETTING AND DESCRIPTION OF THE WIPP

This chapter briefly describes the general physical setting and layout of the WIPP facility. An understanding of these aspects of the WIPP is necessary for later discussion in this report concerning the potential modes and targets of inadvertent human intrusion as well as discussion of potential concepts and strategies for thwarting such activities. The following general descriptions were derived from comprehensive treatments of these topics found in the *Final Safety Analysis Report, Waste Isolation Pilot Plant* (U.S. DOE [Department of Energy], 1990) and in Bertram-Howery et al. (1990). For a more complete discussion of the following topics, the reader is referred to the above reports and other reports as referenced in the text.

Location

The WIPP is located in southeastern New Mexico, approximately 42 km east of the city of Carlsbad, New Mexico (Figure 1). The WIPP is situated within the Delaware Basin, which lies between the high plains of western Texas and the Guadalupe Mountains of southeastern New Mexico (Figure 1). The region immediately surrounding the WIPP has a low population density, with less than 30 permanent residents living within a 16 km radius.

The WIPP Facility

The WIPP is a full-scale facility designed to demonstrate the safe management, storage, and final disposal of transuranic (TRU) wastes produced by the DOE's nuclear-based defense programs. Several different boundaries have been defined around the WIPP and have specific programmatic and/or regulatory meanings and purposes. The secured-area and land-withdrawal boundaries (Figure 2) represent areas that will be under the effective control and protection of the DOE as required by Subpart A of the Standard. Subpart B of the Standard, which regulates the final disposal of nuclear waste, establishes and defines the term "controlled area" for long-term performance-assessment purposes. The controlled area represents a "volume" of earth which cannot extend more than 5 km in any direction from the outer edge of the WIPP waste panels and cannot encompass more than 100 km² of surface area. Figure 2 depicts the maximum allowable extent of the WIPP controlled area based upon the limits set forth in Subpart B of the Standard (40 CFR 191.12[g]) in relation to the other WIPP boundaries. The actual extent of the WIPP controlled area has yet to be established, but will not be less than the land-withdrawal boundary (Bertram-Howery and Hunter, 1989).

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Figure 1. Location of the WIPP in the Delaware Basin (from Bertram-Howery et al., 1990).

(a)

(b)

Figure 2. (a) Plan view of the extent of the secured-area boundary, land-withdrawal boundary, and controlled area in relation to the underground waste panels (modified from Marietta et al., 1989). (b) Perspective view of the WIPP repository and shaft system in relation to the controlled area. Scale of the shaft/repository system is exaggerated (from Bertram-Howery and Hunter, 1989).

The physical facilities of the WIPP will consist of above-ground buildings that are connected by four shafts to a single-level underground repository (Figure 3). The underground workings of the WIPP will be emplaced 655 m below the ground surface within the bedded-salt deposits of the Salado Formation. The WIPP repository contains both TRU-waste disposal and experimental areas (Figure 3). The subsurface facility for TRU-waste disposal will consist of eight waste panels and the connecting drifts (Figure 3).

The projected inventory of waste for the repository will typically be composed of contaminated laboratory and production trash that produces external dose rates so low that it can be contact-handled (CH) within properly sealed drums and boxes without special shielding (Bertram-Howery et al., 1990). A smaller amount of waste that produces higher external dose rates also will be received. This waste will be packaged in specially shielded casks and will be remotely handled (RH), with the casks being emplaced in holes drilled into the walls of the rooms.

Geologic Setting

The host geologic unit for the WIPP repository is the Permian-age (about 286 to 245 million years ago) evaporite deposits of the Salado Formation (Figure 4). At the WIPP, the Salado Formation is approximately 600 m thick and is informally divided into three members (Figure 4). The lower member of the Salado Formation consists mainly of halite, with lesser amounts of anhydrite, polyhalite, glauberite, and occasional layers of fine clastic sediment (Jones, 1978). The proposed WIPP repository will be located within the lower member (Figure 4b). Above the lower member is the McNutt potash member, composed of halite that contains deposits of sylvite and langbeinite (Jones, 1978; Brausch et al., 1982). The upper member of the Salado Formation consists of halite intercalated with beds of polyhalite, anhydrite, and sandstone (Jones, 1978).

The Salado Formation is part of a thick sequence of carbonates, evaporites, and clastic sediments deposited within the Delaware Basin (Figure 1). The Delaware Basin began as part of a much broader basin that formed during the Ordovician Period (about 500 to 440 million years ago) in which transgressing seas deposited carbonate and clastic sediments (Powers et al., 1978; Hills, 1984). During the Pennsylvanian Period (about 320 to 286 million years ago), the uplift of the Central Basin Platform subdivided this basin into the Delaware and Midland basins (Figure 1). The Delaware Basin continued to subside during early to middle Permian time, resulting in the deposition of a thick sequence of clastic sediments rimmed by reef limestone (Capitan Reef, Figure 1). Evaporites, carbonates, and clastic sediments of the Castile, Salado, and Rustler Formations, and the Dewey Lake Red Beds

Figure 3. Perspective drawing of the WIPP facility showing its various components and their dimensions (after Waste Management Technology Department, 1987).

Figure 4. Generalized stratigraphy of the WIPP disposal system. (a) Generalized stratigraphic column for the WIPP disposal system (modified from Lappin, 1988). (b) Location of the WIPP repository in regard to stratigraphic units shown in 4(a) (after Rechard, 1989; based on U.S. DOE, 1980b).

(Figure 4) were deposited during the rest of the Permian Period. The post-Permian geologic record for the WIPP area is almost entirely absent because of nondeposition or erosion, with only relatively minor Triassic- and Quaternary-age sedimentary deposits (spanning the period from 245 million years ago to the present) in the vicinity of the WIPP (Powers et al., 1978).

Only minor tectonic activity has occurred within the immediate region around the WIPP since the Permian Period and is related to the faulting that created the Guadalupe and Delaware mountains in the late Tertiary Period (about 36 million years ago to the present) (Powers et al., 1978; Hills, 1984). The only evidence of igneous activity within the Delaware Basin is the emplacement of a northeast-trending, Oligocene-age (approximately 35 million years old) lamprophyre dike, which is found about 16 km northwest of the WIPP (Powers et al., 1978).

Natural Resources

The possible occurrence of significant and exploitable deposits of natural resources at or near the WIPP is an important factor, because their presence could promote exploratory drilling activities that might compromise the WIPP disposal system. Previous studies that addressed this question (Powers et al., 1978; Brausch et al., 1982; Mast et al., 1989) have concluded that potash and hydrocarbons might occur in amounts great enough to be potentially exploitable at or near the WIPP. For a complete overview of this topic, the reader is referred to Weart et al. (1991).

The majority of potash that is produced within the United States comes from mines in southeastern New Mexico (Greek, 1985). In the northern part of the Delaware Basin, economic quantities of potash occur locally within the McNutt potash member of the Salado Formation; the amount and grade of potash within the McNutt potash member is highly variable (Brausch et al., 1982). The McNutt potash member is present above the WIPP repository (Figure 5), but grade and quantities of potash minerals within this member have been estimated as "uneconomic" at this location (Brausch et al., 1982). However, to the north and northeast of the waste panels, economic deposits of langbeinite (potash mineral) do occur within the land-withdrawal boundary (Figure 5).

Within the Delaware Basin, natural gas and oil are produced from a number of stratigraphic horizons, primarily within Pennsylvanian- to middle Permian-age units (Figures 6 and 7). At least 56 oil and gas wells lie within a 16-km radius of the WIPP (Powers et al., 1978; Figure 8). Evaluation of the WIPP area, reported in Brausch et al. (1982), indicates that only the Pennsylvanian-age Morrow Formation (Figure 7) is a likely target for natural

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Figure 5. Generalized distribution of potash resources in the vicinity of the WIPP (Guzowski, 1990; potash distribution based on Brausch et al., 1982).

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Figure 6. Oil and gas fields in the northern Delaware Basin (Roswell Geological Society, 1977).

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Figure 7. Stratigraphic location of potential hydrocarbon reservoirs within the Delaware Basin. Note that the Salado Formation, the horizon hosting the WIPP repository, lies stratigraphically above these potential reservoir zones. (Powers et al., 1978; after Foster, 1974).

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Figure 8. Number of wildcat oil and gas wells per section in the WIPP region (data from Midland Map Company, 1993a, 1993b).

gas exploration beneath the WIPP. There are currently no direct data pertaining to the presence or absence of economic quantities of hydrocarbons beneath the engineered facility. There is a producing oil and gas well that bottoms out in the southwesternmost section of the 16-section withdrawal area. For a more complete discussion of natural resource potential at the WIPP, the reader is referred to Weart et al. (1991).

3 REGULATORY REQUIREMENTS AND GUIDANCE REGARDING INADVERTENT HUMAN INTRUSION INTO DISPOSAL SYSTEMS

The Standard promulgates four requirements: the Containment Requirements, Assurance Requirements, Individual Protection Requirements, and Ground-water Protection Requirements for disposal systems. However, only the Containment Requirements (40 CFR 191.13) necessitate direct consideration of the effects of inadvertent human intrusion on the disposal system after its closure. Appendix B of the Standard provides further clarification and non-binding guidance on this topic. The following discussion excerpts and summarizes relevant portions of Appendix B of the Standard that address inadvertent human intrusion; portions of Appendix B of the Standard from which excerpts are taken, are produced in full in Appendix A of this report.

Inadvertent human intrusion into a disposal system after its closure is considered by the Standard (40 CFR 191, Appendix B) as "the most speculative potential disruptions of a mined geologic repository...that could result in major disruptions that no reasonable repository selection or design precautions could alleviate." While there is a wide range of potential human activities that might disturb the disposal system, Appendix B of the Standard limits consideration to exploratory drilling for resources as the most severe human intrusion "scenario." Appendix B of the Standard limits the "frequency" of such inadvertent exploratory drilling into a waste disposal system for performance assessment purposes by assuming that "the likelihood of such inadvertent and intermittent drilling need not be taken to be greater than 30 boreholes per square kilometer of repository area per 10,000 years for geologic repositories in proximity to sedimentary rock formations...."

If the drilling frequency of 30 boreholes per square kilometer per 10,000 years established in the Standard is applied to the entire area of the Delaware Basin, 900,000 boreholes would be drilled within this basin over the next 10,000 years (Guzowski, 1991). Given the 0.5 km² area of the WIPP's waste panels, this worst-case drilling frequency would predict a maximum of 15 borehole penetrations over the post-closure period (Appendix A of Guzowski, 1991). However, given the current level of knowledge about the resource potential of the region hosting the WIPP, Guzowski (1991) believes the worse-case drilling frequency established by the Standard is too high. Instead Guzowski (1991) proposes an alternative worse-case drilling "density" based upon existing drilling regulations as established by the State of New Mexico. This alternative method would estimate far fewer penetrations (less than 9) of the WIPP's waste panels during the post-closure period. Regardless of the method used, a nonzero probability still remains of at least one exploratory borehole penetration of the WIPP's waste panels during the post-closure period (Guzowski, 1991; Bertram-Howery and Swift, 1990).

Appendix B of the Standard states that the likelihood of inadvertent human intrusion into a disposal system can be reduced, but not totally eliminated, by the following:

- proper site selection -- the site for the disposal system would contain no unique or easily exploitable natural resources and, therefore, provide no inherent incentives for resource exploration and exploitation;
- disposal system design -- the design would increase level of difficulty for inadvertent human intrusion; and
- passive institutional controls -- the controls would communicate existence of disposal site and its dangers to future generations.

Such aspects were considered in the site selection and design for the WIPP (U.S. DOE, 1980b, 1990).

The "institutional controls" referred to within the Standard are defined as follows:

"Passive institutional control" means: (1) permanent markers placed at a disposal site, (2) public records and archives, (3) government ownership and regulations regarding land or resources use, and (4) other methods of preserving knowledge about the location, design, and contents of a disposal system (40 CFR 191.12[e]); and

"Active institutional control" means: (1) controlling access to a disposal site by any means other than passive institutional controls, (2) performing maintenance operations or remedial actions at a site, (3) controlling or cleaning up releases from a site, or (4) monitoring parameters related to disposal system performance (40 CFR 191.12[f]).

Although development of protective barriers to inadvertent human intrusion is not specifically mentioned within the Standard, they are being evaluated as another type of passive institutional control (as per 40 CFR 191.14[c]) for the WIPP (Bertram-Howery et al., 1990).

The Standard also sets limits on reliance on post-closure measures employed to deter inadvertent human intrusion into disposal systems. Although it is assumed that the federal government will maintain active institutional controls over the disposal site for as long as possible and thereby prevent inadvertent human activities, the Assurance Requirements limit reliance on active institutional controls, for performance assessments, to the first 100

years after closure (40 CFR 191.14[a])). For the remaining 9,900 years of the post-closure period, passive institutional controls are expected to reduce, but not totally eliminate, the likelihood of inadvertent human intrusion into the disposal system as long as they endure and are understood. The Standard also assumes that the inadvertent intruders will halt their activities once they become aware of the dangers of disturbing the disposal system by either encountering the passive institutional controls (i.e., site markers, protective barrier system) or the disposal system itself.

4 BARRIER TERMINOLOGY AND DEFINITIONS

The term "barrier" is defined in the Standard (40 CFR 191.12[d]) as "any material or structure that prevents or substantially delays movement of water or radionuclides toward the accessible environment." Examples of such barriers, as defined by the Standard (40 CFR 191.12[d]), can be "a geologic structure, a canister, a waste form with physical and chemical characteristics that significantly decrease the mobility of radionuclides, or a material placed over and around waste, provided that the material or structure substantially delays movement of water or radionuclides." The term "barrier," as defined by the Standard, applies to features of the disposal system that prevent or retard radionuclide migration toward the accessible environment, and not to constructs emplaced to thwart inadvertent human intrusion into the disposal system.

The term "protective barrier," as it is used in this report, is defined as any passive, fabricated structure emplaced within, around, or above the disposal facility with the capability of thwarting inadvertent human intrusion into those portions of the disposal system defended by the barrier system after closure. Protective barrier systems would fall under the classification of a passive institutional control for the WIPP (Bertram-Howery et al., 1990) as allowed by the Standard (40 CFR 191.14[c]).

As mentioned in Chapter 1, a protective barrier system is just one element of a defense-in-depth system of passive institutional controls that includes widespread dissemination of records and documents as well as a surface marker system. The function of the record system and surface marker system is to convey a message of warning to future societies about the dangers of disturbing the WIPP disposal system. As long as these passive controls endure and are understood, they should deter inadvertent exploratory drilling at the WIPP. On this basis, a protective barrier system would only be needed if the other passive controls (i.e., records and markers) are not understood or are destroyed. Therefore the role of a protective barrier system is to act as the final defensive measure to thwart inadvertent human intrusion.

5 REVIEW OF PREVIOUS INVESTIGATIONS AND THEIR FINDINGS

Introduction

With the serious consideration of using a mined, geologic repository as one final disposal option for nuclear waste in the late 1960s, efforts were undertaken to evaluate what combination of natural/manmade conditions would be required to assure the long-term isolation of waste in such a disposal system. The majority of the studies were related to the Civilian Radioactive Waste Management (CRWM) Program. These efforts were directed towards designing and siting a mined, geologic repository to serve as the final disposal site for spent-fuel from commercial nuclear-power plants.

Studies conducted under the auspices of the CRWM Program, the Defense Waste Management Program, as well as other international efforts (Table 1), have developed lists of human activities that could pose a potential threat to a mined, geologic repository. The human activities most frequently identified were

- (1) resource exploration/recovery (conventional drilling, solution mining, and conventional mining/tunneling);
- (2) non-nuclear waste disposal (fluid injection, burial);
- (3) storage of hydrocarbons/compressed gases (injection wells);
- (4) waste recovery;
- (5) weapons testing;
- (6) war;
- (7) sabotage;
- (8) archaeological exhumation.

A recent study of potential modes of inadvertent human intrusion into the WIPP (Hora et al., 1991) expanded some of the categories of activities listed above (e.g., resource exploration) by factoring in the possibilities of highly advanced or futuristic technologies (e.g., remote-controlled or autonomous mining machines, or "mole miners," and nanotechnology).

Concepts for Deterring Inadvertent Human Intrusion into Geologic Repositories

By the late 1970s, studies examining potential modes of failure for geologic repository systems (e.g., Claiborne and Gera, 1974; Lee et al., 1978; Table 1) had identified a number of human-intrusion/interference events and processes that could pose a threat to a repository. While such studies evaluated the types of activities and their potential effects, it was apparently beyond the scope of these studies to develop concepts for reducing the likelihood of inadvertent human intrusion into a repository.

Table 1. Categories of Information Addressed in Available, Selected Reports in Regard to Human Intrusion (HI) into Radioactive-Waste Disposal Sites

Source	Categories Addressed			Comments
	Identification of HI events	Assessment of effects associated with HI events	Suggest measures to deter HI	
Claiborne and Gera (1974)	yes	yes	no	Examined failure events and processes for a hypothetical bedded salt site in New Mexico.
Hill and Grimwood (1978)	yes	yes	no	Preliminary assessment of potential failure modes for a hypothetical repository in the U.K. or Europe.
Lee et al. (1978)	yes	yes	no	Preliminary assessment of potential disruptive events for a hypothetical repository at the Hanford Site, Washington.
ONWI (1981)	yes	yes	yes	Examined solution-mining impact on a hypothetical repository in a salt dome. Advocated employing a defense-in-depth strategy using site markers and physical/chemical barriers.
Kaplan (1982)	yes	yes	yes	Discussed design criteria for an enduring site marker system.
Davis et al. (1983)	yes	yes	no	Risk assessment of HI for the Hanford Site, Washington.
ONWI (1984)	yes	yes	yes	Focused on design/development of site markers.
Sebeok (1984)	yes	yes	yes	Discussed means to communicate repository hazards to future generations.
Tannenbaum (1984)	yes	yes	yes	Discussed means to communicate repository hazards to future generations.
Kaplan (1986)	yes	yes	yes	Discussed design criteria for an enduring site marker system.

Table 1. Categories of Information Addressed in Available, Selected Reports in Regard to Human Intrusion (HI) into Radioactive-Waste Disposal Sites (concluded)

Source	Categories Addressed			Comments
	Identification of HI events	Assessment of effects associated with HI events	Suggest measures to deter HI	
Hunter (1989)	yes	yes	no	Identified events and processes that could potentially lead to the disruption of the WIPP.
Guzowski (1990)	yes	yes	no	Identified events and processes that could potentially lead to the disruption of the WIPP.
Cranwell et al. (1990)	yes	yes	no	Identified events and processes that could potentially lead to the disruption of the WIPP.
U.S. DOE (1990)	yes	yes	no	Identified events and processes that could potentially lead to the disruption of the WIPP.
Fayer et al. (1985)	yes	yes	yes	Addressed design and development of barrier mounds to protect near-surface disposal sites from intrusion by plants, animals, and humans.
Phillips and Hartley (1986)	no	no	yes	Addressed design components of barrier mounds to protect near-surface disposal sites at the Hanford Site from intrusion by plants, animals, and humans.
Adams and Wing (1987)	yes	yes	yes	Addressed design components of barrier mounds to protect near-surface disposal sites at the Hanford Site from intrusion by plants, animals, and humans.
U.S. DOE (1987)	yes	yes	yes	Addressed design components of barrier mounds to protect near-surface disposal sites at the Hanford Site from intrusion by plants, animals, and humans.
Hora et al. (1991)	yes	no	no	Identified events and processes that could potentially lead to the disruption of the WIPP.

In the early 1980s, the DOE created the Human Interference Task Force (HITF) to investigate and develop practical concepts for deterring human activities that might inadvertently pose a threat to a repository. The concepts and strategies developed by this group (summarized in ONWI, 1984) were adopted by the DOE and used within the CRWM Program.

The HITF concluded (ONWI, 1984, p. 6) that there are three mechanisms for reducing the likelihood of inadvertent human interference with a repository system. They are (1) reducing the incentive for human interference, (2) designing the repository to increase the difficulty of interference, and (3) communicating the existence of the repository to generations far into the future. These mechanisms of the "defense-in-depth" strategy against inadvertent human intrusion can be further divided into individual components as illustrated in Figure 9.

In regard to the first two mechanisms, the HITF concluded that existing and proposed repository siting and design guidelines would effectively mitigate the impacts of human interference (ONWI, 1984, p. 16-17). However, the HITF did suggest that these factors be assessed on a site-specific basis to ascertain if additional steps might be taken to enhance the effectiveness of these first two mechanisms.

The majority of the HITF report (ONWI, 1984) focused on the third mechanism (communication) and how a message containing a warning about the hazards of the wastes contained within the repository could be effectively communicated to future generations. It was the HITF's conclusion that the development of methods to ensure the long-term communication of potential hazards and dangers posed by the waste within the repository provides the best defense against inadvertent human intrusion (e.g., permanent site markers and widely disseminated records that provide multiple levels of protection to the message against loss, destruction, and major language/societal changes). The advantage to the communication strategy, as perceived by the HITF, was that it would ideally warn off the intruder before the repository system was compromised. Aspects of the communication strategy outlined in the HITF report (ONWI, 1984) have been subsequently expanded upon by a number of additional studies (see Table 1 for a partial listing of these studies).

No published CRWM Program studies have specifically addressed ways of designing barriers for a repository system that would thwart inadvertent human intrusion. Most studies dealing with the topic of human intrusion note that such physical barriers would be an important aspect of any "passive" defense system for a repository (e.g., ONWI, 1981, 1984) because of the

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Figure 9. Components of the "defense-in-depth" strategy proposed by the HITF for deterring inadvertent human intrusion into deep, mined geologic repositories (ONWI, 1984). Note that the terms "physical barriers" and "chemical barriers" would be considered "protective barriers" in this report.

possibility that records and surface marker systems might be lost, destroyed, or rendered unintelligible to future generations for a host of reasons. While the importance of developing a viable protective barrier system to inadvertent human intrusion is acknowledged by these studies, they do not specifically develop this concept further.

It should be noted that the conceptual designs for engineered barrier systems for proposed CRWM Program repositories (e.g., U.S. DOE, 1988 [Basalt Waste Isolation Program, Hanford Reservation]) were not designed to thwart inadvertent human intrusion. The function of these engineered barrier systems are primarily to protect, contain, and mitigate any potential releases of radioactivity resulting from natural disruptive events. The tacit assumption is that the natural system, coupled with engineered barriers, would be resilient enough to mitigate, to some degree, the effects of inadvertent human intrusion into a repository system.

Barrier Mound Systems for Near-Surface, Radioactive-Waste Disposal Sites

The DOE is evaluating alternative methods for the final disposal of radioactive defense waste currently contained within buried tanks and trenches at a number of its sites (e.g., ERDA, 1977). Among the final disposal alternatives under consideration is the in-place stabilization and isolation of the waste. Such disposal sites are regulated by the Standard and have to meet the same long-term performance and isolation requirements as the WIPP.

The long-term (up to 10,000 years) isolation of the waste from the accessible environment would be accomplished at these disposal sites by using natural barriers as well as manmade barrier systems emplaced over the disposal site. The long-term function of the "protective" barrier system would be to control water infiltration, erosion, and thwart plant/animal/human intrusion into the disposal system. Descriptions and evaluations of the conceptual design of one such barrier mound system for the in-situ disposal of defense waste at the Hanford Reservation (Washington State) have been published (Adams et al., 1981; Fayer et al., 1985; Phillips and Hartley, 1986; U.S. DOE, 1987).

Figure 10a shows the proposed design and components of such a barrier mound system under consideration for use at the Hanford site (U.S. DOE, 1987). This protective barrier system takes the form of an extensive 5.4-m-thick, above-ground mound that is situated directly over the disposal site. The barrier mound is composed of a series of layers (Figure 10b) primarily consisting of natural construction materials (e.g., clay, fine soil, sand,

Figure 10a. Perspective drawing of a protective barrier mound for a near-surface disposal site at the Hanford Reservation, Washington (U.S. DOE, 1987).

Figure 10b. Generalized cross section through a portion of the barrier mound at the Hanford Reservation, Washington, showing its proposed internal structure and components (U.S. DOE, 1987).

Figure 10c. Detailed drawing and dimensions of the subsurface marker discs to be placed within the barrier mound at Hanford Reservation, Washington (U.S. DOE, 1987).

gravel, and coarse gravel/boulders [riprap]), as well as asphalt, and grout. Another key component of this protective barrier mound system is subsurface marker discs (Figure 10c) that are emplaced within several of the layers that compose the mound. These buried marker discs contain an inscribed message warning potential intruders of the dangers of disturbing the waste entombed below the mound (Figure 10c).

The barrier mound system shown in Figure 10 relies on several different components to reduce the risk of inadvertent human intrusion into the disposal site. A preliminary analysis, based upon subjective judgment, of the ability of such a barrier mound system to reduce the likelihood of inadvertent human intrusion has been conducted by the DOE (U.S. DOE, 1987, Appendix M, p. M.12-M.17). Note that the proposed in-situ disposal of the waste at the Hanford Site results in the disposal "facility" being located just below the ground surface level in contrast to a deep, mined disposal facility like the WIPP. Because of this factor, the evaluation of the barrier mound system for Hanford disposal sites had to address both drilling and surface excavations as potential modes of inadvertent human intrusion into the disposal system.

The DOE evaluation (U.S. DOE, 1987) noted that the effectiveness of the different components of the barrier mound system varied, depending on the type of intrusion. For a drilling event, the physical size of the barrier mound, as well as the riprap/gravel layers on and within the mound, were judged to be the greatest deterrent; the subsurface marker discs were judged to be the least effective deterrent against exploratory drilling due to their large size (U.S. DOE, 1987, Appendix M, p. M.13-M.14). The basis for these judgments was threefold. First, it was assumed that a driller would be inclined to move to either side of the mound to avoid having to drill through the additional thickness (greater than 5 m) of the mound (Figure 10b). Second, the riprap/gravel layers would be expected to present varying degrees of drilling problems, depending on the type of drilling method and technology used, for the intruder. Such problems might cause the intruder to cease drilling and move to another location where it would be easier to drill. Finally, it was judged that the subsurface marker discs would not reduce the likelihood of inadvertent drilling because they would either (1) be destroyed by the drilling process on account of their size or (2) be missed by the borehole.

In the case of excavation activities, however, the judged effectiveness of the barrier-system components significantly changes. While the physical size of the mound was judged a deterrent to drilling, it was judged not to be a significant deterrent to excavation. It was postulated that the mound itself could potentially attract intruders because the intruders might mistakenly think that the mound concealed something of value. For this mode

of intrusion, the physical presence of the mound was judged to enhance the chance of inadvertent intrusion. In contrast, the effectiveness of the subsurface marker discs was judged much better for an excavation event because the subsurface marker discs would probably be unearthed intact.

6 DEVELOPMENT OF A PROTECTIVE BARRIER SYSTEM TO INADVERTENT EXPLORATORY DRILLING: ADDITIONAL OBSERVATIONS AND CONCEPTS

Introduction

As discussed in the last chapter, essentially no published studies exist addressing concepts or actual designs of a protective barrier system that would thwart inadvertent intrusion into deep, mined disposal systems. This chapter presents some observations and comments concerning the possible scale(s) and character of a protective barrier system. In keeping with guidance presented in Appendix B of the Standard, the following discussion focuses mainly on conventional exploratory drilling as the mode of inadvertent intrusion (Marietta et al., 1989; Bertram-Howery et al., 1990), although a recent study by Hora et al. (1991) raises concerns regarding additional modes of intrusion into the WIPP.

The study by Hora et al. (1991) has identified a number of potential modes of inadvertent human intrusion, in addition to exploratory drilling, by which the WIPP disposal system could be unintentionally compromised. As noted in Chapter 5, the possible occurrence of these additional modes of inadvertent intrusion are predicated on a host of factors and conditions governing the character and motivations of future societies and the nature of their technology (Hora et al., 1991). Some of these modes of intrusion into the WIPP, involving highly futuristic tunneling or mining technologies (e.g., mole mining), could conceivably come from any direction. However, the "unknown" nature of such futuristic technologies also makes it highly doubtful that an effective protective barrier system against such advanced technology could be practically designed and employed. It would appear that the best defense against such highly advanced technological threats would have to largely rely on the other passive institutional controls (i.e., site markers and records).

Potential Scales and Form of a Protective Barrier System to Exploratory Drilling

As previously discussed in Chapter 5, no conceptual designs presently exist for use of a protective barrier system at a deep, mined geologic disposal system. However, it is possible to outline some of the attributes that such a protective barrier system should possess to properly carry out its defensive role. Ideally, the protective barrier system would

- be capable of disabling a drill bit, be impervious to a drill bit or, at the minimum, be capable of deflecting the drill bit safely away from the disposal system;

- be potentially capable of withstanding multiple encounters with a drill bit without the loss of function;
- be composed of materials with little or no economic value and that will not degrade over the 10,000-year, post-closure period; and
- not attract unwanted attention to the site or encourage exploration activities.

The overall physical size of the protective barrier would seem to be largely predicated on where it would be positioned within the disposal system. Determination of where to place protective barriers within the disposal system would obviously require the careful evaluation of many factors. Foremost among these factors is to identify which parts of the disposal system would benefit from the emplacement of a protective barrier to inadvertent human intrusion. Once potential locations within the disposal system have been identified, it would be possible to develop conceptual designs for various types of barriers and evaluate their feasibility, practicality, and overall performance versus the potential post-closure benefits and cost.

The identification of those portions of the disposal system that might benefit from the emplacement of a protective barrier requires an understanding of how potential inadvertent exploratory drilling events and scenarios might impact the post-closure performance of the disposal system. In the case of the WIPP, the potentially "sensitive" portions of the disposal system have already been identified as part of performance-assessment activities (e.g., see Hunter, 1989; Marietta et al., 1989; Bertram-Howery et al., 1990). These assessments considered the potential consequences of a series of possible exploratory drilling events and scenarios that would inadvertently penetrate the WIPP and lead to the release of radionuclides to the accessible environment (Hunter, 1989; Marietta et al., 1989; Cranwell et al., 1990; Guzowski, 1990; Bertram-Howery et al., 1990). Examples of such events and scenarios (combinations of events and processes) that were considered (Bertram-Howery et al., 1990) follow:

- (1) drilling an exploratory borehole through a waste-filled room or drift and into a pressurized brine reservoir in the underlying Castile Formation (termed Scenario E1);
- (2) drilling an exploratory borehole into a waste-filled room or drift (termed Scenario E2);
- (3) drilling and pumping from one or more water wells in the overlying Culebra Dolomite Member down-gradient from the disposal system (termed Scenario E3) in combination with Scenarios E1 and/or E2;
- (4) potash mining outside of the controlled area that results in surface subsidence and the formation of a catch basin for runoff (termed Scenario TS) also in combination with Scenarios E1, E2, and/or E3.

Figures 11 and 12 present a diagrammatic illustration of some of the scenarios considered with E3.

The primary detrimental event in the above scenarios is the direct breaching of waste containers/casks within the rooms or drifts of the waste panels (Figures 11 and 12) by the borehole(s). However, if the borehole(s) fails to intersect the waste-filled rooms or drifts, such intrusions could have little or no effect (Hunter, 1989; Marietta et al., 1989; Cranwell et al., 1990; Bertram-Howery et al., 1990). Although the above assessment identifies those portions of the disposal system that might benefit from a protective barrier system, it unfortunately does not constrain the host of options regarding the exact location, size, or composition of the barrier system.

Theoretically, numerous potential options and combinations are available for the location and nature of a protective barrier system designed to defend the WIPP waste panel area. In regards to the location, the barrier(s) could be situated anywhere from the ground surface above the waste panels to within the rooms and drifts of the waste panels (Figure 13). The barrier's physical size and composition would probably be directly dependent on the barrier's location. For example, a barrier erected at the ground surface would have to cover a 0.5 km² area directly over the waste panels (Figure 13a). Assuming, for the sake of this discussion, that this hypothetical barrier was analogous in form to that of the proposed Hanford protective barrier mounds described in Chapter 5, tremendous quantities of construction material (natural or manmade) would be required to complete this type of barrier. A potential concern about surface barrier systems, like the Hanford protective barrier mound, is that the types and amounts of the materials used to construct them might inadvertently encourage resource exploration and recovery activities because its location at the surface would provide the intruder relatively easy access (U.S. DOE, 1987). For this reason, certain types of economically valuable materials (e.g., refined metals) that might be useful in constructing an effective barrier against drilling could not be utilized in a surface barrier mound. However, this problem might be mitigated, to some degree, as the depth of the protective barrier emplacement increases and the effort required by an intruder to access it becomes much more difficult.

One alternative to a surface barrier mound would be a subsurface barrier emplaced just below the existing ground surface (Figure 13b). As in the case of the surface barrier mound, the subsurface barrier would have to be emplaced over the waste panels. This would require that the 0.5 km² area above the waste panels be excavated. However, after the barrier is installed, it would be covered and the ground surface could be restored to its previous contour. One benefit of this "near-surface" barrier is that there would be no obvious surface manifestation of its existence to attract possibly unwanted attention.

Figure 11. Examples of conceptual models for inadvertent human-intrusion scenarios E1 and E2 for the WIPP. (a) Conceptual model for scenario E1. Arrows show direction of flow. Exploratory borehole penetrates pressurized brine below the repository horizon. R_c is the release of cuttings and eroded material from the repository. R_{acc} is the release at the subsurface boundary of the accessible environment. DRZ = disturbed rock zone. (b) Conceptual model for scenario E2. Exploratory borehole does not penetrate pressurized brine below the repository horizon. (from Bertram-Howery et al., 1990).

R_o = Release of Cuttings and Eroded Material
 R_{∞} = Release at the Subsurface Boundary of the Accessible Environment
 R_p = Release to Surface through Withdrawal Well

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(a)

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(b)

Figure 12. Examples of conceptual models for inadvertent human-intrusion scenarios ElE3 and ElE2 for the WIPP. (a) Conceptual model for scenario ElE3. R_p is release to surface through withdrawal well. (from Marietta et al., 1989). (b) Conceptual Model for Scenario ElE2. One exploratory borehole penetrates pressurized brine below the repository horizon and is plugged. A second exploratory borehole penetrates the repository, but does not penetrate the pressurized brine below. (from Bertram-Howery et al., 1990).

Not to Scale

Figure 13. Diagrammatic sketch showing some possible placement options for placement of protective barriers to inadvertent exploratory drilling. (a) Surface protective barrier mound. (b) Near-surface protective barrier. (c) Protective barrier emplaced above rooms and drifts. (d) "Armored" canisters emplaced as a protective barrier within the rooms of the waste panels. Each option could either be used alone or in combination with the other options.

A near-surface protective barrier could utilize either natural or manmade materials in its construction. The types of natural material that might be employed in a near-surface barrier would be essentially the same as those used for a surface barrier mound (see Chapter 5). However, discussions with people involved in the installation of wells, as part of environmental characterization and remediation of old landfills, have provided some intriguing suggestions as to potential types of manmade materials, currently not considered a valuable resource, that could be used to construct a near-surface barrier.

As part of the environmental remediation work on old landfills, a number of boreholes are commonly drilled to characterize the nature and extent of contaminants. These wells are typically drilled using a truck-mounted, rotary drill. These rotary drill rigs generally experience few problems drilling through most natural and manmade materials, with the notable exceptions of layers (greater than 10 m thick) of rubber tires or steel fencing/baling wire. In two cases, these "deposits" acted as barriers that forced drilling to stop and eventually resulted in the boreholes being abandoned. The problems that the drillers encountered with both of these materials were (1) the loss of fluid circulation within the borehole, (2) the inability of the rotary drill bit to cut through the materials, and (3) the materials wrapping around the drill bit and string and hindering efforts to remove the drill string from the borehole.

The loss of fluid circulation within these "deposits" is understandable. Despite being covered and compacted with fill dirt, a pile of tires or wire will still have a large percentage of interconnected void-space that will readily drain away drilling fluids. Loss of fluid circulation in a borehole can be remedied using a host of options, ranging from additives to the drilling fluid (e.g., swelling clays) to pumping cement down the borehole to seal off the zone. However, after circulation was re-established within the boreholes, the physical properties of the rubber and steel wire virtually stopped any further deepening of the boreholes. The rotary drill bit was not able to cut its way through the still pliable rubber tires, drilling was halted and a new well site was chosen. In the case of the steel wire (apparently a mix of discarded baling wire, chicken wire, and barbed wire), the wire literally bound-up the drill bit and disabled it. Strands of wire also apparently became wound around the drill bit and string making it extremely difficult to remove the drill string from the borehole. These problems, especially the possible loss of the drill string, caused this borehole to be abandoned and a new well site to be chosen. Although these layers of tires and steel wire defeated small, truck-mounted rotary drill rigs in the above examples, an investigation is needed to determine whether or not a scaled-up version of these "barriers" would be effective and practical as a long-term protective barrier system for the WIPP.

The final options for the placement of protective barriers are immediately above, or within, the rooms and drifts of the waste panels (Figure 13c). A protective barrier, in the form of sheets or mats, might be emplaced directly above the waste containers and casks. Such a barrier might be composed of malleable materials (like metal wire) or extremely hard manmade materials that would halt the downward progress of the drill bit. A final alternative that might be considered would be to develop an "armored" waste container/ cask (Figure 13d). Although the waste containers/casks that are planned to be used with the WIPP are not expected to be able to survive an encounter with a drill bit (Bertram-Howery et al., 1990), it might be possible to design a waste container that could safely survive such an event. Such a waste container would itself serve as a protective barrier and represent a "point-defense" against exploratory drilling.

As noted earlier in this report, a protective barrier system must be considered a final defensive measure against inadvertent human intrusion. For the protective barrier system to be needed, one must assume that the other passive institutional controls (i.e., site markers and widespread records) have been rendered ineffective for whatever reasons. The result would be that exploratory drilling began and inadvertently encountered the protective barrier system emplaced within the disposal system. If the protective barrier system functions as intended, it would create conditions that would thwart or halt the drilling. But what would the intruders reaction be to the barrier system? If one were to assign the attitudes and abilities of people involved in the drilling industry today to those in the future, the inadvertent intruders might well view such a barrier as a curiosity or challenge and try to circumvent it, especially if they do not realize its intended purpose.

In this regard, it would seem prudent to incorporate some type of subsurface marker into the protective barrier system that would help convey a more direct warning to the intruders. One previous study (ONWI, 1981, p. 8) suggested that a chemical dye marker (termed a "chemical barrier" in the study) could be employed in this role and would be suitable for use in waste repositories constructed within bedded salt deposits. The study envisioned that the "chemical barrier" would consist of colored dyes that would be emplaced within the repository. The colored dye would be released (dissolved in the drilling fluids) if the repository was penetrated by a borehole or affected by drilling or solution mining. The dissolved dye would color the recirculating drilling fluids and call attention to the fact that drilling had encountered unusual conditions. It was assumed that the intruder would stop drilling once the dyed drilling fluid reached the surface and was recognized. Whether or not the intruder would correctly infer and interpret the significance of the colored dye in the drilling fluid is uncertain, but

its presence in the drilling fluid would undoubtedly alert the driller and possibly induce him or her to investigate its origin and meaning.

Perhaps this chemical dye marker concept could be merged with a scaled-down version of the subsurface markers concept developed for the Hanford barrier mounds (U.S. DOE, 1987). This hybrid concept would employ the colored dye along with a large number of small "markers" that could contain some form of an inscribed or imbedded message warning of the hazards and dangers of penetrating the disposal system. These markers would have to be small (on the order of several centimeters or less in size) and durable enough to be recirculated to the surface by a rotary drilling process. The small markers would have to be employed in quantities large enough so that even though the drilling process might destroy some of them, enough would survive the trip to the surface, along with the dyed drilling fluid, to convey the warning. The optimal shape and size of such subsurface markers would have to be investigated; these markers might be made out of several different types of materials, each of which is designed to survive different types of drilling technology.

7 SUMMARY

Appendix B of the Standard considers inadvertent human intrusion into a disposal system after its closure as a potentially severe disruptive event(s). The Standard limits the type of inadvertent intrusive activities that need to be considered in performance assessments to exploratory drilling for resources and directs that both active and passive institutional controls be developed and employed to reduce the likelihood of inadvertent human intrusion. The Standard also limits reliance on active institutional controls (e.g., controlling access to disposal site) for performance-assessment calculations to the first 100 years after closure; enduring passive institutional controls (e.g., site markers, widespread records) are to be employed to reduce the likelihood of inadvertent intrusion into the disposal system for the rest of the post-closure period. In addition to passive institutional controls like site markers and records, SNL is evaluating the feasibility of developing a passive protective barrier system to thwart inadvertent human intrusion into the WIPP. The role of such a protective barrier system would be to act as the final passive defensive measure against inadvertent intrusion (i.e., exploratory borehole[s]).

A review of the available literature addressing methods for preventing and/or deterring inadvertent human intrusion into geologic repository systems failed to find any relevant discussions of concepts or designs for a viable protective barrier system. This is despite the fact that many studies (e.g., ONWI, 1981, 1984; see Table 1) acknowledge the importance of employing some sort of protective barrier system as part of a "defense-in-depth" strategy against inadvertent human intrusion into geologic repository systems. The literature review conducted for this report found that the only available information on protective barrier systems pertained to those under consideration for use at DOE near-surface disposal sites for radioactive waste on the Hanford Reservation (Adams et al., 1981; U.S. DOE, 1987). The barrier mound system under development for these near-surface disposal sites is a multipurpose system having a number of protective functions (e.g., preventing erosion, water infiltration, plant/animal intrusion) in addition to thwarting inadvertent human intrusion (U.S. DOE, 1987). This protective barrier mound (Figure 10b) consists of an extensive, thick, above-ground mound situated directly over the disposal site. The mound is composed of a series of layers consisting primarily of various natural materials. Thick layers of riprap/gravel were included within the barrier mound and are expected to provide some measure of protection against inadvertent intrusion by drilling. The physical and mechanical properties of the layers, coupled with the physical size of the mound, is expected to deter or thwart inadvertent drilling at the disposal site (U.S. DOE, 1987). Another feature of the Hanford protective barrier is buried subsurface marker discs (Figure 10c). These marker discs are inscribed with a message warning the finder of the potential dangers of disturbing the waste entombed below the mound, thus

increasing the likelihood that inadvertent intruders would halt their activities at the disposal site.

Although there is little information available on protective barrier systems, it is possible to outline the attributes that a protective barrier system should possess:

- be capable of disabling a drill bit, be impervious to a drill bit or, at the minimum, be capable of deflecting the drill bit safely away from the disposal system;
- be potentially capable of withstanding multiple encounters with a drill bit without loss of function;
- be composed of materials with little or no economic value and that will not degrade over the 10,000-year, post-closure period; and
- not attract unwanted attention to the site or encourage exploration activities.

The development of inadvertent human-intrusion events and scenarios for post-closure performance-assessment requirements (Marietta et al., 1989) suggests that perhaps only a direct breach of the waste panel area of the WIPP (Figure 3) would result in releases of radionuclides to the accessible environment; an exploratory borehole that misses the waste panels could have only minor impact on the long-term performance of the WIPP disposal system. If this is correct, it would suggest that only the area/volume encompassed by, and above, the waste panels would potentially benefit from a protective barrier system. This observation suggests that it would not be necessary to emplace a protective barrier system across the entire WIPP, but only across that small portion containing the waste panels. This drastically reduces the total area/volume of the WIPP requiring a protective barrier system.

The design of a protective barrier system for the WIPP should be guided by the "defense-in-depth" strategy employed by the other passive institutional controls. The barrier system design might be composed of a series of "barriers" at various, selected points within the disposal system. To this end, barriers could potentially be developed for the waste containers, the rooms/drifts, the near surface, and at the ground surface (Figure 13) immediately above the waste panels. The potential effectiveness of a protective barrier system might be enhanced by the adoption of a modified version of the subsurface markers developed as part of the Hanford barrier mound system. Subsurface markers for the WIPP would have to be small and durable enough to survive an encounter with a drill bit and recirculation

to the surface by drilling fluid. These small markers, along with colored dye as suggested by ONWI (1981), could be incorporated with protective barrier(s) emplaced within, or above, the waste panels.

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APPENDIX A:
RELEVANT PORTIONS OF APPENDIX B OF THE STANDARD
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INTO DISPOSAL SYSTEMS

APPENDIX A:

RELEVANT PORTIONS OF APPENDIX B OF THE STANDARD THAT ADDRESS INADVERTENT HUMAN INTRUSION INTO DISPOSAL SYSTEMS

The following excerpt is from Appendix B of 40 CFR 191 (U.S. EPA, 1985):

Institutional Controls. To comply with § 191.14(a), the implementing agency will assume that none of the active institutional controls prevent or reduce radionuclide releases for more than 100 years after disposal. However, the Federal Government is committed to retaining ownership of all disposal sites for spent nuclear fuel and high-level and transuranic radioactive wastes and will establish appropriate markers and records, consistent with § 191.14(c). The Agency [EPA] assumes that, as long as such passive institutional controls endure and are understood, they: (1) can be effective in deterring systematic or persistent exploitation of these disposal sites; and (2) can reduce the likelihood of inadvertent, intermittent human intrusion to a degree to be determined by the implementing agency. However, the Agency believes that passive institutional controls can never be assumed to eliminate the chance of inadvertent and intermittent human intrusion into these disposal sites.

Consideration of Inadvertent Human Intrusion into Geologic Repositories. The most speculative potential disruptions of a mined geologic repository are those associated with inadvertent human intrusion. Some types of intrusion would have virtually no effect on a repository's containment of waste. On the other hand, it is possible to conceive of intrusions (involving widespread societal loss of knowledge regarding radioactive wastes) that could result in major disruptions that no reasonable repository selection or design precautions could alleviate. The Agency believes that the most productive consideration of inadvertent intrusion concerns those realistic possibilities that may be usefully mitigated by repository design, site selection, or use of passive controls (although passive institutional controls should not be assumed to completely rule out the possibility of intrusion). Therefore, inadvertent and intermittent intrusion by exploratory drilling for resources (other than any provided by the disposal system itself) can be the most severe intrusion scenario assumed by the implementing agencies. Furthermore, the implementing agencies can assume that passive institutional controls or the intruders' own exploratory procedures are adequate for the intruders to soon detect, or be warned of, the incompatibility of the area with their activities.

Frequency and Severity of Inadvertent Human Intrusion into Geologic Repositories. The implementing agencies should consider the effects of each particular disposal system's site, design, and passive institutional controls in judging the likelihood and consequences of such inadvertent exploratory drilling. However, the Agency assumes that the likelihood of such inadvertent and intermittent drilling need not be taken to be greater than 30 boreholes per square kilometer of repository area per 10,000 years for geologic repositories in proximity to sedimentary rock formations, or more than 3 boreholes per square kilometer per 10,000 years for repositories in other geologic formations. Furthermore, the Agency assumes that the consequences of such inadvertent drilling need not be assumed to be more severe than: (1) Direct release to the land surface of all the ground water in the repository horizon that would promptly flow through the newly created borehole to the surface due to natural lithostatic pressure -- or (if pumping would be required to raise water to the surface) release of 200 cubic meters of ground water pumped to the surface if that much water is readily available to be pumped; and (2) creation of a ground water flow path with a permeability typical of a borehole filled by the soil or gravel that would normally settle into an open hole over time -- not the permeability of a carefully sealed borehole.

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