Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix EPIC

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Effectiveness of Passive Institutional Controls in Reducing Inadvertent Human Intrusion into the Waste Isolation Pilot Plant for Use in Performance Assessments

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Effectiveness of Passive Institutional Controls in Reducing Inadvertent Human Intrusion into the Waste Isolation Pilot Plant for Use in Performance Assessments

Kathleen M. Trauth,[1] Robert V. Guzowski,[2] Chris G. Pflum,[3] and Ronald J. Rodriguez[4]

ABSTRACT

The U.S. Environmental Protection Agency requires the use of passive institutional controls (PICs) to discourage future generations from inadvertently intruding into the Waste Isolation Pilot Plant (WIPP) waste repository and the contiguous 16 sections. The controls are to include markers, records, archives, and government ownership and land-use restrictions. Credit may be allowed in performance assessments for these controls to reduce the frequency of inadvertent intrusion for several hundred years after disposal.

A task force was formed to estimate the credit for the passive controls for the WIPP repository. The estimate was constrained by the use of existing conceptual designs of these controls, the use of historical analogues for the endurance of materials and structures, the consideration of possible failure modes for each control, and the regulatory assumption of societal "common denominators."

Because of the redundancy of messages to be built into the passive controls, human error was identified by the task force as the only mechanism that could result in inadvertent intrusion for the 10,000 years of regulatory concern. An examination of 80 years of drilling records for the New Mexico portion of the Delaware Basin identified no instances of the mislocation of drilling sites due to human error. The task force concluded that the failure of passive controls to correctly communicate the location and hazards of the waste, thereby deterring inadvertent intrusions for the first several hundred years of performance assessments will be no greater than 0.01. This failure rate is a bounding value intended to account for possible failure mechanisms that the task force failed to identify.

[1] Sandia National Laboratories, Albuquerque, NM 87185
[2] Science Applications International Corporation, Albuquerque, NM
[3] Carlsbad Technical Assistance Contractor, Carlsbad, NM
[4] Westinghouse Waste Isolation Division, Carlsbad, NM

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EXECUTIVE SUMMARY

The Waste Isolation Pilot Plant (WIPP) is an experimental facility located in bedded-salt deposits in southeastern New Mexico that is owned by the U.S. Government and operated by the U.S. Department of Energy (DOE). This facility is being evaluated as a permanent disposal location for transuranic waste produced by defense-related activities and programs. To demonstrate suitability, the DOE must comply with the performance criteria established by the U.S. Environmental Protection Agency (EPA) in *Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, Final Rule* (40 CFR Part 191). Four main provisions apply to the postdisposal performance criteria: (1) probabilistic radionuclide release limits to the accessible environment (§ 191.13), (2) additional assurance requirements to supplement the natural radionuclide-containment capabilities of the disposal system (§ 191.14), (3) dose limits to individuals for undisturbed conditions (§ 191.15), and (4) protection of underground sources of drinking water from radionuclide contamination for undisturbed conditions (§ 191.24). With the exception of the qualitative assurance requirements, each of the other performance criteria is based on 10,000 years of regulatory concern after disposal.

One of the Assurance Requirements (§ 191.14[c]) states that "disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location" (50 FR 38086c). Another role for the passive institutional controls (PICs) was identified by the EPA with the promulgation of *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule* (40 CFR Part 194). This role (§ 194.43) allows credits for PICs to reduce the frequency of inadvertent human intrusion into the WIPP disposal system for the performance assessments (PAs) required to address the Containment Requirements of § 191.13.

The PICs Task Force (PTF) was created by the DOE to assess the level of correct communication of the location and hazards of the waste that a system of PICs, conforming to the design considerations of the Assurance Requirements, would have in the context of reducing (i.e., deterring) inadvertent intrusion frequencies for PAs. Guidance about societal "common denominators" was identified in EPA's *Compliance Application Guidance for 40 CFR Part 194* (EPA 402-R-95-014). These "common denominators" were a partial list that are a foundation for a "prudent extrapolation for the future state assumptions established in § 194.25." The PTF defined additional assumptions ("common denominators") for use in assessing the effectiveness of PICs.

In order to assess the effectiveness of the PICs in deterring inadvertent intrusion, the PTF examined the DOE's conceptual designs of the PICs components that will form an integrated system of PICs. This system will be composed of monuments and other markers that will be located both at the repository footprint and at the boundary of the Withdrawal (i.e., 16 sections of the WIPP), records in both archives and records centers, and a variety of other PICs intended to distribute knowledge about the WIPP to future generations. These components are consistent with the EPA's requirements and will include redundancy and reinforcement of the warnings. Estimates were made about the durability of the material that will be used to construct/develop the PICs and the messages themselves (i.e., engraved and printed) based on comparisons with historical analogues. In addition, possible failure modes for each component were identified and examined in the context of how the conceptual designs of the various PICs components would counter the failure modes.

Of the PICs components, the marker system to be located at the repository footprint will be the most durable and effective deterrent. Based on the durability of materials at Stonehenge, the Egyptian pyramids, the stele containing the Code of Hammurabi, and the Rock of Behistun as analogues, the granite monuments, information center, and the engraved messages that will be exposed to the weathering at the WIPP are not expected to undergo significant deterioration within the regulatory time frame. Additional deterrence will be provided by the buried markers and storage rooms. The berm itself will be an awareness trigger and not a deterrent by itself.

The monuments at the boundary of the Withdrawal are expected to last as long as the monuments at the repository footprint. The danger associated with intrusion in the Withdrawal is more obscure than the warning on the inner monuments about intruding into the repository. These monuments will lose some deterrent value in the future, starting perhaps about 1,000 years after closure when the more subtile messages in the nearby records centers becomes more difficult to decipher.

Historical analogues used to estimate the life expectancy of the WIPP records are paper fragments that have lasted almost since the beginning of paper, nearly 2,000-years ago, and pieces of papyrus that are about 5,000-years old. Modern technology should be able to at least duplicate these durabilities. Working assumptions of the PTF were that the records will not be duplicated if the original records deteriorate because of wear and age, and that catastrophic loss of records due to fire or natural disaster will result in reconstruction of the entire records center and contents from other surviving records centers and archives.

Records about the WIPP submitted to records centers will be printed on archival paper with special ink to ensure a long life expectancy for the documents. Special bindings and covers will be used to emphasize the importance of these documents. These records are expected to be completely effective in deterring inadvertent intrusion early in the regulatory time frame. Records submitted to records centers associated with property and resource rights are expected to be a completely effective deterrent much longer than in the general records centers because of the importance of these rights to society. Some loss of effectiveness of records in the resource centers may begin at the time when paper deterioration may start to be a problem in the 4,000- to 5,000-year time period, when the paper deteriorates. English will continue to be decipherable by the resource community for thousands of years.

Records submitted to archives also will be printed on special archival paper with special ink to ensure a long life expectancy for the documents, especially under the controlled environmental conditions within the archives. In addition, a special filing code will be developed and special bindings and covers will be used in order to emphasize the importance of the documents within the vast quantities of documents that will accumulate in the archives during the regulatory time frame. The PTF concluded that the archives would have little deterrence value early in the regulatory time frame because of the distant locations of the archives from the WIPP. As documents in the records centers closer to the WIPP deteriorate or are "lost," the effectiveness of the archives as deterrents will increase.

Government control of land use is based on written instructions being submitted to the appropriate agencies and covenants being included in surface and resource leases and stored in records center. As with records center previously discussed, land use controls will be a completely effective deterrent for thousands of years.

The remaining PICs (e.g., encyclopedias and road maps) components will act as awareness triggers rather than deterrents. These components will increase the public's and the potential intruders' awareness of the WIPP so that other components will be consulted prior to any type of human intrusion into the WIPP disposal system. The PTF did not assume any contribution of the awareness triggers to the deterrence provided by the PICs system.

Based on the assessments of the PICs components and the fact that the PICs system will be as effective as the most effective component, the PTF concluded that the PICs system will offer virtually complete effectiveness in deterring inadvertent human intrusion into the repository footprint for the entire regulatory time frame. The PICs system will deter inadvertent intrusion into the Withdrawal outside the repository footprint for thousands of years after disposal with this deterrence decreasing slightly over time to account for the more esoteric warning on the outer monuments and the possible deterioration of confirmatory records.

After examining the historical analogues and failure modes, the PTF ascertained that the PICs will be highly effective for long periods of time within the 10,000-year regulatory period. An examination of drilling records and personal interviews with individuals having extensive experience with drilling in the Delaware Basin revelated no instances of wells being drilled in the wrong location in the Delaware Basin (i.e., failure of 0.00). When the survey was extended to a much larger area, five instances of wells drilled in the wrong location out of over 400,000 wells drilled in total were identified (i.e., failure of 0.00001) For the sake of addressing the needs of the PA and to account for unidentified possible failure mechanisms and sources of human error that could result in reduced effectiveness of the PICs system, the PTF recommends that the failure of the PICs system in deterring inadvertent human intrusion within the entire Withdrawal be increased to a bounding value of 0.01 for the time interval from 100 to 700 years after disposal.

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1.0 INTRODUCTION

1.1 WIPP and Its Regulatory Requirements

The Waste Isolation Pilot Plant (WIPP) is a research and development facility authorized in 1979 (Public Law 96-164, 1979) to "demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission." After the successful demonstration, the WIPP will become a facility for the permanent disposal of this transuranic waste. The proposed disposal facility is located in southeastern New Mexico (Figures 1-1 and 1-2) at a depth of 655 meters (2,150 feet) and within a bedded-salt unit (the Salado Formation) (Figures 1-3 and 1-4).

Before permanently disposing of the defense-generated transuranic waste at the WIPP, the Department of Energy (DOE) must demonstrate compliance with applicable long-term disposal standards of the U.S. Environmental Protection Agency (EPA). These disposal standards have been promulgated at Title 40 Code of Federal Regulations (CFR) Part 191, Subparts B and C.

Title 40 CFR Part 191, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, Final Rule" was promulgated on September 19, 1985 (EPA, 1985). Parts of 40 CFR Part 191 were vacated and remanded to the EPA for reconsideration in 1987 in response to a lawsuit. The aspects of 40 CFR Part 191 relating to passive institutional controls (PICs) were not impacted as a result of the lawsuit. The aspects of 40 CFR Part 191 that were impacted by the lawsuit were repromulgated on December 20, 1993 under the title "40 CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, Final Rule" (EPA, 1993).

Subparts B and C of the *1993 40 CFR Part 191* contain four main provisions related to disposal of radioactive waste in a repository. Firstly, in Subpart B, performance-assessment (PA) analyses calculate the performance of a disposal system for 10,000 years and compare calculated radionuclide releases to probabilistic radionuclide release limits found in §191.13. Secondly, the Assurance Requirements, found in §191.14, indicate complementary actions (e.g., PICs and monitoring) to be taken to provide additional confidence for long-term compliance with §191.13. Thirdly, the radionuclide doses that individuals may receive from an undisturbed disposal system are limited for the *10,000* years of regulatory concern in §191.15. Fourthly, Subpart C incorporates the requirements of the National Primary Drinking Water Regulations (40 CFR 141.15 and 141.16) to protect underground sources of drinking water (USDWs) from radionuclide contamination from an undisturbed disposal system for 10,000 years (§191.24).

On October 30, 1992, Congress passed the WIPP Land Withdrawal Act (LWA) (Public Law 102-579, 1992). The major purpose of the LWA was to transfer jurisdiction over the 16-square-mile area including and surrounding the WIPP facility, from the Department of the Interior to the DOE. Congress has defined this area as the "Withdrawal" in the LWA. The term Withdrawal is used throughout this report for this area. In addition, Congress required that the EPA promulgate proposed "criteria for the Administrator's certification of compliance with the final disposal

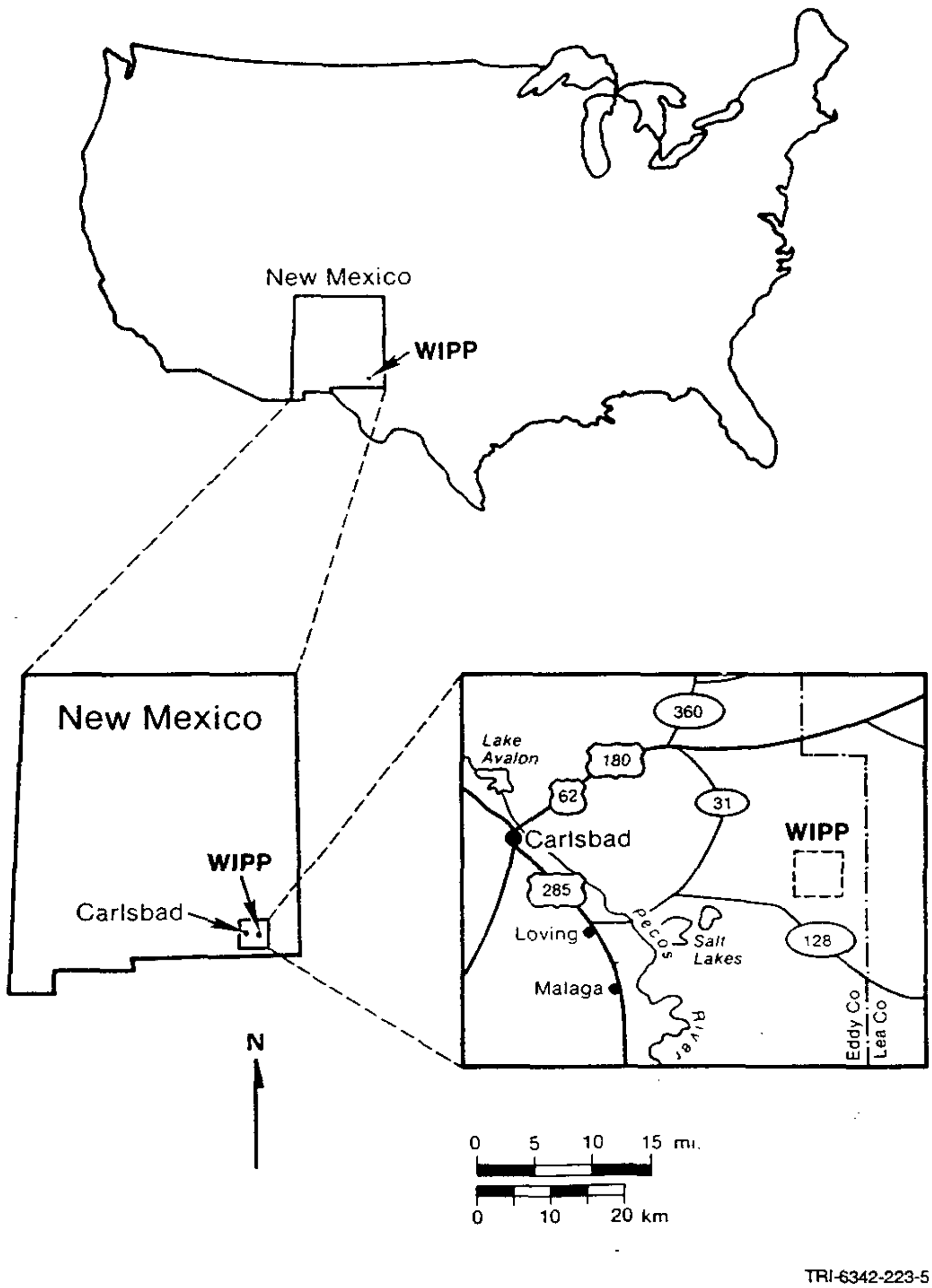

Figure 1-1. Location of the WIPP (after Bertram-Howery and Hunter, 1989).

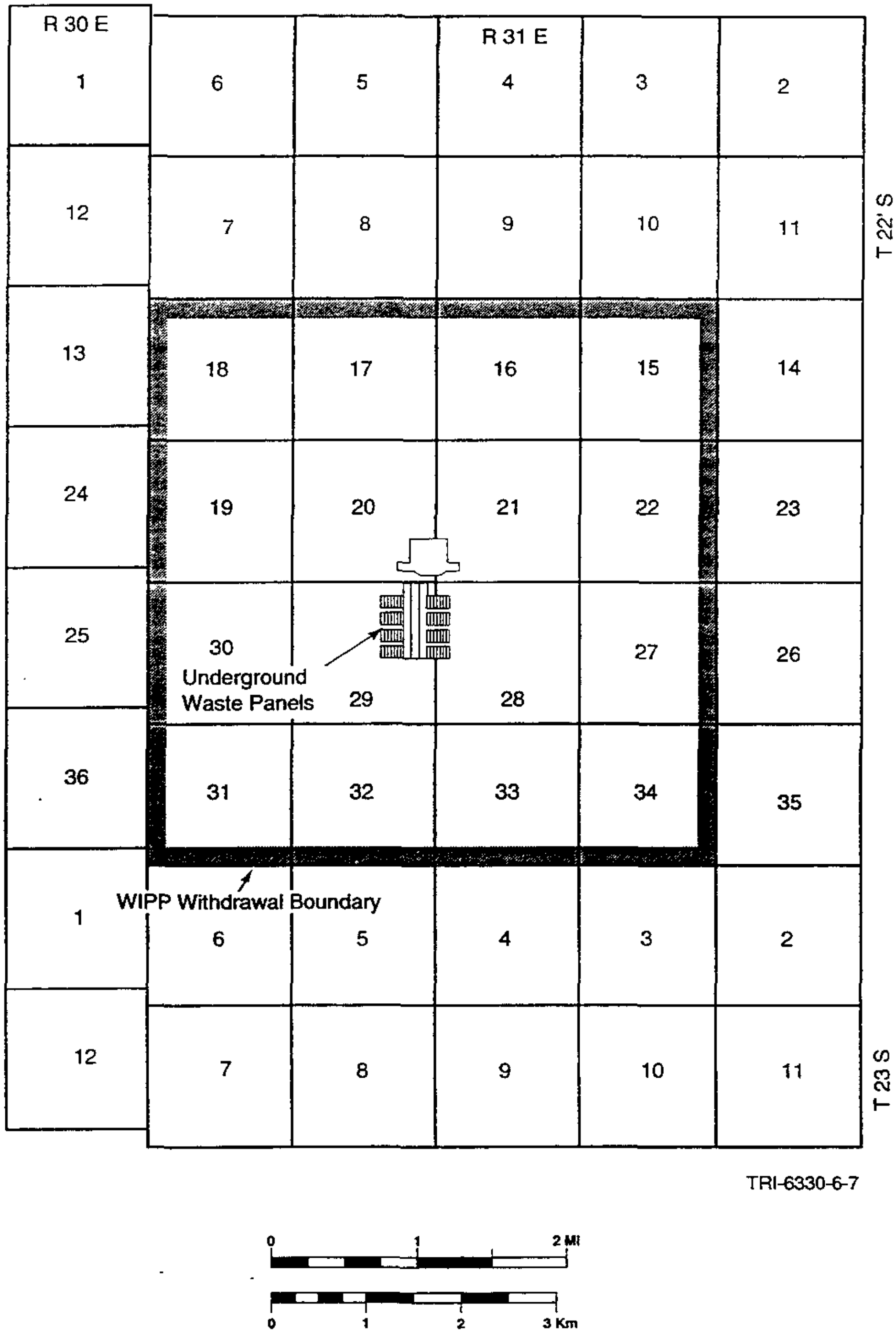

Figure 1-2. Position of the WIPP waste panels within the Withdrawal (DOE, 1990a).

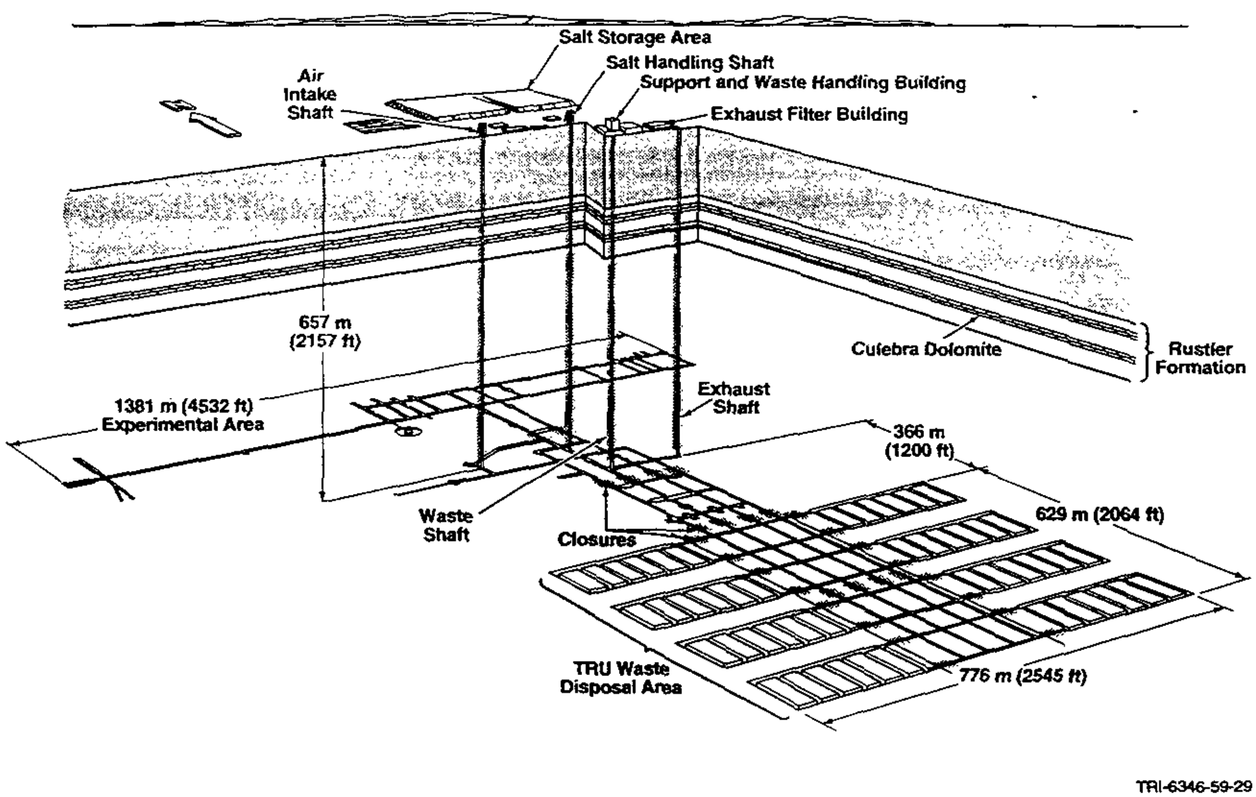

Figure 1-3. Relationship between the WIPP surface and subsurface facilities (after Waste Management Technology Department, 1987).

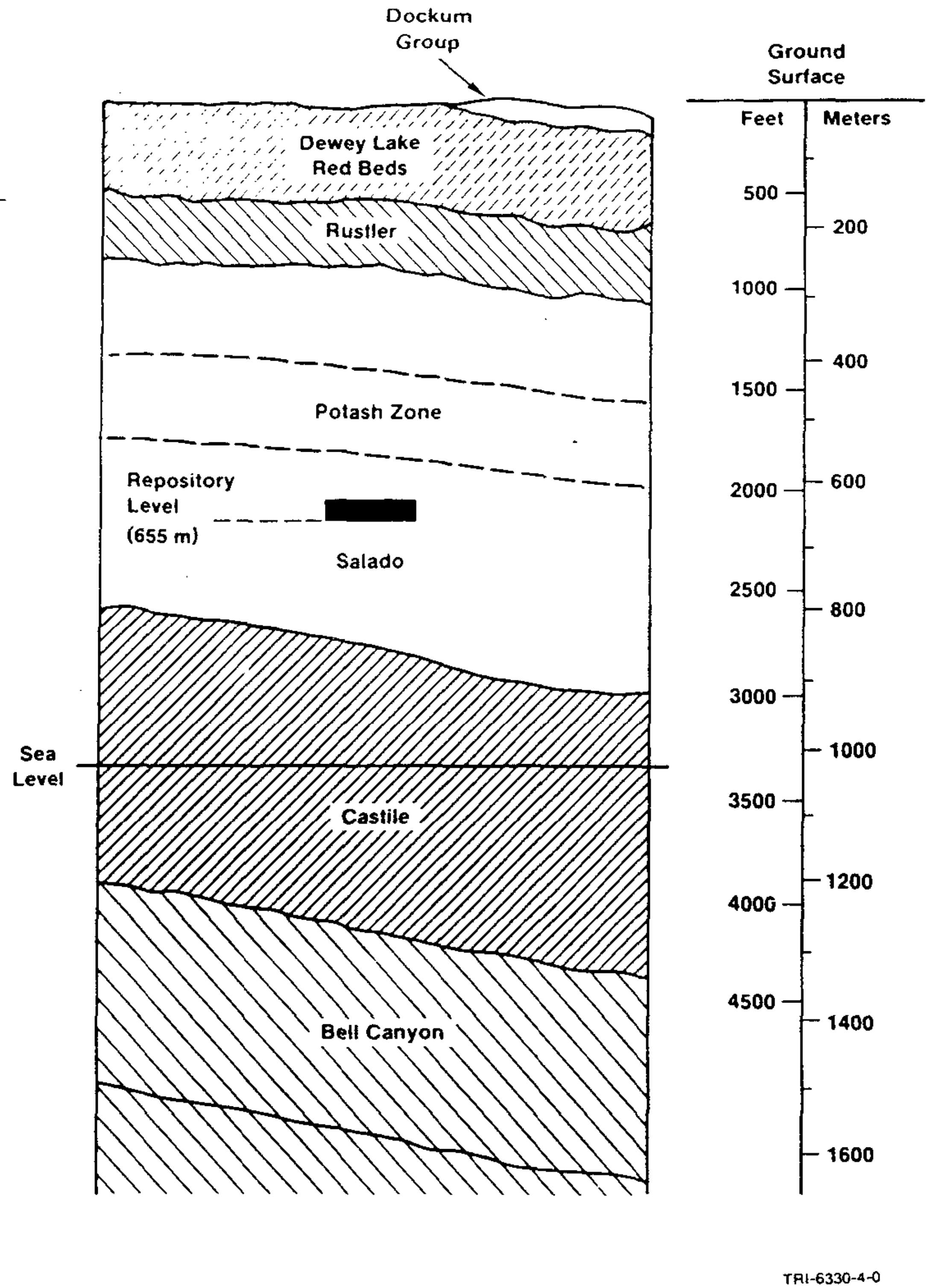

Figure 1-4. Generalized stratigraphy at the WIPP (after Waste Management Technology Department, 1987).

regulations" (Public Law 102-579, 1992, Sec. 8[c][1]). The EPA's proposed rule, "Criteria for the Certification and Determination of the Waste Isolation Pilot Plant's Compliance With Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Proposed Rule" (40 CFR Part 194) (EPA, 1995a) was published in the *Federal Register* (FR) January 30, 1995. As stated in the LWA, the criteria were intended to be used to determine "whether the WIPP facility will comply with the final disposal regulations" (Public Law 102-579, 1992, Sect. 8 [c] [1]). The EPA promulgated the final version of 40 CFR Part 194 under the title "Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance With the 40 CFR Part 191 Disposal Regulations; Final Rule" on February 9, 1996 (EPA, 1996c).

1.2 Passive Institutional Controls

PICs are intended to communicate to potential intruders information about the existence and location of the repository, the wastes buried there, the nature of the hazard the wastes represent, and the goal of not disturbing the disposal system. A fundamental assumption about nuclear-waste disposal is that if future generations have and understand the appropriate information, they will not intrude into the repository or disturb the remainder of the disposal system. With the requirement to mark the withdrawal, the message for the larger area outside the repository footprint is not the danger of intruding into the repository, but the danger of impacting ground-water flow and possibly affecting radionuclide transport from the disposal facility toward the biosphere.

The recently promulgated WIPP-specific 40 CFR Part 194 (EPA, 1996c) states both the requirement for PICs and the permission for the PA to take advantage of PICs to reduce drilling and mining frequencies. The language states that the DOE may take credit for the PICs in deterring inadvertent human intrusion into the WIPP facility and disposal system in the PA calculations for the Compliance Certification Application (CCA) that will be submitted. Concurrently, § 194.26 establishes requirements on the use of expert judgment and indicates that expert judgment would probably be used to assess the effectiveness of PICs in deterring inadvertent human intrusion into the disposal system.

In other language, the EPA indicates a concern about the justification for such credit and a desire for clear justification for this credit within the EPA's regulatory assumption (61 FR 5231/EPA, 1996c). The regulatory language also indicates an expectation that the effectiveness of PICs will be assessed by individuals independent of the DOE (61 FR 5228 and 61 FR 5232/EPA, 1996c).

1.3 PICs Task Force Objectives

The PICs Task Force (PTF) has been charged with developing a numerical representation of the effectiveness of PICs in deterring inadvertent human intrusion into the WIPP disposal system. This numerical representation must be developed in a usable format for the PA calculations. The documentation of the deliberations of the PTF provide well-reasoned arguments to support the results.

As described in Section 1.4, the deliberation of the PTF will be followed by external peer review of the results and the process by which the results were developed. As such, the PTF will provide the input materials for the peer review—writing the issue statement that the peer reviewers will address, supplying the effectiveness estimates and supporting arguments, and providing the peer-review panel with answers to questions or concerns.

This report does not address the conduct of the external peer review, which will be conducted within the DOE's peer-review process.

1.4 Work Approach

A work approach has been developed by the DOE that addresses the dual requirements of (1) providing justified input to the PA calculations as to the efficacy of the PICs in deterring inadvertent human intrusion, and (2) developing such information based on existing evidence and with the assistance of individuals with perspectives beyond the DOE.

The DOE has developed a four-step approach to achieve these goals. The first step was to convene the Markers Panel in 1991 (Trauth et al., 1993) in a process following steps refined in NUREG-1150 (Hora and Iman, 1989). A comparison of the process for convening the Markers Panel in 1991 with the 1996 requirements of §194.26 Expert Judgment leads the DOE to conclude that they are substantially equivalent. The two Markers Panel teams developed marker designs that were distilled into a set of fundamental design principles about long-term marking and communicating with future generations. The second step took these design principles and specific marker elements, supplemented by other documentation of structures, records systems, and information that have endured for long periods of time, to develop the PICs Conceptual Design Report (DOE, 1996). The third step (which is documented here) was to utilize a PTF comprised of individuals with relevant knowledge supplemented by external expertise, to examine existing documentation (information and perspectives developed external to the DOE), to finalize the conceptual models of the system of PICs that the DOE will commit to implementing, and to assess the effectiveness of the PICs in reducing the inadvertent intrusion frequency for the PA calculations. The fourth step in the approach will be to submit the report of the PTF to external peer review. The results of the PTF analysis will be used as input to the PA forming the basis of the CCA.

The PTF consists of representatives from the DOE Carlsbad Area Office (CAO), the Carlsbad Technical Assistance Contractor (CTAC), Sandia National Laboratories (SNL), Westinghouse Waste Isolation Division (WID), and technical consultants. The following is a list of the PTF members:

Task Coordinator
- Michael M. Oliver - CAO

Report Authors
- Kathleen M. Trauth - SNL
- Robert V. Guzowski - SNL/SAIC
- Chris G. Pflum - CTAC

Ronald J. Rodriguez - WID

Technical Consultants
David Givens - American Anthropological Association
Suzanne Pasztor - Randolph-Macon College

1.5 Constraints

Two major constraints directed this effort. The first of these constraints is that the PTF must work within the regulatory confines established by the EPA in 40 CFR Part 191 and 40 CFR Part 194 (including the Supplementary Information (SI) and the Background Information Document [BID] [EPA, 1996a]), as to what is required and what assumptions to make. These limitations for the PA calculations are that (1) PICs cannot be assumed to completely eliminate inadvertent human intrusion for any portion of their life; (2) credit for the effectiveness of PICs in deterring inadvertent human intrusion cannot be taken for more than approximately 700 years after disposal; and (3) the future-state assumptions in §194.25, that characteristics of the future unrelated to hydrogeologic, geologic, and climatic conditions are to be assumed to be as they are today. The second constraint is that estimates of the efficacy of PICs must be clearly linked with existing evidence on the longevity of structures and materials and the long-term maintenance and interpretability of messages.

A number of operational constraints were imposed on the deliberations of the PTF. One constraint was to begin deliberations using the system of PICs discussed in the Passive Institutional Controls Conceptual Design Report (DOE, 1996), with expansion and modification of the system as necessary. Another operational constraint was to work within what is practicable to implement in the construction and development of the PICs, and what the DOE will commit to implementing.

1.6 Preview of Chapters

Chapter 2 outlines the pertinent regulatory language from 40 CFR Part 191 and 40 CFR Part 194 (including the Supplementary Information and the BID). Chapter 3 discusses the role of PICs in nuclear waste management and includes national perspectives other than the EPA. Chapter 4 builds upon the strict regulatory requirements and indicates assumptions used by the PTF in the assessment, both from the EPA and by the PTF when an assumption had to be made to implement the language of the regulations. Chapter 5 begins with a discussion of the systems approach to long-term communication and addresses the relationships between PICs components. Chapter 6 is a linked discussion of the PICs components, the historical analogues that support the design, potential failure mechanisms, and design characteristics that counter the potential failure mechanisms. Chapter 7 outlines the numerical representation of the effectiveness of PICs and provides the corresponding justification by examining historical analogues, while showing graphically the interrelationships of the PICs components in supporting deterrence. Chapter 8 contains the references cited throughout this report.

2.0 APPLICABLE REGULATIONS

2.1 Basis for Regulatory Aspect

The PTF's estimation of the effectiveness of the PICs must take place within a regulatory context that establishes the requirements for the PICs and the assumptions that govern considerations of their effectiveness. This chapter deals with these regulatory requirements.

2.2 Requirements for Active Institutional Controls in 40 CFR Part 191

This discussion of active institutional controls (AICs) is relevant because the AICs establish when consideration of PICs is assumed to be a factor in the PA and are another example of the EPA's treatment of human intrusions.

The EPA defines AICs as:

> "(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." (50 FR 38085c/EPA 1985)

For the PA, which assesses the performance of the disposal system for isolation of wastes from the accessible environment, the EPA prohibits consideration of any contribution from AICs for more than 100 years after disposal.

The PTF traced the origin of this 100-year limit to the EPA's 1978 draft "Criteria for Radioactive Wastes" (EPA, 1978). These criteria were intended to provide general guidance for the disposal of all forms of radioactive waste. Criteria No. 2 states:

> "The fundamental goal for controlling any type of radioactive waste should be complete isolation over its hazardous lifetime. Controls which are based on institutional functions should not be relied upon for longer than 100 years to provide such isolation; radioactive wastes with a hazardous lifetime longer than 100 years should be controlled by as many engineered and natural barriers as are necessary." (43 FR 53265/EPA, 1978)

Although the EPA's standards and criteria for the WIPP impose limits on AICs, the EPA's standards for uranium and thorium mill tailings (40 CFR Part 192/EPA, 1995b) do not.

The 100-year limit on AICs portends an early end to the United States government. The PTF does not believe that the U.S. government—with its institutions, laws, and sanctions—will collapse in 100 years or change to an extent that a location as important as the WIPP will be forgotten. Indeed, other countries have expressed more faith in their governments. Their waste disposal systems will rely on active controls for 100 to 500 years (NEA, 1995).

The EPA's limitations on the credit for AICs (100 years) in the PA calculations represent conservative assumptions meant to place the emphasis for regulatory compliance on the isolation afforded by the site, and limit reliance on societal actions (either active or passive). This limitation should not be construed as meaning that active control over the site by the federal government will end after 100 years. In fact, the existence of PICs means that AICs would have further reinforcement by virtue of activities involved with testing and constructing the PICs.

2.3 Requirement for Passive Institutional Controls in 40 CFR Part 191

As part of the assurance requirements of the general standard, 40 CFR Part 191, the EPA requires the implementation of PICs. Section 191.14 states that:

> "(c) Disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location."
> (50 FR 38086c/EPA, 1985)

In §191.12, the EPA defined PICs as:

> "(1) Permanent markers placed at a disposal site, (2) public records and archives, (3) government ownership and regulations regarding land or resource use, and (4) other methods of preserving knowledge about the location, design, and contents of a disposal system." (50 FR 38085c/EPA, 1985)

The definition of "passive" can be understood, in part, by contrasting the definitions of PICs and AICs, in §191.12. 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."
> (50 FR 38085c/EPA, 1985)

The distinction between active and passive is the nature of the deterrence. For AICs, an institution (i.e., the DOE) deters intrusions, whereas for PICs, the warning is the deterrent.

The DOE reads the text within the Supplementary Information that was published with the original promulgation of 40 CFR Part 191 to further explain the rationale in developing the rule as indicating that the EPA intended for the implementing agency to take credit for the effectiveness of PICs in deterring inadvertent human intrusion:

> "The Agency [EPA] 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 institutional controls (although passive institutional controls should not be assumed to completely rule out the possibility of intrusion)." (50 FR 38089a/EPA, 1985)

and

> "Not allowing passive institutional controls to be taken into account to some degree when estimating the consequences of inadvertent human intrusion could lead to less protective geologic media being selected for repository sites." (50 FR 38080b,c/EPA, 1985)

DOE's reading of the above regulatory language, and the need to address PICs, resulted in the Markers Panel being convened in 1991 to address this issue in a multidisciplinary fashion. The language in 40 CFR Part 191 provided the context for the deliberations of the Markers Panel.

2.4 Criteria for Passive Institutional Controls in 40 CFR Part 194

The requirements in 40 CFR Part 191 are explicitly applied to the WIPP through 40 CFR Part 191. Section 194.43(a) builds upon the language of 40 CFR Part 191 and requires a description of the proposed PICs:

> "Any compliance application shall include detailed descriptions of the measures that will be employed to preserve knowledge about the location, design, and contents of the disposal system. Such measures shall include: (1) Identification of the controlled area by markers that have been designed and will be fabricated and emplaced to be as permanent as practicable." (61 FR 5243c/EPA, 1996c)

In addition, §194.43(b) requires that an assessment of how long PICs might be effective must be undertaken:

> "Any compliance application shall include the period of time passive institutional controls are expected to endure and be understood." (61 FR 5243c/EPA, 1996c)

2.5 EPA's Allowance of Credit for Passive Institutional Controls

In §194.43, the EPA has clearly stated that the DOE may take credit for the PICs deterring inadvertent human intrusion in the PAs:

> "(c) The Administrator may allow the Department to assume passive institutional control credit, in the form of reduced likelihood of human intrusion, if the Department demonstrates in the compliance application that such credit is justified because the passive institutional controls are expected to endure and be understood by potential intruders for the time period approved by the Administrator. Such credit, or a smaller credit as determined by the Administrator, cannot be used for more than several hundred years and may decrease over time. In no case, however, shall passive institutional controls be assumed to eliminate the likelihood of human intrusion entirely." (61 FR 5243c/EPA, 1996c)

The Supplementary Information for 40 CFR Part 194 provides further detail and indicates the importance of the justification of the credit proposed:

> "Additionally, the final rule allows the Department to reduce the likelihood of future human intrusion that is used in performance assessments by a proposed amount corresponding to the predicted effect of PICs . . . . Thus, DOE may propose in its compliance application to reduce the rate of human intrusion by a fractional amount, extending over a technically supportable period of time, and must justify this using the plans for the implementation for PICs and associated evidence of their effectiveness." (61 FR 5231a,b/EPA, 1996c)

as well as the means of mathematically describing such credit:

> "This credit may take the form of a constant reduction in the rate of human intrusion lasting several hundred years or may be a reduction in the rate which tapers off in size over several hundred years." (61 FR 5231b/EPA, 1996c)

Further qualifications on the implementation of credit are:

"Such credit cannot be assumed to eliminate completely the possibility of human intrusion, even for a short period of time after the active institutional controls at the WIPP are assumed to be ineffective." (61 FR 5231b/EPA, 1996c)

and

"Having considered the public comments regarding PICs, the Agency believes that such credit could be no more than approximately 700 years past the time of disposal. Thus, the final rule limits to several hundred years the amount of credit that EPA may grant for PICs. Any determination that a specific numerical credit would be appropriate for a much longer period of time would be unduly speculative and therefore inappropriate." (61 FR 5231b/EPA, 1996c)

The EPA quotes from the Supplementary Information published with the 1985 promulgation of 40 CFR Part 191 to provide the context for the treatment of PICs in 40 CFR Part 194:

"With respect to performance assessments, the Agency examined whether PICs should be taken into account to some degree when estimating the likelihood of inadvertent human intrusion and concluded that 'a limited role for passive institutional controls would be appropriate when projecting the long-term performance of mined geologic repositories to judge compliance with (the containment requirements of 40 CFR part 191).' At the same time, the Agency explicitly determined that PICs should not be assumed to completely prevent the possibility of inadvertent human intrusion." (61 FR 5231c/EPA, 1996c)

The EPA goes on to note that some comments received on the draft 40 CFR Part 194 stated that the Agency was acting beyond their authority in proposing to allow credit for PICs in the analyses for the containment requirements:

"Still other comments asserted that, in allowing for the possibility of credit, the Agency had revised the intent of the assurance requirements, one of which being the requirement for the implementation of PICs. Specifically, comments stated that the assurance requirements were not intended to be considered when determining compliance with the numerical containment requirements found at 40 CFR 191.13." (61 FR 5231c-5232a/EPA, 1996c)

The EPA's statement immediately following that comment is:

"The provisions of the final rule entertaining possible credit for PICs are within EPA's authority." (61 FR 5232a/EPA, 1996c)

The BID for 40 CFR Part 194 is another source of information as to not just the appropriateness of taking credit for PICs, but the necessity:

"In this chapter the *necessity* [emphasis added] of incorporating passive institutional controls in the WIPP compliance criteria is discussed in terms of their ability to reduce the likelihood of human intrusion." (EPA, 1996a, p. 12-1)

DOE's reading of the above regulatory and associated language caused the DOE to conclude that in addition to being necessary under the Assurance Requirements, the PICs were intended to be a part of determining compliance with the Containment Requirements of §191.13. The PTF was convened to provide the input to PA.

While the EPA stated the necessity for including PICs in the compliance criteria, the EPA also stated concerns in Chapter 12 of the BID (EPA, 1996a) that were used to justify limiting the amount of credit that PICs can provide in deterring inadvertent human intrusion. Appendix A contains a discussion of a selected number of the EPA's concerns and the PTF's responses as to why these limitations are not appropriate.

2.6 Reasonable-Expectation Requirement in 40 CFR Part 191

The measure by which the compliance of the WIPP with the disposal standards will be determined to be one of a "reasonable expectation" as stated in the Supplementary Information published with the original promulgation of 40 CFR Part 191:

> "The containment requirements call for a 'reasonable expectation' that their various quantitative tests be met. This phrase reflects the fact that unequivocal numerical proof of compliance is neither necessary nor likely to be obtained. A similar qualitative test, that of 'reasonable assurance,' has been used with NRC regulations for many years. Although the Agency's intent is similar, the NRC phrase has not been used in 40 CFR Part 191 because 'reasonable assurance' has come to be associated with a level of confidence that may not be appropriate for the very long-term analytical projections that are called for by 191.13. The use of a different test of judgment is meant to acknowledge the unique considerations likely to be encountered upon implementation of these disposal standards." (50 FR 38071c/EPA, 1985)

The concept of reasonable expectation in the Containment Requirements was not an issue in the legal challenge 40 CFR Part 191. With the repromulgation of 40 CFR Part 191 in 1993, the EPA did not reverse its position on reasonable expectation in the containment requirements, and in fact the EPA extended the concept of reasonable expectation to the Individual Protection Requirements in §191.15:

> "Compliance assessments need not provide complete assurance that the requirements of paragraph (a) of this section will be met. Because of the long time period involved and the nature of the processes and events of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with paragraph (a) of this section will be achieved."
> (58 FR 66414c/EPA, 1993)

2.7 Reasonable-Expectation Requirement for PICs

The estimation of the effectiveness of PICs in deterring inadvertent human intrusion into the disposal system is to be used to modify an input to the PA calculations that are used to produce families of complementary cumulative distribution functions (CCDFs). These CCDFs are then compared with the release limits in the Containment Requirements of §191.13 to determine compliance with the disposal standards. As quoted above, the Containment Requirements of 40 CFR Part 191 are guided by the reasonable-expectation requirement. Because the effectiveness of the PICs are an integral part of the PA calculation used to address the Containment Requirements, the reasonable-expectation requirement also applies to the estimation of the effectiveness of PICs. DOE reads the reasonable-expectation language in 40 CFR Part 191 as meaning that absolute proof of the longevity of a marker, a records system, or a message is neither achievable nor required to take credit for PICs in the PA calculations. The fact that the EPA required the implementation of the reasonable-expectation concept at two different times (the 1985 and 1993 promulgations of 40 CFR Part 191) and for different contexts (PAs and Compliance Assessments) supports the DOE's interpretation of the language for the concept.

2.8 Deterring Inadvertent Human Intrusion

References to human intrusion in 40 CFR Part 191 and in the Supplementary Information are to inadvertent human intrusion. Statements such as the following suggest that the requirement for PICs is to protect against the inadvertent human intrusion:

> "The most speculative potential disruptions of a mined geologic repository are those associated with inadvertent human intrusion." (50 FR 38088c/EPA, 1985)

The EPA has included provisions in 40 CFR 194.33(b)(1) that limit consideration of intrusion into the disposal system to inadvertent drilling:

> "Inadvertent and intermittent intrusion by drilling for resources (other than those resources provided by the waste in the disposal system or engineered barriers designed to isolate such waste) is the most severe human intrusion scenario." (61 FR 5242b/EPA, 1996c)

This provision allows for the assumption that the message of the PICs is to be directed at discouraging those efforts to locate and exploit natural resources. Under this assumption, individuals locating and conducting drilling operations will avoid intruding into the repository and disturbing the disposal system if warning messages against intruding and disturbing are correctly conveyed to future generations. If, however, a potential intruder realizes that a drilling or mining activity may intersect the repository or the Withdrawal and understands the associated risks, but decides to intrude anyway, the intrusion is not inadvertent. Intentional intrusions are not to be considered in the PA calculations. "Deter" consists of the messages enduring and being correctly understood. Correct communication means that inadvertent human intrusion has been deterred. Understanding but ignoring the messages results in intentional human intrusion, which is beyond the scope of PA.

2.9 EPA Definition of Human Intrusion and the Area of Concern for Drilling

The definition of "human intrusion" has changed between the promulgation of 40 CFR Part 191 and the promulgation of 40 CFR Part 194. In 40 CFR Part 191, the term human intrusion was limited to boreholes drilled within the surface projection of the repository "footprint" and that actually penetrated to at least the depth of the repository. Appendix C of 40 CFR Part 191 restricted the consideration of drilling for natural resources to the repository area:

> " . . . 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* [emphasis added] . . . . " (50 FR 38089b/EPA, 1985)

As a result of this guidance, the area of interest in considering the effectiveness of PICs by the Markers Panel was limited to the area of the repository. The revised guidance in 40 CFR Part 194 does not limit the area in which drilling can occur. Title 40 CFR 194.33(a) states that:

> "Performance assessments shall examine deep drilling and shallow drilling that may potentially affect the disposal system during the regulatory time frame." (61 FR 5242b/EPA, 1996c)

The EPA has thus indicated that "human intrusion" is not limited to events that actually penetrate the repository, but includes a broader list including shallow drilling and excavation mining. By this definition, human intrusion (drilling) must be considered to occur anywhere in the Withdrawal—within the footprint or within the Withdrawal outside the repository footprint. Thus, when the EPA states that PICs may reduce the likelihood of inadvertent human intrusion, it has indicated that PICs may be useful in deterring these other activities, including mining for natural resources.

With 40 CFR Part 194, the EPA has stated that drilling and mining will be treated the same in terms of the efficacy of PICs to deter inadvertent intrusion:

> "Performance assessments may assume that the likelihood of mining may be decreased by PICs and active institutional controls, to the extent that can be justified in the compliance application and to a degree identical to that assumed for drilling." (61 FR 5230a/EPA, 1996c)

Because the risks that are associated with drilling directly into the repository are potentially greater than those associated with drilling into the Withdrawal outside of the repository footprint, a greater effort will be made to deter intrusion into the repository footprint than outside of this footprint. The result is that the PICs are assumed to have different levels of deterrence for these areas.

When the Markers Panel was convened in 1991, the existing regulatory guidance stated that:

> "Therefore inadvertent and intermittent intrusion by *exploratory drilling* [emphasis added] for resources (other than any provided by the disposal system itself) can be the most severe intrusion scenario assumed by the implementing agencies." (50 FR 38089a/EPA, 1985)

Based on 40 CFR Part 194, the definition of inadvertent human intrusion as used in this report includes any human activity that disrupts the disposal system (i.e., deep or shallow within the Withdrawal). These inadvertent human intrusions are limited to drilling and mining for natural resources, but include both exploration and development.

2.10 Dual Nature of Passive Institutional Controls for Assurance Requirements and for PA

To comply with the Assurance Requirements, a system of PICs has been identified for implementation at the WIPP (DOE, 1996). When the DOE addressed the issue of markers for the WIPP, by convening the Markers Panel, the charge was to design a system of markers that would be effective in communicating with individuals in unknown future societies. Thus, one could not assume anything about the nature of the individuals or their actions (e.g., level of technology, language, culture, and natural-resource usage). The designs of the Markers Panel have formed the basis of the DOE's conceptual design. The PICs that the DOE is committing to implementing are comprehensive. (See Appendix A, "Compliance with the Passive Institutional Controls Assurance Requirement," for a brief discussion on the compliance of the PICs with the Assurance Requirements, as opposed to the effort described in this report that supports the PA calculations.)

The Assurance Requirements do not require a specific level of efficacy for the PICs in order to show compliance, only that within the four specified categories (markers, records and archives, government ownership and regulations, and other) that the most permanent practicable means be used. These requirements are thus qualitative requirements.

There is no indication in §194.43(c) that if credit were not applied for or granted, that the PICs would not be sufficient to comply with the assurance requirements. The requirement for having PICs, and applying for credit for their use in the PA are separate issues. Applying credit for PICs only makes sense for those cases where inadvertent human intrusion is a factor—the Containment Requirements of §191.13.

The BID, published with the promulgation of 40 CFR Part 194, indicates the dual nature of PICs:

> "In developing the 40 CFR part 191 rule, EPA recognized that the quantification of risk over long periods of time was subject to considerable uncertainty and consequently introduced assurance requirements into the rule to *qualitatively address this uncertainty* [emphasis added]. One of the assurance requirements deals with passive institutional controls. Passive institutional controls are designed to reduce the probability of inadvertent human intrusion into a repository by conveying information about location, design, and hazards of the WIPP."
> (EPA, 1996a, p. 12-1)

Thus, PICs play a dual role in the compliance with the disposal standards. The design and implementation of the most permanent PICs practicable are required for compliance with §191.14. Assessing PICs for efficacy in deterring inadvertent human intrusion, and providing appropriate justification is wholly within the tasks associated with compliance with §191.13.

3.0 ASSUMPTIONS USED IN ESTIMATING THE EFFECTIVENESS OF PICS IN DETERRING FUTURE INADVERTENT HUMAN INTRUSIONS

The PICs are intended to convey a convincing message to future generations that discourages them from disturbing the disposal system. Because of the changing nature of most aspects of society and technology, the long-term effectiveness of the PICs in conveying the warning messages to future generations depends on what the message says, how it is conveyed, and the nature of its audience. The EPA has recognized that long-term predictions about society and technology include a level of uncertainty that can have a significant impact on the PAs.

> "The Agency recognizes the inherently conjectural nature of specifications on future states and wishes to minimize such speculation in compliance applications. The Agency has found no acceptable methodology that could make reliable prediction of the future state of society, science, languages or other characteristics of future mankind." (61 FR 5227c/EPA, 1996c)

The EPA helped reduce the uncertainty associated with predicting the risk of inadvertent human intrusion by mandating certain assumptions about the future in areas where scientific predictions cannot be validated. These future-state assumptions, which are really "present-day" assumptions, are based on the language in §194.25(a), which states:

> "Unless otherwise specified in this part or in the disposal regulations, performance assessments conducted pursuant the provisions of this part to demonstrate compliance with §191.13, §191.15, and part 191 subpart C shall assume that characteristics of the future remain what they are at the time the compliance application is prepared, provided that such characteristics are not related to hydrogeologic, geologic or climatic conditions." (61 FR 5241a/EPA, 1996c)

The rule's supplementary information elaborates that for the purposes for assessing inadvertent human intrusion, PAs can assume that current social conditions persist for 10,000 years:

> "...the final rule requires that performance assessments and compliance assessment shall include dynamic analyses of geologic, hydrologic and climatic processes and events that will evolve over the 10,000-year regulatory time frame. DOE shall assume that *all other present day conditions will exist in their present state for the entire 10,000-year regulatory time frame*" (emphasis added) (61 FR 5228a/EPA,1996c)

Although future uncertainty represents itself in assessments of both human intrusion and the PICs that would deter human intrusion, only the uncertainty associated with human intrusion may be reduced by using future states assumptions. In regard to PICs, the EPA's Compliance Application Guidance (CAG) states,

> "Explicit application of future state assumptions to passive controls — i.e., the assumption that all present-day societal and demographic factors will remain constant — will not be considered by EPA to justify adequately the design of PICs or the estimation of credit." (EPA, 1996d)

To accommodate the EPA's guidance, assumptions regarding PICs and human intrusion cannot be contemporaneous. The PICs must deter an unknown intruder from the faraway future, while the DOE must assume that the repository would attract a contemporary intruder with contemporary skills and values. To some extent, the CAG relieves this inequity:

"EPA expects that DOE will establish a framework of assumptions for PICs that is a prudent extrapolation of the future state [i.e., present day] assumptions established in §194.25" (EPA, 1996d)

In determining the amount of credit that the PA may take for PICs, this "prudent extrapolation" would consider certain societal "common denominators," such as the existence of some form of government and some level of regulatory control over the exploration for and development of resources. According to the CAG,

"These common denominators are patterns of human behavior that may be detected throughout history and around the world. The degree to which the PICs implemented at the WIPP rely on common denominators will determine the degree to which the PICs are effective at being understood by potential intruders in the future." (EPA, 1996d)

Besides these "common denominators," the PTF made assumptions that are consistent with EPA's requirements for consideration of drilling events in the PA:

"Future drilling practices and technology will remain consistent with practices in the Delaware Basin at the time a compliance application is prepared" (40 CFR 194.33(c)(1)).

According to the Supplementary Information, these requirements provide "further clarification on which activities fall within the scope of human intrusion." Because the requirements of §194.33 and their basis are not part of the EPA's future state assumptions, there is no apparent prohibition from applying them to PICs. The PTF therefore considers that current drilling practices in the Delaware Basin are activities that fall within the scope of PICs. The following sections list and develop both the basic working assumptions from the CAG and assumptions developed by the PTF.

3.1 Basic Human Attributes

Assumption (1): Curiosity of humans [will continue]. (CAG)

People will continue to be curious about writing, pictures, symbols, and structures, and they will attempt to decipher them.

Assumption (2): The use of the written word to transmit information and concepts [will continue]. (CAG)

Assumption (3): Story-telling or the generational "passing down" of history [will continue]. (CAG)

People will continue to be interested in their past history and will continue to pass it down to future generations through writings and story telling.

Assumption (4): The ability of pictures to convey meaning [will continue]. (CAG)

Basic symbols will be understood (e.g., moon, people, animals), and basic emotions can be expressed through facial expressions (e.g., horror, disgust, happiness). Pictographs will reinforce the linguistic messages as long as languages can be understood, and replace the linguistic warnings if the language is no longer functional.

Assumption (5): Some people will avoid, ignore or be ignorant of governmental controls. (CAG)

Some people will always try to avoid controls that they do not agree with and from which no perceived benefits are derived or from which there is a perceived harm.

Assumption (6): Individuals will continue to look out for their own self interest. (PTF)

Individuals will continue to monitor the activities of their competitors to gain a personal benefit or to prevent the competition from gaining a perceived unfair advantage. "Individual" can be a single person, a corporation, or the State.

3.2 Government

Assumption (7): The existence of some form of government [is assumed]. (CAG)

Government will exist in some form for the entire regulatory period. When people form an association, someone either assumes control or is elected to be in charge. The "individual" or "group" in control makes decisions either for its own benefit or the benefit of the association.

Assumption (8): [Government will exert] some level of regulatory control. (CAG)

Governments are established to provide a certain level of control upon society. The level of control depends on the type of government. One means of exerting control is to issue regulations or edicts to inform the society about what is and is not permitted, and to provide a mechanism to enforce the regulations or edicts (e.g., legal procedures, armed force, penalties).

Assumption (9): Governments will require and maintain records as part of the procedure to maintain controls. (PTF)

Records address the issues of who did what, where, and when. Knowledge of these issues is vital for the government to exert control. By requiring records, government establishes the information needed to exert control.

Assumption (10): Governments will continue to protect property rights. (PTF)

Under a government that respects individual property rights, the government will establish procedures and laws to protect those rights, including surface and mineral rights associated with property ownership. In the case where the government is the steward for the society (e.g., publicly owned material resources), agents of the government will monitor societal property in order to assure that society's rights are protected and compensation is received in exchange for the sale of societal property. If the government does not recognize individual property rights, agents of the government have a vested interest in protecting society property (e.g., natural resources) from exploration or development by nongovernmental entities.

Whereas some individuals have a tendency to avoid or ignore government control (see Assumption 5) that is perceived to be of no direct benefit, individuals and agents of the state have a vested interest in eliminating this avoidance (e.g., in the area of illicit exploration or development of natural resources).

3.3 Language

Assumption (11): Current English will continue to increase in the size of its vocabulary and the areas of use, but the basic vocabulary and structure will resist change. (PTF)

Current English is now the international language of science, technology, commerce, and diplomacy, which are major societal drivers. Estimates of the number of people who speak English world-wide range from 800,000,000 to 1,500,000,000, and English has official status in over 60 countries (Crystal, 1994). The widespread use of current English by the international community presents considerable resistance to rapid and drastic changes in the basic vocabulary and structure of English. People have invested so much time and effort in learning English that they will not accept wholesale changes except over extremely long time frames.

Assumption (12): Current English will remain decipherable by future generations of English readers for at least 1,000 years after disposal. (PTF)

Current high school students can read the works of Shakespeare (i.e., modern English), which are approximately 350 years old, and understand the basic concepts. College students can read the works of Chaucer (i.e., Middle English), which is approximately 600 years old, with some effort and understand the concepts. Linguistic scholars can read the epic poem *Beowulf* (i.e., Old English), which is approximately 1,000 years old (Crystal, 1994). Current English will remain decipherable to some members of society for at least as long as Old English has remained decipherable to current society.

In a case where the structure of English does change significantly, the fact that information is economically important will result in a concerted effort being made to understand the information. For example, when treasure hunters were trying to locate the wreck of the Spanish treasure ship *Atocha*, the available documents were handwritten in Spanish in a form in which the characters bear no resemblance to current written Spanish and the text contains no punctuation (e.g., no commas and no periods). Because of the potential value of the treasure, considerable effort was expended to translate the documents (Sullivan, 1987).

Assumption (13): English will continue to be read by the natural-resources exploration and exploitation industries. (PTF)

Because of the specialization of the vocabulary in the natural-resources industries, the extent of changes that may occur in current English for the general populace will not extend into the technical aspects of these industries. As a result, current English will become an industry-specific "second" language. This situation is analogous to Latin, which was used as the written language by the scientific community many centuries after the fall of Rome.

3.4 Natural Resources

Assumption (14): Resource exploration and extraction will be conducted using drilling technology that is basically the same as today's. (40 CFR 194.33 and Supplementary Information)

This is not a future-state assumption because it is presented in the section on Human Intrusion, which is guidance for the PA. These assumptions are being developed to provide input to the PA and are not used in any other context.

> 40 CFR 194.33(c)(1): "Future drilling practices and technology will remain consistent with practices in the Delaware Basin at the time a compliance application is prepared." (61 FR 4242c)
>
> 40 CFR 194, Supplementary Information: "...drilling practices will remain as those of today and may vary depending on the resource." (61 FR 5230b)
>
> Assuming the use of higher technology is nonconservative, because higher technology is likely to include the means to detect the repository and radioactivity.
>
> Assuming the existence of a lower technology is nonconservative, because drilling to the depths being considered requires a relatively sophisticated technology that will not exist under this assumption (Guzowski, 1990, see Appendix C)

This assumption is consistent with the position of the International Atomic Energy Agency (IAEA) (1994) that stated:

> "For the purposes of assessing the consequences of future human actions . . . the future level of technology should be assumed to be at least equivalent to that existing at present. A lower level of technology would make it less likely that intrusion could be technically achieved. On the other hand, an improved technology supposes an increased knowledge, retention of records and an awareness of the risks of such repositories." (IAEA, 1994, p. 18)

Assumption (15): Because of the uncertainties associated with predicting future natural resources, the historical drilling rates for oil and gas in the Delaware Basin are to be used in the PA as surrogates for future drilling rates for these unknown other resources. (40 CFR 194.33 and Supplementary Information)

As the EPA has explained, this is not a future-state assumption. This assumption was established by the EPA to address the uncertainties of what resources will be important to societies in the near to distant future for the PA calculations. For example, uranium was a novelty element prior to the development of the theoretical basis for nuclear reactions. During and after WW II when a use for uranium was discovered, this element became a major source of resource exploration and production efforts.

> 40 CFR 194, Supplementary Information: "In effect, when used for the purpose of determining the future drilling rate, today's drilling activities act as surrogates for the unknown resources that will be drilled for in the future." (61 FR 5233c)

Assumption (16): There will always be natural resources of value within the Delaware Basin that will attract future exploration and support exploitation efforts. (40 CFR 194.33 and Supplementary Information)

As the EPA explained, this is not a future-state assumption. This assumption was established by the EPA to address the uncertainties of when and where resources will be found by societies in the near to distant future for the PA calculations.

> 40 CFR 194.33(b)(2): "In performance assessments, drilling events shall be assumed to occur in the Delaware Basin at random intervals in time and space *during the regulatory time frame* [emphasis added]." (61 FR 5242b)
>
> 40 CFR 194, Supplementary Information: "With respect to drilling rates, the Agency reasoned that while the resources drilled for today may be the same as those drilled for in the future, the present rates at which these boreholes are drilled can nonetheless provide an estimate of the future rate at which boreholes will be drilled. The Agency does expect that drilling will never completely cease; while some resources may become depleted over time and, while the rate of extraction of those resources may decrease, the increased rate of drilling for newly discovered resources will compensate for this decline." (61 FR 5233c)

Assumption (17): There will be virtually continuous natural-resource exploration and exploitation activities in the Delaware Basin during the entire regulatory time period. (40 CFR 194.33 and Supplementary Information)

40 CFR 194.33 requires the PA calculations to consider future drilling for exploration and exploitation to be random in time and space (see Assumption 6). Thus over time, the drilling rate will approximate an even distribution of boreholes (i.e., boreholes will be drilled at approximately equal intervals of time). Historical drilling rates for oil and gas in the Delaware Basin have been calculated to be approximately 48 boreholes/km^2 for 10,000 years. With a withdrawal area of 41 km^2, this drilling density results in one borehole being drilled within the Withdrawal every five years.

The drilling rate is assumed to extend beyond the boundaries of the Withdrawal to include the entire Delaware Basin (194.33(b)(2)). With the Delaware Basin area of approximately 23,100 km^2, this drilling density results in 111 boreholes being drilled per year. This level of drilling activity will attract attention from the competition and also keep the records centers busy processing the paperwork associated with this activity.

Assumption (18): Resource exploration and exploitation is not a casual activity. (PTF)

Resource exploration and exploitation requires a significant expenditure of time and money. As a result, certain procedures have been developed to optimize the benefits received from these expenditures. These procedures include investigating records centers to address ownership issues, checking pertinent literature to obtain resource information, and site investigations. All these steps occur prior to drilling.

3.5 Estimating PICs Effectiveness

Assumption (19): The determination of intrusion as inadvertent or intentional is not based solely on the actions of an individual but is also based on the actions of government in carrying out its responsibilities. (PTF)

For example, Congress has established the LWA that prohibits intrusion into the Withdrawal in perpetuity. Given that WIPP records will continue to exist, be understood, and be stored with resource records, if Congress decides to rescind the LWA, it will be done with full knowledge of the WIPP and any subsequent intrusions are not inadvertent. Government has failed its obligations by removing this prohibition, and this failure is not the responsibility of the generation responsible for the construction and disposal of the waste within. These same obligations apply to any subsequent governments that assume power.

Assumption (20): Communicating with future societies using words, pictographs, symbols, and diagrams through a variety of media is possible. (PTF)

Assumption (21): Historical analogues of structures, media, and messages that have withstood the test of time allow the DOE to design for success. (PTF)

Assumption (22): Today's scientific and engineering communities have the capability to create PICs that will perform at least as effectively as historical analogues. (PTF)

3.6 Summary

The EPA (1996d) suggests that the DOE not explicitly use "future state" assumptions to assess the effectiveness of PICs. Rather the DOE should establish a framework of assumptions for PICs that is a "prudent extrapolation" of the future state (i.e., present-day) assumptions established in §194.25. In determining the amount of credit that the PA may take for PICs, this "prudent extrapolation" would consider certain societal "common denominators." The PTF has identified the common denominators that could be prudently extrapolated into assumptions regarding the future environment in which PICs would deter inadvertent human intrusion. Other EPA assumptions that are not "future state" but are relevant to the assessment of human intrusion and PICs are incorporated. The PTF's assumptions are numbered and italicized throughout this chapter. These assumptions provide a basis for the communication concepts discussed in Chapter 5, the PICs discussed in Chapter 6, and the conclusions presented in Chapter 7.

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4.0 BASIC COMMUNICATIONS CONCEPTS

The regulatory bases for PICs are discussed in Chapter 2. In developing the conceptual designs for the PICs, care has been taken to ensure that all of the areas of PICs development and message transmittal established by the EPA (§191.12) have been addressed. The PICs are an integrated system of components that contains both on-site and off-site components, general and detailed warnings, written messages targeted at the technical and academic communities, and symbolic messages targeted at a more general audience. In addition, the system of PICs includes both redundant components (defense-in-"depth"), in that more than one component will convey the same information and warnings, and complementary components, in that some components will contain information and messages to direct individuals to other components with more detail. Some individual components also contain redundancy that can include how the message is transmitted and the locations in which the messages are stored. The integration of the PICs components into a system along with redundancy of messages within certain components suggests that the effectiveness of the PICs system in deterring future drilling and mining activities will remain high even if the effectiveness of individual components is compromised by some failure mechanism.

4.1 Systems Approach for PICs

The PICs being proposed for the WIPP disposal system (see Chapter 5) are an integrated system of components that include redundancy of the information being transmitted and reinforcement of the information; some components direct potential intruders to other components. This systems approach is derived directly from the design characteristics proposed by both teams (Team A and Team B) of the Markers Panel. As stated by Team A:

> "This team's thinking is founded on two major themes. The first theme states that the use of communication technology cannot bypass the problem of the certain transformation and succession of cultures, but use of fundamental and enduring psychology can. The second theme states that the entire site must be experienced as an integrated system of mutually reinforcing messages, and designed accordingly." (Trauth et al., 1993, p. F-27)
>
> "As well, we use the more culture-bound modes of communications such as languages and diagrams, but these are used as part of a larger system of communications. This system is to be one with great redundancy of messages and modes, so that even with some loss the goals of the system are met.
>
> "As well as being conceived as (1) a whole communication experience, (2) having a systemic character in which pieces are related in meaningful ways that add meaning, and (3) being sufficiently redundant to endure loss of elements, we apply the principle of Gestalt, in which the experience of the total communicated message is greater than the sum of the parts (even with some of the parts missing or degraded)." (Trauth et al., 1993, p. F-29)

Archives and records were not within the purview of the Markers Panel. Thus, their systems approach addressed only physical markers. Consistent with the requirement in 40 CFR Part 191, the DOE has extended the systems concept to incorporate archives, records, government land ownership and control, and other means of communication into the total PICs design.

Because of this redundancy and reinforcement, the effectiveness of the PICs system is not adequately represented as the sum of the effectiveness of the individual components. To estimate the effectiveness of the PICs system in reducing the frequency of inadvertent human intrusion, the interrelationships of the components must be recognized. This is clearly stated by Team B of the Markers Panel:

> "The probabilities and performance characteristics proposed above [Markers Report, Trauth et al., 1993] for the individual markers would be greatly enhanced by their inclusion within a larger, well-integrated marking system.
>
> "Message redundancy would be increased, of course. But the additional cross-referencing and multiple linkages of markers, signs, symbols, text and diagrams also would help reduce the likelihood of inadvertent intrusion. Furthermore, use of teaching principles throughout the message system (i.e., defining the meaning of a given symbol or iconic sign by placement within appropriate linguistic and diagrammatic messages) would augment performance of the entire marker." (Trauth et al., 1993, p. G-64)

The design of the PICs in order to comply with the Assurance Requirements is based on the two premises that (1) the PICs must be the most permanent practicable, and (2) one can make no assumptions about the future state(s) of society, technology, and language (i.e., one must design for the range of possibilities). With no assumptions about the future, the systems approach means (1) that the multiple (a) messages, (b) levels of complexity, and (c) communication media all reinforce each other to fill in gaps in communication, and (2) that the PICs are actually available to reestablish societal knowledge about the WIPP should there be societal discontinuities.

The use of the PICs, as designed to meet the Assurance Requirements, to take credit in PA is undertaken within EPA's framework of societal assumptions. Credit for PICs in PA is also limited to the much shorter time frame of 700 years. For PA, EPA's expectation is for assumptions based on a prudent extrapolation of today's conditions and using common denominators of human behavior. Under these circumstances, the PICs design exceeds what the assumptions would call for, and the systems approach means that each PICs component (other than the berm) is redundant and any one could correctly communicate the information and deter the potential intrusion.

4.2 Complexity of Messages

Five levels of messages will be used for the PICs at the WIPP based on Givens (1982):

- Message Level I conveys the message that the site is manmade. The message itself is in the physical form of the marker system and the effort expended in constructing it.
- Message Level II conveys the message that something dangerous is buried here and that no digging or drilling should be conducted.
- Message Level III conveys basic information that tells what, why, when, where, who, and how.

- Message Level IV conveys complex information in seven languages along with symbols and pictures.

- Message Level V is archival and stores a more complete rulemaking record than the messages provided at the WIPP site.

4.3 Encountering the PICs

Some of the PICs components are designed to instill a knowledge of the WIPP into the general public. Information about the PICs in textbooks, dictionaries, and encyclopedias should expose a large segment of the population to basic information about the WIPP. Although individuals in general are unlikely to remember much about the WIPP, those individuals who become involved in natural resources and environmental endeavors are more likely to be exposed to more detailed information about the WIPP and may be more likely to recognize the term "WIPP" because of an interest in the topic. These PICs may heighten the awareness of the potential intruder to the WIPP's presence so that other sources of information will be checked.

Natural-resource exploration/exploitation consists of three basic steps: (1) identification of areas that have resource potential, (2) evaluation of the resources in the areas, and (3) exploitation of the resources if the area-evaluation results confirm the presence of economically viable resources. Because of high levels of expenses in evaluating resources through field work, the first step in locating areas with resource potential is to research available sources of geologic and related information. Selected PICs components are designed to provide warnings and/or information on geologic and resource-related maps that someone interested in the resource potential of the northern part of the Delaware Basin is likely to check. These PICs are likely to heighten the awareness of the potential intruder to the presence of the WIPP so that other sources of information will be checked. Government ownership of the land at the WIPP could be determined at this stage of the investigation. The PICs component of government ownership would not be a deterrent, because government ownership of land is a common occurrence in resource exploration in the West.

If the WIPP region has resource potential, the next step would be a check of the ownership of the surface and mineral rights prior to any exploration activities. Expending time and effort to locate resources would be pointless if no opportunity exists to recover these investments. An investigation of ownership would lead to various government offices (federal, state, county, and local) where deeds and leases could be checked. This search could extend to birth/death records and probate-court records if surface or mineral rights could have been inherited. This phase of the investigation would encounter a number of PICs. Someone driving to a records center could encounter an area designated as "the WIPP" on road maps and atlases. As with other maps, these PICs would heighten the awareness of the investigator to the presence of the WIPP so that other sources of information will be checked. At the records centers, the investigator would encounter the fact in property records that the land within the land-withdrawal boundary is owned by the federal government and that leases contain land-use restrictions as covenants prohibiting drilling. The location and design of the WIPP facility and the hazards associated with the buried waste will be determined from the special, WIPP-specific records on file in the records center. Government ownership by itself would not deter a potential intruder but would force the investigator to obtain the proper permits to avoid charges of mineral/resource trespass. Such permits could not be obtained because of the covenants. Land-use restrictions by themselves would not prohibit a potential intruder unless the government at some level is willing and able to enforce the restrictions. The WIPP-specific records within the records center would provide a major deterrent to intruding at or near the WIPP.

As part of the regional site evaluation, the investigator might conduct a field check of the WIPP out of curiosity or as part of the investigation of land adjacent to the Withdrawal. A site visit would encounter the markers. The warnings provided by the messages on the markers would reinforce the warnings already encountered at the records center(s). If the site visit occurs prior to visiting a records center, the warnings on the markers would still be deterrents and also provide additional incentives to find out more about the WIPP at records centers or archives, where the investigator would encounter the PICs of government ownership, land-use restrictions, and the formal WIPP-specific records.

4.4 Relationships between PICs Components

The PICs components form an integrated synergistic system that contains redundancy and reinforcement of information. Some components are designed to act primarily as deterrents on their own, while other components are primarily designed to direct an investigator or potential intruder to other components that contain more information and/or more explicit warnings.

Based on the discussion in Section 6.1, the following PICs components are intended to inform the general public about the existence of the WIPP; they are called "awareness triggers" (see Chapter 7):

- textbooks
- dictionaries
- encyclopedias
- road maps
- road atlases

The following components are more likely to reinforce this same function in the technical and resource-related community:

- geologic maps
- resource-related maps

For each of these components, the basic message is that something named "WIPP" is present in the northern part of the Delaware Basin, and the investigator should seek additional information before proceeding with any resource exploration or exploitation activities. More detailed information about the WIPP will be provided in textbooks, dictionaries, and encyclopedias, but investigators for the resource industry are likely to consult more "technical" sources.

Government ownership of the surface and mineral/resource rights conveys no information about the WIPP, but does convey the message that certain procedures must be followed in order to obtain permission to evaluate resources. In following procedures to obtain permission, the investigator will encounter other PICs that will provide information about the location and hazards of the WIPP. An absence of government ownership would have little effect on deterring human intrusions, because the investigator would still go to records centers to identify ownership of the surface and mineral/resource rights.

The following PICs components are the primary deterrents to human intrusions at the WIPP:

- markers
  - monuments at boundary of repository footprint
  - buried markers throughout repository footprint
  - monuments at boundary of the Withdrawal
- records centers
- archives
- government control of land-use (covenants)

Although the level of detailed information provided by each component differs on why intrusion into the Withdrawal or the repository footprint should be avoided, the basic warning not to intrude is present in each component. Each component is an independent deterrent to future human intrusions. The warnings communicated by each component are reinforced if the investigator or potential intruder encounters more than one of these components, but the message of each component does not depend on the investigator or potential intruder encountering more than one component. Because of this relationship between components, potential future intruders should be effectively deterred from drilling into the Withdrawal as long as one of these components remains sufficiently intact to provide a warning.

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5.0 PASSIVE INSTITUTIONAL CONTROLS CONCEPTUAL DESIGN

5.1 Introduction

This chapter presents a linked discussion of the conceptual design for the PICs, the historical analogues that illustrate long-term survival of structures, institutions, and messages, potential mechanisms for the failure of PICs, and how the design of the PICs can serve to counteract the potential failure modes. The descriptions of the permanent markers, messages, and records embodied in this report are general. For a detailed description of the conceptual design of individual components of the permanent markers system and their associated messages, as well as the type of records and the locations of records archives that the DOE intends to establish as PICs, the reader is referred to the *Passive Institutional Controls Conceptual Design Report* (DOE, 1996).

Historical analogues define characteristics that have allowed structures and human institutions to endure for extended periods of time. As a result they influenced the thinking on the conceptual design of the PICs components. With a recognition of these characteristics, the PTF assumes that with current technology, these characteristics can be matched or exceeded to ensure the durability of the PICs components.

In addition, for each component, potential failure mechanisms are listed, along with a brief description of how the PICs design addresses the failure mechanisms. The climate to which an historical analogue is subjected versus the climate at the WIPP will vary. In general, the climate at the WIPP is as dry or drier than the climate at the historical analogue. Thus, weathering impacts related to water at the WIPP will be less than or equal to the impacts on historical analogues. Wind blown sand may be a concern at the WIPP as well as at various of the historical analogues. In response to this concern with erosion, pristine granite has been selected for its durability, and most of the elements of the site marker system will be placed within a protective berm that will reduce wind velocity. An experimental program for PICs will assess potential impacts of the natural environment on PICs and identify any design modifications necessary to address these impacts.

The specific PICs components are based on the requirements established by the EPA in 40 CFR Part 191: (1) markers, (2) public records and archives, (3) government ownership and land-use regulations, and (4) other (see Section 2.3). "Markers" were not defined in the regulation and are not defined in common usage, so the DOE convened the Markers Panel (Trauth et al., 1993) to address this issue. Of the PICs components, the issue of markers is unique in that the development of the design considerations that will assure "success" requires the input from and interaction of a broad spectrum of disciplines. The Markers Panel developed concepts for the designs for physical markers and for the mechanisms of long-term communication with future generations. The charge to the Markers Panel was not constrained by cost or level-of-effort requirements. Thus, the development of a conceptual design for the PICs components that are intended to be implemented by the DOE requires the consideration of what is "practicable." As a result, the DOE has maintained the design considerations of the Markers Panel recommendations while modifying the specific recommended designs in order to be "practicable."

"Public records and archives," on the other hand, have specific definitions and specific disciplines that direct their creation and maintenance. Functioning archives and records centers exist, and so DOE has based its design considerations on these institutions. In addition, the EPA, in 40 CFR Part 194, has indicated the materials that must be stored in the records centers and archives. This report combined with a consideration of how communication can fail have resulted in specific recommendations on details of document storage.

5.2 Permanent Markers

The marker system conceptual design was derived from the conceptual designs developed by the Marker Panel (Trauth et al., 1993), and is described in detail in "Passive Institutional Controls Conceptual Design Report" (DOE, 1996, Sections III through VIII, and XI). Figure 6-1 depicts the general layout and relative positions of the major components of the permanent marker system at the repository footprint. The most massive component is a large berm that surrounds the repository footprint. Buried within the berm are radar reflectors and large permanent magnets to permit future generations to find the berm should environmental effects cover the structure over the years. Sixteen large granite monuments outline the footprint perimeter. These monuments will include engraved warning messages in seven different languages. Two large rooms also are buried. One room will be buried within the southern segment of the berm (Figure 6-1), and the other room will be buried outside the berm at a location aligned with the room in the berm, the Information Center, and the decommissioned and decontaminated WIPP Hot Cell (located within the Support and Waste Handling Building in Figure 1-3). Each buried room has a more detailed message describing the WIPP site, the waste contents, and their danger. This detailed message will be engraved in granite and will be repeated within each room in seven languages. At the center of the footprint a readily accessible "Information Center" will be erected on the surface. The Information Center contains the same messages as the two buried rooms. Throughout the repository footprint, small markers engraved with a warning not to drill or dig will be buried randomly between 0.6 and 1.8 meters (2 and 6 feet) below the surface.

The conceptual model includes marking the 16-section Withdrawal with 32 granite monuments evenly spaced around the area perimeter (Figure 6-2). The design of these monuments will be similar to the monuments marking the repository footprint, although the message on these markers will primarily attempt to deter potentially disruptive inadvertent human intrusions within the Withdrawal but outside of the repository footprint.

5.2.1 Berm

5.2.1.1 <u>Conceptual Design</u>

The largest component of the PICs is a 10-meter-high (33-feet-high) berm with a 30-meter-wide (98-feet-wide) base tapering to a 4-meter-wide (13-feet-wide) top constructed just outside of the repository footprint (DOE, 1996, Section VIII). The berm is to be made up of a salt core from repository tailings, a layer of crushed caliche, a layer of riprap, and a final layer of mixed riprap and soil planted with vegetation native to the area. The total volume of the berm will be approximately 750,000 cubic meters (975,000 cubic yards). Within the berm will be buried

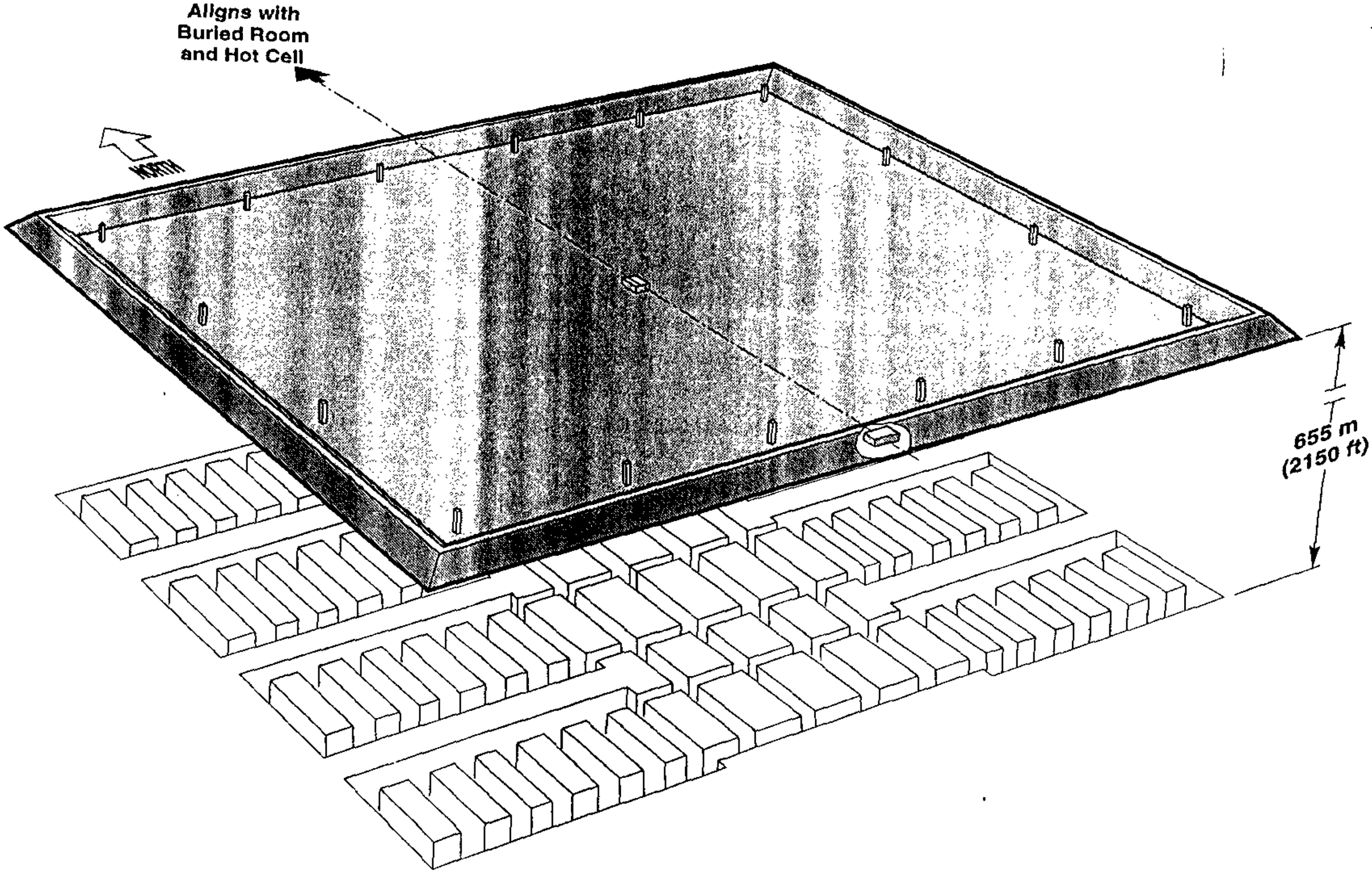

Figure 5-1. **General layout of major components of the permanent-marker system at the repository footprint.**

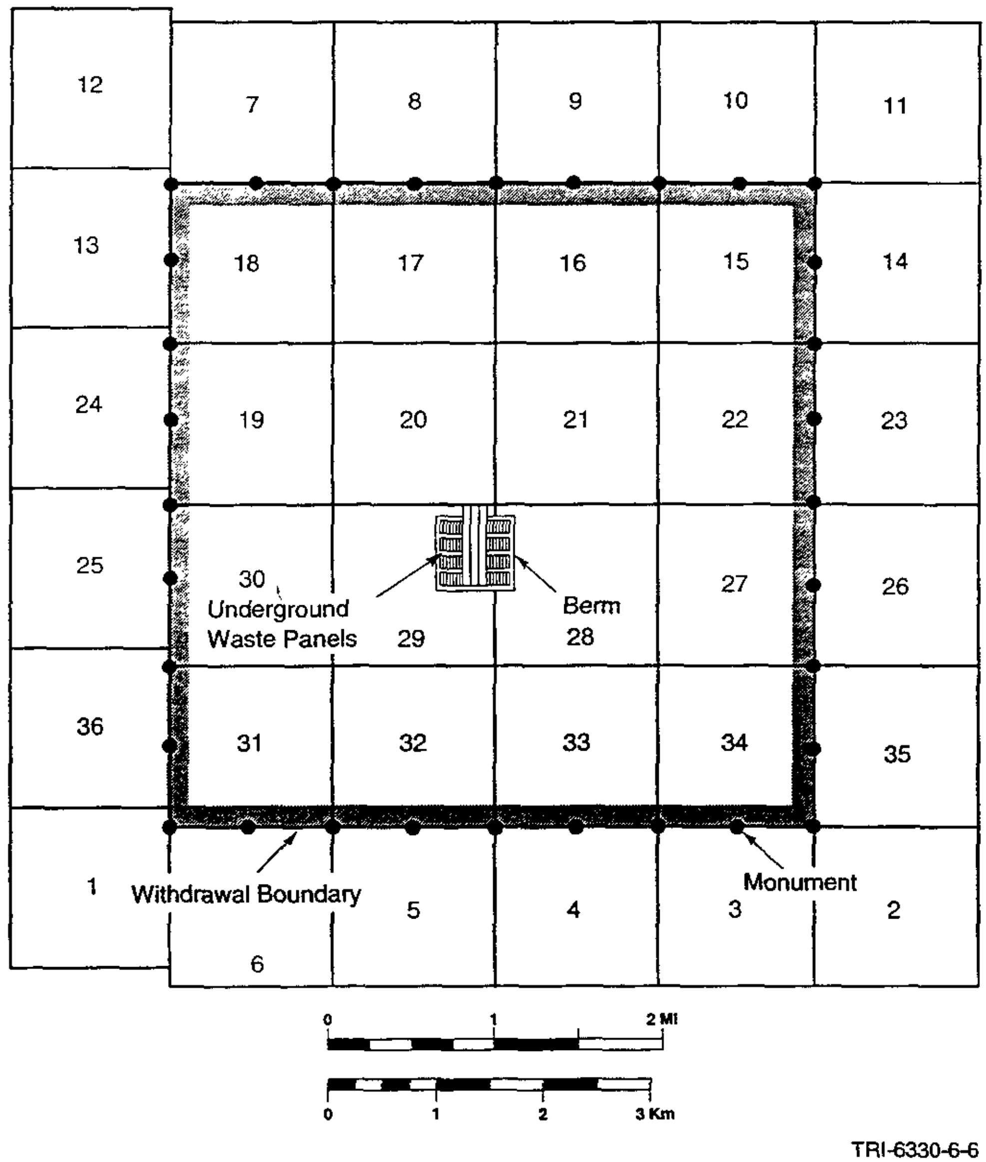

Figure 5-2. Proposed distribution of the permanent markers at the withdrawal boundary (modification of DOE, 1989).

concrete-encased steel radar reflectors and large permanent magnets. These devices will provide the capability for future generations to locate the berm with remote-sensing techniques.

5.2.1.2 Historical Analogue: Stonehenge

One of the most famous structures that has endured for thousands of years is Stonehenge. Located on the English plain about 32 kilometers (20 miles) south of Marlborough Downs, construction of Stonehenge began about 2700 to 2500 B.C. and concluded about 2100 to 1900 B.C. (Kaplan, 1982).

That earthworks can survive for thousands of years is demonstrated by the two concentric banks (i.e., earthen mounds surrounding the circular configuration of the stone structures) present at Stonehenge. The first building phase at Stonehenge began circa 2700 to 2500 B.C. and included the construction of the banks (Kaplan, 1982). The banks are made of chalk (a soft limestone) and the outer bank is 2.4 meters (8 feet) wide and 0.6 to 0.9 meters (2 to 3 feet) high with a diameter of approximately 115 meters (380 feet). The inner bank was originally 6 meters (20 feet) wide and 1.8 meters (6 feet) high with a diameter of approximately 98 meters (320 feet). Due to erosion, the bank is now approximately 0.3 meters (1 foot) high (Hawkins, 1973). A ditch 3 to 6 meters (10 to 20 feet) wide and 1.2 to 2.1 meters (4 to 7 feet) deep lies between the banks (Kaplan, 1982). The ditch probably served as the source of material for the banks. The banks are an example of an earthworks aged 4,500 to 4,700 years old.

5.2.1.3 Historical Analogue: Serpent Mound

The Serpent Mound in Ohio is not as old as Stonehenge. However, it is generally accepted that it was built by the Adena Indians who lived in the area from 1000 B.C. to 700 A.D. (Kaplan, 1982). The Serpent was formed by blocking out the pattern with stones and clay. A 0.3-meter (1-foot) layer of clay was then laid over the stones and another 0.7-meter (2-foot) layer of dark soil on top of the clay. The Serpent length is 383 meters (1,254 feet) long, an average width of 6 meters (20 feet) wide and 1.2 meters (4 feet) high. The mound was restored to its present contours by Putnam in 1886 (Kaplan, 1982).

5.2.1.4 WIPP Relevance: Stonehenge and Serpent Mound

Both the Stonehenge and Serpent Mound earthworks are ancient structures built of on-site or near-site materials in climates more severe with respect to erosion of earthen structures than the climate found in southeastern New Mexico. The current remains of the banks and the mound do not contain any design features explicitly intended for the long-term preservation of the structures. Both structures originally had cross sections substantially smaller than that of the planned berm. The maintenance of a significant portion of the original cross-sectional area is what allows the berms to be identified as human construction (Level I message).

With the larger cross-sectional area of the berm compared to the historical analogues and the incorporation of a layered design to minimize erosion, and considering the age of ancient mounds, the DOE asserts that the berm will endure as a Level I message for at least 5,000 years, and has a high probability of lasting beyond the period of regulatory concern.

5.2.1.5 Potential Failure Mechanisms and Design Solutions

Erosion. *(1) Materials selection—soil to support plants to stabilize surface against water or wind erosion; riprap to drain away water and as safety factor against wind erosion; caliche as safety factor to keep water away from salt core. (2) Size—so large so as to take a long time to obliterate; such a large volume of material so that even if the berm were to lose its shape, material would remain in the area as a Level I message.*

Buried by migrating dunes. *(1) Height of the berm—higher than the height of surrounding existing dunes. (2) Design—even if portions were covered, the berm has such a large lineal design that it all could not be covered.*

Deliberate dismantling and /or removal. *Size—large effort required to completely dismantle and completely remove. Even a decision to mine the salt or recover the magnets or reflectors would still result in a large amount of material at the site, at least a portion of which is not native to the immediate area.*

5.2.2 Monuments

5.2.2.1 Conceptual Design

Sixteen monuments will be evenly spaced around the perimeter of the repository footprint (inside the boundary of the berm). Each of these monuments will extend 7.6 meters (25 feet) above the surface (DOE, 1996, Section V). Each monument will comprise two granite stones. The upper stone will weigh 36.4 metric tons (40 tons) and will be placed over the base tendon weighing 59.1 metric tons (65 tons). Pristine granite blocks will be used in the construction and surface preparation will include polishing to shed water rather than containing small pits places for water retention. Each stone will be engraved with Level II and Level III messages. Thirty-two monuments similar to the footprint monuments will outline the Withdrawal and convey the message that the entire area enclosed by the monument should not be disturbed. The monuments will be shipped by rail to the WIPP.

5.2.2.2 Historical Analogue: Stonehenge

Durability. Initial construction of Stonehenge included the placement of the 32 metric-ton (35 ton) "Heel Stone" (sarsen rock) and concluded 400 to 800 years later with placement of 4 ton "Horseshoe" rocks (bluestone). The structure also includes a horseshoe of "Trilithons" 6.1 to 7.3 meters (20 to 24 feet) high made of sarsen stone and weighing 41 to 45.5 metric tons (45 to 50 tons) each. Three of the original five trilithons are intact. The other two lack a lintel and one is upright. Eighteen monoliths and five lintels of a ring originally consisting of 30 monoliths with lintels of 23 metric tons (25 tons) each still exist today (Kaplan, 1982). Compared to the environment at the WIPP, the structure has endured the ravages of the much wetter environment of the British Isles for 4,000 years without losing the characteristics that define its configuration. The sarsen rock is silicified sandstone, which is a common rock type on the surface of the English chalk downs. Bluestone is a local term used in Great Britain for bluish rocks, most of which are dolomite, but with some rhyolite, sandstone, and consolidated volcanic ash. The bluestones occur together only in a small area (1.6 kilometers square [about one mile square]) in the Prescelly Mountains of Wales, some 322 kilometers (200 miles) from Stonehenge (Kaplan, 1982).

Since the construction of Stonehenge, the British Isles have been subject to numerous foreign invasions (e.g., Romans, the Jutes, the Angles, the Saxons, the Normans, the Danes, and the Norwegians) (Kinder and Hilgemann). There were also numerous episodes of internal strife (e.g., lines of successions, the War of the Roses) (Kinder and Hilgemann) that introduced political turmoil to the land.

After nearly 4000 years of weathering impacts and being subject to potential vandalism, engravings of two axes and a sword can be seen on one of the uprights at Stonehenge, as photographed by Mohen (1989). Thus, engravings can remain visible for thousands of years.

Communication. Stonehenge was no doubt useful to the society(ies) that used this structure in antiquity. Construction by humans is obvious (Level I message). Indirect evidence from excavations within and beyond the site's footprint conveys a fragmentary Level III message (i.e., who built the monument, when, what for and why [in part, for astronomical observation]) (Mohen, 1990). No evidence exists of an attempt by the creators of Stonehenge to communicate the structure's usage across the centuries to future generations living in societies different than the creators' society.

5.2.2.3 WIPP Relevance: Stonehenge

The people who built Stonehenge selected specific rock types based on hardness (e.g., they selected bluestone rather than the much softer chalk). The blocks selected were at or near the surface, which suggests that the blocks had experienced some weathering prior to quarrying. For the WIPP monuments, pristine granite will be used. The weathering and erosion characteristics of this granite are superior to the rock types (silicified sandstone and dolomite) employed in the construction of Stonehenge. The WIPP monuments will be located in a drier environment than are the Stonehenge monuments, providing an environment more conducive to long-term durability. Weathering is the physical disintegration and chemical decomposition of rock by such processes as hydration of minerals, dissolution of minerals, chemical alteration of minerals, abrasion of minerals (e.g., by blowing sand), and physical breakup of minerals (e.g., freeze/thaw). Physical removal of the altered material generally is considered to be part of erosion and not part of weathering. In the case of the monuments to be emplaced at the WIPP, the exposure to rain and snow will lead to the hydration of some minerals in the granite (i.e., the feldspar will eventually weather to clay) and the weathering products will be removed by rainwater and/or wind. Some mechanical abrasion by wind-blown sand is likely to occur, although the abrasion typically occurs close to the land surface and will be limited by the protection offered by the berm and/or local vegetation. Any cracks that develop in the rock or between mineral crystals will tend to be enlarged by freezing and thawing when the rock is wet. Dissolution is not a process to consider for the silicate minerals of granite.

The durability of the Stonehenge monument system both in terms of natural deterioration and survival through numerous episodes of social turmoil provides evidence that a system of monuments can endure for thousands of years. Based on the WIPP design of a set of multiple monuments, the DOE asserts that some of the WIPP monuments will remain to define an area for at least 4,000 years, with a high probability of lasting beyond the regulatory period. Even fallen monuments, as has occurred to some monoliths at Stonehenge, can contribute to defining the perimeter of the repository footprint. Based on the usage of rocks of greater durability than those used at Stonehenge and the survival of Stonehenge engravings on an exposed surface, individual WIPP monuments and their engraved warnings on all four sides will survive for at least 4,000 years, with a high probability of lasting beyond the regulatory period.

The historical analogues listed in a later section for the Information Center provide further support for a reasonable expectation that the WIPP monuments will last for thousands of years.

5.2.2.4 Historical Analogue: Rock of Behistun

At the foot of the Zagros Mountains in the Kermanshah region of Iran, over 2,500 years ago the Persian King, Darius I, inscribed a memorial commemorating events that took place from about the autumn of 522 to the spring of 520 B.C. in his victory over a group of rebels and his ascension to power. An enormous bas-relief was carved more than 61 meters (200 feet) above an ancient road from Hamadan to Babylon into the sheer face of a 610-meter (2000-foot) high mountain proclaiming the might of Darius to all who pass by (Frimmer, 1969; Encyclopedia Britannica, 1994). Darius chose this location for its prominence. The message was inscribed for the purpose of reaching generations to come and includes a sculptured scene with 14 columns of writing at its sides and beneath it. The writing, using cuneiform script, is in three languages that today are known to be Old Persian, Elamite, and Babylonian. The memorial is 45.7 meters (150 feet) wide and 30.5 meters (100 feet) long (Frimmer, 1969). This memorial has withstood the rigors of time and weather in an exposed location so that its inscriptions can still be read today.

As is the case with the Egyptian pyramids, the sculpture has endured longer than the common use of the languages its contains, but the essence of its message remains interpretable by modern day scholars. It is an example of an authority creating a message for future generations to learn of the deeds of an earlier generation.

5.2.2.5 WIPP Relevance: Rock of Behistun

The Rock of Behistun is another example of exposed engravings that have endured for thousands of years. The purpose of the WIPP Permanent Markers is to inform future generations of the existence of the WIPP and the risk of intruding into the Withdrawal. As does the Rock of Behistun, the monuments will provide this information in several languages. The information medium for the WIPP monuments is granite into which the text is engraved. Based on the durability of the rock used and the depth of the inscriptions, there is a reasonable expectation that the WIPP monuments will perform as well as the ancient inscriptions. This reasonable expectation provides further support for the DOE's previous assertion that monuments and their inscriptions will survive for at least 4,000 years, with a high probability of lasting beyond the regulatory period.

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The multiple languages repeating the message on the Rock of Behistun are an analogue for the design concept of multiple languages on the WIPP monuments to communicate with a broad spectrum of cultures.

5.2.2.6 Potential Failure Mechanisms and Design Solutions

Weathering (chemical alteration of rock structure). *(1) Material selection—granite is the most durable of rocks routinely used for building construction. Granite will be used that has not experienced weathering. (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Dry climate at the WIPP (limited water available for ice wedging in freeze and thaw cycles).*

Erosion (physical removal of material). *(1) Material selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Message location—messages will not be directly at ground level because that is where erosion from blowing sand would be the most destructive. (4) Protection offered by the berm—the presence of the berm will reduce wind speeds within the berm, especially as the berm is higher than the monuments, and thus reduce possible wind erosion.*

Buried by migrating dunes. *(1) Height—monument height will be higher than existing dunes. (2) Multiple monuments—some individual monuments can be removed and the component can still communicate effectively. (3) Distribution of monuments over a wide area—dunes migrating in one area will leave other monuments untouched. (4) Protection offered by the berm (only for those monuments located within the berm)—because the berm is so high, with an original height of 10 meters (33 feet), it will reduce the amount of sand that could be carried up over the berm and into the area of the repository footprint. The presence of the berm will reduce wind speeds within the berm, and reduce the possibility that the material within the berm will form huge dunes.*

Removal intact (museum). *(1) Multiple monuments—some individual monuments can be removed and the component can still communicate effectively. (2) Size and weight—difficult to transport. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission. (4) Exhibition in museums provides wider distribution of information; encourages interpretation and study.*

Removal for recycling. *(1) Multiple monuments—some individual monuments can be removed and the component can still communicate effectively. (2) Size and weight—difficult to break up. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission*

Defacement (including gouges from target practice, being knocked over, and destruction of the messages). *(1) Materials selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering. (2) Multiple monuments—some individual monuments can be removed and the component can still* *communicate effectively. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission. (4) Engraved messages—messages will still be readable under paint.*

5.2.3 Information Center

5.2.3.1 Conceptual Design

An Information Center will be erected at the center of the repository footprint (DOE, 1996, Section VII). This Information Center will have internal walls but no roof. The overall dimensions of the Information Center are 12.2 meters by 9.8 meters by 3.0 meters (40 feet by 32 feet by 10 feet). These dimensions exclude 1.5 meters (5 feet) of each wall buried in the caliche. Complex information (Level IV) will be contained within the Information Center, and includes a highly detailed written record of location, design, and hazards of the WIPP and in addition to text, includes tables, figures, diagrams, and maps. The Level IV text information contained on the engraved granite walls will be provided in seven languages.

5.2.3.2 Historical Analogue: Australian Rock Art

The EPA (1996a, p. 12-14) discusses ancient Australian rock art that includes paintings, engravings, and peckings located on protected (but not in enclosed tombs, etc.) surfaces. This rock art is estimated to be approximately 25,000 years old and possibly 35,000 years old. The location of the rock art in a desert environment means it has endured the onslaught of wind-borne sand, and wide temperature fluctuations, although weathering was not a problem.

5.2.3.3 WIPP Relevance: Australian Rock Art

While the relatively fragile media of Australian painted and pecked rock art has endured for thousands of years, the messages in the WIPP information center will be engraved for maximum durability. The location of messages on the inside of the granite walls and on the exterior granite walls within the protection of the berm will protect the engravings from some of the wind-borne erosion. The DOE asserts that performance of the Information Center will be at least as good as the endurance of Australian rock art and will be recognizable for the entire regulatory period.

5.2.3.4 Historical Analogue: The Acropolis

The Acropolis, a world-famous site of antiquity, is an elevated region overlooking Athens, Greece. This location and position have attracted human habitation since approximately 5000 B.C. During the Mycenian period (c. 1400-1200 B.C.), a massive fortification wall was built, part of which can still be seen today near the Propylia. This wall and an altar seem to have survived intact until the Persian sack of Athens in 480 B.C. Pericles was the prime mover in the decision to rebuild the Acropolis on a monumental scale after peace was made with Persia. The following monuments exist today within the Acropolis:

- Beule Gate. The first ceremonial entrance to the Acropolis is the Beule Gate. This monument was built from limestone blocks taken from an earlier monument that dates from approximately 310 B.C. An inscription on the monument states that the structure was built in about A.D. 280 and was paid for by F. Septimus Marcellinus (Kaplan, 1982).

- Agrippa Monument. The monument stands on a natural terrace between the Beule Gate and the Propylia. The slab for the statue stands 8.8-meters (29-feet) high and is made of marble. The slab originally bore a four-horse chariot dedicated to celebrate a chariot victory by the city of Pergamon in the Panathenaic Games in about 178 B.C. Inscriptions on the slab tell us that the latest statue was raised to Marcus Agrippa in 27 B.C. From writings of Plutarch and Dio Cassius, we know that the slab once bore statues of Anthony and Cleopatra, but that these statues blew down in 31 B.C. (Kaplan, 1982).

- Propylaia. This is the classical gateway to the Acropolis. It is a part of the overall monumental rebuilding of the Acropolis undertaken by Pericles after the Persian Wars. Construction was begun in 437 B.C. with work halted in 432 B.C. because of the start of the Peloponnesian War. Work on this structure was never resumed. The gate is constructed of Pentelic Marble (Kaplan, 1982).

- Temple of Athena Nike. This structure was constructed during the period of 427 to 424 B.C. to celebrate peace with Persia. The major construction material was marble. A frieze, sculpted in high relief, ran around the exterior of the building. Four of the 14 slabs originally in the frieze are now in the British Museum (Kaplan, 1982).

- Erechtheion. This structure is a multiple-level building meant to house several cults, including those of Athena, Poseidon, and the founding rulers of Athens. Construction began in 421 B.C. and was completed in 409 B.C. The building was part of Pericles' plan for the Acropolis. This building is also constructed of Pentelic marble. In one part of the building known as the Porch of Maidens, six statues of young maidens support the roof. One of these statues has been removed to the British Museum (Kaplan, 1982).

- The Parthenon. This temple occupies the highest part of the Acropolis. It was built in the period from 447 to 438 B.C. as the cardinal feature of Pericles' plan. The best and most celebrated sculptors in Athens were engaged in its construction. Forty-six columns, each 10.5-meter (34.5-feet) high, ring the building. A frieze made up of alternating sculptures and grooved panels also originally surrounded this structure. Of the original 92 sculptures/panels, 15 are in the British Museum, one is in the Louvre, and 41 remain in place. In A.D. 1687 while the Turks were using the building as a powder magazine, a direct hit by a mortar caused a major explosion blowing the temple into two parts. The explosion destroyed 35 of the frieze panels (Kaplan, 1982).

Durability. Part of the massive fortification wall built approximately 1400 to 1200 B.C. can still be seen today. The major construction materials for all of the Acropolis' structures are marble and limestone. The metal features of the structures have been removed over the ages. However, the stone structures have endured the weather and the ravages of war, and although damaged, much of their original materials of construction and their overall configuration remain. As noted above, most of the structures in existence today date from the fifth century B.C., more than 2400 years ago.

Communication. Much is known about the Acropolis from ancient texts that have also passed through the ages. The degree of detail known about the Acropolis demonstrates that written communication can convey an extensive amount of knowledge across many centuries. For example, it is known that Pericles was the prime mover in the decision to rebuild the Acropolis on a monumental scale after peace was made with Persia (Kaplan, 1982). In several cases the architects and sculptors who worked on the project are known. Records indicate that money was raised from the sale of old building material, from grants by the Treasuries of Athena and Hephaistos, and from the Delian League in order to beautify the Acropolis. Annual building accounts for the Parthenon and Propylaia that were publicly displayed on the Acropolis still exist (Kaplan, 1982). Information documenting much of the history of the Acropolis has survived more than 2,400 years in a region of the world that has experienced much conflict and occupation by armed foreigners. An important point to note is that in more recent history portions of the Acropolis have been removed to museums elsewhere in the world. Because the site contains a substantial amount of material, sufficient information remains at the site to convey the configuration of the structures and enough records have survived to convey their meaning. In addition, placing portions of the Acropolis' structures in foreign museums has increased the exposure to many people outside of Greece to the existence and meaning of the Acropolis.

5.2.3.5 WIPP Relevance: Acropolis

The major materials found in the Acropolis are limestone and marble (Kaplan, 1982). Calcite ($CaCO_3$) is the predominant mineral of these rock types. As a result, both limestone and marble have relatively low resistance to abrasion, and both rock types have a relatively high solubility when exposed to acidic conditions. Based on historical records, the main threats to the buildings of the Acropolis have been their accidental (e.g., war) and deliberate (e.g., recycling of building stone) destruction. In the past 50 years, a significant amount of damage has been done to the Acropolis' structures because of the atmospheric pollution and acid rain that have accompanied the industrialization of Greece (Kaplan, 1982). The use of pristine granite for the major WIPP structures will provide an increased resistance to weathering and the adverse affects of acid rain over the marble and limestone used at the Acropolis. In addition, the location of the WIPP site will provide a lower acid-rain risk than many areas of the world because of insufficient water in this region to support significant industrialization and urbanization. Minimizing heavy industrialization and urbanization of the area also reduces the risk of significant levels of atmospheric pollution developing from vehicle exhaust and industry.

The PICs marker system includes redundancy of monuments and markers and could accommodate removal of some of the markers without destroying the definition of the extent of the site, the purpose, and the dangers associated with intrusion into the repository. Upon comparison of the Acropolis' lower durability structural materials to WIPP markers and the history of conflicts in the Mediterranean area that did not destroy either the physical artifacts or their purpose and meaning for more than 2,400 years, the conceptual design of the WIPP marker system using granite provides a credible argument for confidence in the marker system's ability to survive many centuries and convey the intended warnings. With the monuments of the Acropolis having survived for more than 2,400 years, survival of the granitic WIPP monuments and rooms well in excess of the 2,400 years is a reasonable extrapolation.

Using the more durable granite, rather than limestone or marble, combined with the less damaging environment, the WIPP Information Center will have higher durability than the building of the Acropolis. The DOE asserts that the building of the WIPP Information Center will survive with its engravings legible for at least 2,400 years, with a high probability of enduring for the entire regulatory period.

5.2.3.6 Potential Failure Mechanisms and Design Solutions

Weathering (chemical alteration of rock structure). *(1) Material selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering. (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Dry climate at the WIPP (limited water available for ice wedging in freeze and thaw cycles).*

Erosion (physical removal of material). *(1) Material selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering. (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Message location—messages will be located on the walls inside the information center to reduce the impact of blowing sand. (4) Protection offered by the berm—the presence of the berm will reduce wind speeds within the berm. Lower wind speeds within the berm, especially for the Information Center that is well protected by the berm by its height of 3 meters (10 feet), will reduce possible wind erosion.*

Buried by migrating dunes or the impact of vegetation. *Protection offered by the berm—because the berm is so high, with an original height of 10 meters (33 feet), it will reduce the amount of sand that could be carried up over the berm and into the area of the repository footprint, and be available to form dunes. The presence of the berm will reduce wind speeds within the berm, and reduce the possibility of the material within the berm from forming huge dunes.*

Removal intact (museum). *(1) Interior walls of the Information Center contain two layers of messages—one entire layer can be removed and the component can still communicate effectively. (2) Size and weight—message panels are large and difficult to transport. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission. (4) Exhibition in museums provides wider distribution of information; encourages interpretation and study.*

Removal for recycling. *(1) Interior walls of the information center contain two layers of messages—one entire layer can be removed and the component can still communicate effectively. (2) Size and weight—message panels are large and the granite is difficult to break up. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission.*

Defacement (gouges from target practice, walls knocked down, and destruction of the messages). *(1) Material selection—granite is the most durable of rocks routinely used for construction and thus gouging with hand tools is difficult. Fresh granite will be used that has not experienced weathering. (2) Messages located on interior walls of the Information Center—perpetrator* *would be harmed from ricocheting gunfire within the information center. (3) Interior walls of the information center contain two layers of messages—one entire layer can be defaced and removed and the component can still communicate effectively. (4) Engraved messages—messages will still be readable under paint.*

5.2.4 Buried Storage Rooms

5.2.4.1 Conceptual Design

One granite storage room with an overall dimension of approximately 11.9 meters long by 6.7 meters wide by 4.9 meters high (39 feet long by 22 feet wide by 16 feet high) will be buried within the berm that surrounds the repository footprint (DOE, 1996, Section VI). A second room with the same dimensions will be buried in the Withdrawal outside the footprint approximately half way between the berm and the Hot Cell. Within each room, message texts and diagrams will be engraved on both sides of the interior walls and on the interior of the external walls. To provide redundancy, additional granite slabs engraved with the message text and the diagrams will be held in place against the interior walls. The granite slabs making up an individual room and the internal walls will have a combined weight of approximately 545 metric tons (600 tons). The existence of the storage rooms will be documented in the records located in the archives. The information contained in the buried storage rooms is the same as in the information center.

5.2.4.2 Historical Analogue: Newgrange

Newgrange, located in County Meath, Ireland, is an ancient passage grave, even older than the Egyptian pyramids. This passage grave was constructed by Stone Age farmers in approximately 3150 B.C. When constructed, the grave was an unmortared stone structure approximately 85 meters (280 feet) in diameter, with a facing of white quartz. The internal structure consists of a single passage into the center of the grave, opening up into a central chamber 5 meters (17 feet) long. Located off of this central chamber are three recesses. Far from being simply a mound of stones, the grave was carefully designed, as described by Fagan (1994):

> "The ceiling of the passage is six feet high and made of large slabs of overlapping boulders that form a corbel vault. The roof in the central chamber is twenty feet high and is made of boulders tightly packed with clay and sand. O'Kelly [the individual who excavated Newgrange between 1962 and 1975] found cleverly placed grooves pecked into the boulders designed to carry rainwater away from the apex of the chamber, effectively keeping it dry for 5,000 years." (Fagan, 1994, pp. 16-17)

Engraving on the internal walls include spirals and zigzag patterns. These engravings are distinct and show no signs of weathering, making them clearly discernible today.

5.2.4.3 WIPP Rélevance: Newgrange

The existence of Newgrange indicates that stone structures can last for thousands of years, providing protection for openings within the structures and the engraved messages. Use of corbel construction, while stable in the case of newgrange, can foil resulting in collapse of the roof, as in the case of one passge in the passage grave at Knowth, which is near Newgrange (Fagan, 1994). To avoid potential structural instabilities, the buried storage rooms designed for the WIPP will consist of slabs of pristine granite specifically designed to maximize the structural integrity of the rooms. Consistent with the Newgrange analogue, the rooms are expected to survive for at least 5,000 years, with a high probability of lasting beyond the regulatory period. The engravings will be protected from weathering for this same time period. When and if the buried storage rooms are exposed by excavation, their durability will be that of the Information Center planned for the center of the repository footprint.

5.2.4.4 Historical Analogue: The Egyptian Pyramids

The Pyramids of Egypt represent examples of the ability of stone structures erected by human beings to successfully function as monuments for thousands of years. The three great pyramids at Giza were built during the Fourth Dynasty of Egypt approximately 2600 to 2500 B.C. (Kaplan, 1982). These pyramids were burial tombs for the pharaohs who had them built. The messages conveyed by these structures and their associated inscriptions are Levels I, II, III, and IV.

Durability. The core of the Khufu (Cheops in the Greek historical text) pyramid, which is the first and largest of the Giza pyramids, consists of limestone blocks from a local quarry. The basic construction materials of the other two pyramids at Giza were quarried from the same location. The blocks vary in weight from about 2.3 to 13.6 metric tons (2.5 tons to 15 tons). Within Khufu's pyramid, the final chamber is lined with granite slabs. The roof slabs for this chamber are estimated to weigh 45.5 metric tons (50 tons) each. The name Khufu appears in the quarry marks on some of these stones (Kaplan, 1982). The stone used for the pyramids is the best and hardest stone from the quarry.

If the funerary nature of these structures was ever in doubt, any alternate hypotheses would be disproved by the Pyramid texts. These texts are inscribed on the walls of the burial chamber in the pyramid of Onis, who, having died about 2350 B.C., was the last pharaoh of the Fifth Dynasty (Kaplan, 1982) and in all other remaining pyramids of the Old Kingdom. The texts contain chants and incantations to insure the future happiness of the deceased pharaoh. Although the pyramids were looted during times of central-government chaos, the inscriptions remained.

Information about the Egyptian Pyramids was recorded by several historians. These include Herodotus (5th century B.C. Greek historian), Diodorus Siculus (1st century B.C. Roman historian), and Abd el Latif (12th century A.D. Arab historian). Siculus was in Egypt from 60 to 57 B.C. Much of what he reported echoes Herodotus' reports about who built the Pyramids. In addition, Siculus noted that ramps were used to construct the pyramids. The remains of such a ramp occur at the Unfinished Pyramid of Sekhment (approximately 2650 B.C.) (Kaplan, 1982). Abd el Latif (born A.D. 1179) mentions numerous inscriptions that covered the casing of the Great Pyramid. These inscriptions were lost when the casing stones were quarried away during and after the 13th century. The inscriptions had endured for almost 4,000 years before being removed (2500 B.C. to A.D. 1200). What is significant is that these inscriptions had not been obliterated by the blowing sands and erosion that had damaged the Sphinx (Kaplan, 1982). The fact that historical information recorded about a certain site by several individuals at several points in time is known today bears witness to the ability for information to remain accessible for many centuries.

The records of the history of the pyramids conveyed through Greek, Roman, and Arabic historians is demonstrative of the ability of written records to endure across cultures and centuries. A significant consideration is the fact that during the history of the pyramids, chaos reigned repeatedly in the region of the pyramids and centralized government control was lost and regained several times. Yet, throughout this period, both the structures and their purpose were preserved.

5.2.4.5 WIPP Relevance: Egyptian Pyramids

Engraving messages on the granite walls in the buried rooms can be reasonably assumed to preserve the information for many thousands of years. The granite in the rooms within the pyramid is harder than the limestone used to construct the rest of the pyramid. The Khufu markings on 45.5 metric-ton (50-ton) granite slabs buried within the pyramid have remained intact and communicated their message over a period of more than 4,500 years. As long as the WIPP buried rooms remain buried, they will be available for at least 4,500 years, with a high probability of lasting beyond the regulatory period. When and if such rooms are exposed or excavated, the durability of the newly exposed rooms and their engravings will be similar to that of the Information Center (i.e., a durability of at least 2,400 years starting at the time of excavation).

5.2.4.6 Potential Failure Mechanisms and Design Solutions

The following discussion is for the room buried in the berm (at grade, but covered).

Weathering (chemical alteration of rock structure). *(1) Material selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering. (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Dry climate at the WIPP (limited water available for ice wedging in freeze and thaw cycles). (4) Message location—rooms will be buried within the berm and should thus be protected from infiltration of rainfall.*

Erosion (physical removal of material). *(1) Material selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering. (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Message location—messages will be located on the interior walls of the buried room to reduce the impact of blowing sand. (4) Protection offered by the berm—the presence of the berm will reduce wind speeds in the vicinity of the berm. Lower wind speeds around the berm, especially if only part of the buried room is uncovered, will reduce possible wind erosion.*

Buried by migrating dunes or the impact of vegetation. *If the buried room has been uncovered, then dunes or vegetation are not an immediate problem. Even if the room becomes covered over, it is then potentially available to another generation.*

Removal intact (museum). *(1) Interior walls of the buried rooms contain two layers of messages—one entire layer can be removed and the component can still communicate effectively. (2) Size and weight—message panels are large and difficult to transport. (3)*

Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission. (4) Exhibition in museums provides wider distribution of information; encourages interpretation and study.

Removal for recycling. *(1) Interior walls of the buried rooms contain two layers of messages—one entire layer can be removed and the component can still communicate effectively. (2) Size and weight—message panels are large and the granite is difficult to break up. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission.*

Defacement (target practice, walls knocked over, and destruction of the messages). *(1) Material selection—granite is the most durable of rocks routinely used for construction and thus gouging with hand tools is difficult. Fresh granite will be used that has not experienced weathering. (2) Messages located on interior walls of the buried rooms—perpetrator would be harmed from ricochetting gunfire within the buried rooms. (3) Interior walls of the buried rooms contain two layers of messages—one entire layer can be defaced and removed and the component can still communicate effectively. (4) Engraved messages—messages will still be readable under paint.*

The following discussion is for the room buried outside of the berm (below grade). The following are potential failure mechanisms if the room is excavated but left in place below grade.

Weathering (chemical alteration of rock structure). *(1) Material selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering. (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Dry climate at the WIPP (limited water available for ice wedging in freeze and thaw cycles). (4) Message location—messages will be located on the interior walls of the buried room to protect the message panels from rain*

Infill. *Material selection—Pristine granite is so durable that if the buried room becomes covered over, then it is available to another generation.*

Removal intact (museum). *(1) Interior walls of the buried rooms contain two layers of messages—one entire layer can be removed and the component can still communicate effectively. (2) Size and weight—message panels are large and difficult to transport. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission. (4) Exhibition in museums provides wider distribution of information; encourages interpretation and study.*

Removal for recycling. *(1) Interior walls of the information center contain two layers of messages—one entire layer can be removed and the component can still communicate effectively. (2) Size and weight—message panels are large and the granite is difficult to break up. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission.*

Defacement (target practice, walls knocked over, and destruction of the messages. *(1) Material selection—granite is the most durable of rocks routinely used for construction and thus gouging* *with hand tools is difficult. Fresh granite will be used that has not experienced weathering. (2) Messages located on interior walls of the buried rooms—perpetrator would be harmed from ricochetting gunfire within the buried rooms. (3) Interior walls of the buried rooms contain two layers of messages—one entire layer can be defaced and removed and the component can still communicate effectively. (4) Engraved messages—messages will still be readable under paint.*

If the room buried below grade is excavated, dismantled, and reconstructed on the surface, certain potential failure mechanisms become issues.

<u>Weathering (chemical alteration of rock structure)</u>. *(1) Material selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering. (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Dry climate at the WIPP (limited water available for ice wedging in freeze and thaw cycles). (4) Message location—messages will be located on the interior walls of the buried rooms to protect the message panels from rain.*

<u>Erosion (physical removal of material)</u>. *(1) Material selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering. (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Message location—messages located on the walls inside the buried rooms to reduce the impact of blowing sand. (4) Protection offered by the berm—the presence of the berm will reduce wind speeds within the berm. Lower wind speeds within the berm, especially for the buried rooms that are well protected by the berm by their height of 4.9 meters (16 feet), will reduce possible wind erosion.*

<u>Buried by migrating dunes or the impact of vegetation</u>. *Durability of materials—if the reconstructed buried room becomes covered over, then it is available to another generation.*

<u>Removal intact (museum)</u>. *(1) Interior walls of the buried rooms contain two layers of messages—one entire layer can be removed and the component can still communicate effectively. (2) Size and weight—message panels are large and difficult to transport. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission. (4) Exhibition in museums provides wider distribution of information; encourages interpretation and study.*

<u>Removal for recycling</u>. *(1) Interior walls of the buried rooms contain two layers of messages—one entire layer can be removed and the component can still communicate effectively. (2) Size and weight—message panels are large and the granite is difficult to break up. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission.*

<u>Defacement (target practice, walls knocked over, and destruction of the messages</u>. *(1) Material selection—granite is the most durable of rocks routinely used for construction and thus gouging with hand tools is difficult. Fresh granite will be used that has not experienced weathering. (2) Messages located on interior walls of the buried rooms—perpetrator would be harmed from ricochetting gunfire within the buried room. (3) Interior walls of the information center contain*

two layers of messages—one entire layer can be defaced and removed and the component can still communicate effectively. (4) Engraved messages—messages still readable under paint.

5.2.5 Small Buried Markers

5.2.5.1 Conceptual Design

Several thousand small warning markers will be buried 0.6 to 1.8 meters (2 to 6 feet) below the surface (DOE, 1996, Section V). A Level II message will be engraved on each marker. Each marker will have the message in one of seven languages. Warning markers will be placed throughout the repository footprint, within the berm, and in the shaft-sealing system. Individual warning markers will be made of one of three materials: granite, aluminum oxide, or fired clay. Spacing between warning markers will be random within a range of 4.6 to 12.2 meters (15 to 40 feet).

5.2.5.2 Historical Analogue: Code of Hammurabi

In 1901, a diorite stele was discovered in a tell in Iraq that contained 282 legal decisions of Hammurabi, who was the 6th ruler of the 1st (Amorite) dynasty of Babylon (c. 1792-1750 B.C.). The stele is now located at the Louvre in Paris. The legal decisions known as the Code of Hammurabi were case law including economic provisions, family law, criminal law, and civil law. The text was in cuneiform and in the Akkadian (Semitic) language. This is another example of communications enduring for over 3,700 years. Much of the Code of Hammurabi was used by following generations and civilizations (Encyclopedia Britannica, 1994).

5.2.5.3 WIPP Relevance: Code of Hammurabi

The WIPP buried markers are essentially modern stela. Similar to Hammurabi's diorite stele, the markers will be made of granite and other materials specifically selected for their durability when buried. The WIPP buried markers will be engraved with information warning against intrusion into the repository. The small buried markers are expected to survive burial and the inscriptions remain legible for 4,000 years, with a high probability of enduring for the entire regulatory period.

5.2.5.4 Historical Analogue: Mesopotamian Artifacts

As described in EPA, 1996a:

"Fired clay tablets containing written material in cuneiform script are commonly found in Mesopotamian tells, as are elaborately carved statuary and bas-relief panels portraying rulers, wars, rituals, and aspects of daily life." (EPA, 1996a, p. 12-10)

For example, rich burial gifts were excavated at Ur (Tell Magajir) dating from approximately 2500 B.C. Inscribed clay tablets have been recovered in the same region dating from as early as 3200 B.C. (Kinder and Hilgemann, 1974).

5.2.5.5 WIPP Relevance: Mesopotamian Artifacts

In addition to the granite markers, other buried markers are also to be fashioned using other durable materials for redundancy purposes, as suggested by Team A of the Markers Panel (Trauth et al., 1993). One of the other materials being considered for the buried markers is fired clay. Based on evidence found in the Mesopotamian tells, the DOE asserts that buried clay markers will last for 5,000 years, with a high probability of enduring for the entire regulatory period.

5.2.5.6 Potential Failure Mechanisms and Design Solutions

Weathering (chemical alteration of structure). *(1) Material selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering. (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Dry climate at the WIPP (limited water available for ice wedging in freeze and thaw cycles). (4) Message location—buried markers to be located 0.6 to 1.8 meters (2 to 6 feet) below the surface will reduce the amount of rainfall that infiltrates down to the markers.*

Excavated during a previous exploration and not there for future communication. *Aerial coverage afforded by the buried markers—surface preparation would have to be done in the exact same location for no markers to be found. Any larger area or slightly different location would mean that buried markers would be found.*

Removal intact (museum). *(1) Multiple markers—if a museum were to remove a few of the markers for a collection, there will still be many markers in place to correctly communicate. (2) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission. (3) Exhibition in museums provides wider distribution of information; encourages interpretation and study.*

Removal for recycling. *(1) Multiple markers—if a museum were to remove a few of the markers for a collection, there will still be many markers in place to correctly communicate. (2) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission. (3) random distribution and depths of markers precludes a cost-effective process for recovering the markers.*

5.3 Archives

5.3.1 Conceptual Design

Webster's Collegiate Dictionary (Merriam-Webster, 1991) defines archive as "a place in which public records or historical documents are preserved." This definition implies control of the environment, control of access to the records and documents, and control/selection of the storage medium. A significant part of the overall plan to provide PICs is the distribution of important information remote from the repository for preservation. The archived material will include information that is important to defining the location, design, content, and hazards associated with the WIPP (DOE, 1996, Section XIV). This information will be broader in scope and more extensive in volume than that available within the PICs at the repository-footprint location and will be widely distributed in a number of locations including some locations worldwide. The initial form of the information will be on archival-quality paper.

Specific documents that will be included in the archived information portfolio include:

1. The *Final Safety Analysis Report* (FSAR) (DOE, 1990a) and the addenda that describe the disposal phase of the WIPP.

2. The Final Environmental Impact Statement (DOE, 1980) for the WIPP and the Supplement(s) to the Environmental Impact Statement (DOE, 1989; DOE, 1990b.)

3. The No-Migration Variance Petition (DOE, 1995b) and the No-Migration Determination for Disposal.

4. The Resource Conservation and Recovery Act (RCRA) Permit (DOE, 1995a).

5. The Certification of Demonstration of Compliance with Title 40 CFR 191.

6. Environmental and ecological background data collected during the pre-operational phase of the WIPP and summaries of data collected during the disposal and decommissioning phases of the WIPP.

7. Records of the waste container contents and disposal locations within the WIPP repository.

8. Drawings defining the construction and configuration of the repository and shafts.

9. Drawings, procedures, and design report(s) describing how the waste was emplaced; how the rooms, drifts, and panels were closed; and how the shafts were backfilled and sealed.

10. Detailed maps describing the exact location of the repository.

11. Design information for the PICs.

In addition, a summary document will be developed that will provide, in a quickly accessible format, the information necessary to communicate the nature and hazards of the waste in the WIPP, in order to deter inadvertent human intrusion.

Locations for this information will include publicly funded organizations that may be more likely to expend the resources necessary to preserve the documents in well-controlled environments. However, the most likely strategy for long-term protection of the information is through widespread distribution. The information will be submitted to the following facilities/ organizations for archiving pending their agreement to receive these documents:

- National Archives and Records Services
- The State Archives of New Mexico and Texas

- The national archives of the world nations that possess nuclear weapons and/or operate nuclear power generating plants
- The archives of the United Nations
- The national archives of the world nations that possess natural gas and/or petroleum resources

5.3.2 Historical Analogue: Vatican Archives

The Vatican Archives (Pasztor and Hora, 1991) were established by Pope Paul V in 1612, almost 400 years ago. The oldest series of documents contained in the Secret Vatican Archives are handwritten copies of the official letters of the popes that form a continuous collection beginning with the papacy of Innocent III from 1198 to 1216, more than 750 years ago. These archives also contain documents dating back to the ninth century (Pasztor and Hora, 1991). The current holdings of the archives consist of some 48 kilometers (30 miles) of full shelves and 15,240 linear meters (50,000 linear feet) of administrative records. For more than 800 years the Vatican Archives and predecessor archives that were incorporated into the Vatican Archives have been receiving documents.

Papal documents are written on organic materials. In 1881, Pope Leo XIII began a restoration laboratory that is today the Vatican's School of Paleography. This laboratory has been supplemented with modern facilities for photographic reproduction. Despite restoration efforts, thousands of documents have turned purple because of a violet-colored fungus scientists have so far been unable to control (Pasztor and Hora, 1991). Several projects are reproducing portions of the Vatican Archives. Some archival documents have been microfilmed and are deposited in the Pius XII Library of St. Louis University. The Vatican Library now stores its most valuable documents in a steel and aluminum vault with a controlled environment and shelving covered with neutral polished aluminum. The covering resists parasites and water seepage.

5.3.3 WIPP Relevance: Vatican Archives

The relevance of the Vatican Archives is both in the durability of the materials and the long-term existence of an institution dedicated to maintaining information despite repeated periods of turmoil.

Various documents within the Vatican Archives have survived for 1,100 years, without the archives' manager being able to control temperature or humidity for most of this period. The materials used were those available at the time, not specially selected papers or inks. Paper with a high cloth content was the norm.

The Vatican Archives represents an institution created to maintain information that was important within a particular religious context. The survival of the archives is evidence that institutions can survive for long periods of time if the information is deemed to be important. The underlying human tendency for story telling, with increased worldwide literacy, is being transformed into a desire to maintain written records of our history. Thus, archives maintaining information of a historical importance can be expected to have a greater impetus for survival than in the past. The health issues associated with nuclear waste disposal will make the information important as long as cancer is still a disease that causes suffering and death and will contribute to the information being maintained within archives. In addition, the archives will contain data and information of economic importance toindustries and government agencies involved in natural resource exploration and exploitation. Economic importance also will contribute to maintenance of the archives.

The experience of the Vatican Archives provides lessons about what to do and what not to do for long-term maintenance of records. The Vatican, for much of its history, was in the midst of the surrounding political maneuverings, and control of the Vatican and possession of the archives was a strategic prize. For example, Napoleon annexed the Papal States in 1809 and ordered the archives moved to France. The transfer of the archives to France (1810-1811) and the eventual return to Rome (completed by 1817) resulted in the loss of almost one-third of the documents then in the archives; the loss occurred mainly during the period the archives were in France. To guard against such a situation for the WIPP information and to establish the importance of maintaining the WIPP information in the context of personnel safety, the information about the WIPP should be placed in a non-political context. Also for the Vatican records, single copies of documents meant that political turmoil with its attendant destruction could eliminate information. Thus, for the WIPP, multiple storage arenas must exist to guard against losing information.

The DOE will provide WIPP documentation to archives worldwide. The documents will be prepared on archival quality paper. Unlike the one-of-a-kind Vatican documents, many copies of the WIPP documents will exist, adding significantly to a reasonable expectation that catastrophes will not destroy all copies of the documents and that the information will survive for an extended period of time. This philosophy mitigates the risks involved from individual authorities causing the archival material to be moved over a period of hundreds or thousands of years. Multiple copies also provide society with the ability to reconstruct portions or all of a given archive of WIPP documentation should that particular information be lost or destroyed.

The Vatican Archives analogue, combined with improvement associated with lessons learned, would mean that an archive could be expected to endure and maintain records for at least 1,100 years, and have a high probability of enduring for thousands of years. WIPP information could be expected to endure as long as the original paper can survive (i.e., thousands of years).

5.3.4 Historical Analogue: Ancient Documents

Many thousands of ancient documents composed of organically based materials currently are stored in museums, monasteries, and archives around the world. The existence of these documents proves that writing materials other than engravings in stone or clay tablets can preserve information for thousands of years. The British Museum's Department of Antiquities has the world's largest collection of original papyrus documents from Egypt. Thousand of these papyrus documents are from the period of 2400 to 30 B.C. (Rodriguez, 1996a). The University of Michigan has the world's fifth or sixth largest collection of ancient documents. Most of these documents are on papyrus and parchment and are from about 400 B.C. to A.D. 800 (Rodriguez, 1996b). The Greek manuscripts of the Philotheou Monastery on Mt. Athos in Greece number in the hundreds. A catalogue of 125 of the manuscripts cover the period from the 9th century to the 19th century A.D. The oldest of these original documents are on parchment. For the documents printed on paper, the oldest document on Arabic paper dates from about A.D. 1292, and the oldest document on European paper dates from about A.D. 1315 (Allison, 1996).

Examples of paper enduring for thousands of years are confirmed by Hunter (1978). According to Hunter (1978), a number of original papers have been unearthed covering every century from its "original invention by Ts'ai Lun in China, A.D. 105, onward through the introduction of papermaking in the Occident and its eight hundred years of history in Europe." Illustrations of the oldest printed text in Japan dated from A.D. 770, fragments of paper from the Eastern Han period (A.D. 25 to 220), and a manuscript on paper found in ruins of the Great Wall of China dated from about A.D. 150 are included in Hunter (1978).

5.3.5 WIPP Relevance: Ancient Documents

The examples described above provide evidence of the preservation of documents for thousands of years. The fact that paper exists today that dates to near the time paper was invented supports the premise that society can preserve paper documents for thousands of years. As described above, archiving WIPP information on archival-quality paper in multiple archives worldwide is an unprecedented effort to save information for future generations.

The fact that manuscripts have survived for 1500 to 2000 years, from the time when paper was invented, and can still be read and interpreted by scholars lends credence to society's ability to preserve information and the media upon which that information is recorded. Based on the historical analogue of ancient documents, the DOE asserts that paper will last for 2,000 years and has a high probability of lasting 4,400 years (the duration of papyrus, another crganic material for records).

5.3.6 Potential Failure Mechanisms and Design Solutions

Decay of paper. (1) *Archival paper. (2) Carbon black ink. (3) Controlled environment—even small records centers control temperature. Not withstanding the desirability of controlling the environment to increase durability, temperature and humidity will be controlled for the comfort of the individuals working in an archive.*

Theft. (1) *No original signatures, seals or other items to make the physical record salable on the black market. (2) Multiple copies—records can be recreated; reduces sale value.*

Misfiling. (1) *Indexing system created and agreed upon before records are ever sent to a records center or an archive. (2) Distinctive (inexpensive) binding for the records.*

Catastrophes (including fire, flood, tornadoes, earthquakes). *Multiple copies—records can be recreated.*

Recycling. (1) *Concise summary—reduces the shelf space required for the information and discourages the entire collection from being discarded. (2) Cover contains language about long-term importance of the information contained in the record (safety).*

Archivist deciding that records are no longer important. (1) *Concise summary—reduces the shelf space required for the information and discourages the entire collection from being discarded. (2) Cover contains language about long-term importance of the information contained in the record (safety).*

Lost (including while consolidating collections, moving). *Multiple copies—records can be re-created.*

Deliberate destruction (other than governmental actions). *Multiple copies—records can be re-created.*

Warning understood but believed to be for prior generations or other intruders. *Cover contains language about long-term importance of the information contained in the records (safety issues).*

Warning not understood. *(1) Endurance of English (Assumptions 11-13). (2) Communication through means other than language (e.g., pictures, graphs, figures, and maps) (see assumptions).*

5.4 Records Centers

5.4.1 Conceptual Design

Records centers, for the purpose of making a distinction from archives, are locations that would generally permit freer access by members of the public and do not normally exercise the degree of environmental control and information-medium selection to be found in modern archives. These records centers will not receive the same quantity of information allocated to archives (DOE, 1996, Section XV). Information provided to these records centers will be focused on location, design, and hazards information. The DOE will provide a summary document with a distinctive and easily recognizable binding for each records center. The records centers will include various federal and state agencies and commercial mapping agencies to ensure that the WIPP location and drilling or mining restrictions are identified on widely distributed maps used by almost all public and private organizations. These federal and state agencies (or their successors) include:

- The U.S. Nuclear Regulatory Commission
- Bureau of Land Management
- U.S. Geological Survey
- Library of Congress
- Defense Mapping Agency
- International Boundary Commission
- Federal Highway Administration
- New Mexico State Highway Department Planning and Research Division, Cartography Section
- One-Call System of notification of underground utilities
- The local office of the Bureau of Land Management
- The local office of the Bureau of Reclamation
- The Albuquerque office of the Bureau of Indian Affairs

- The Federal Records Center serving New Mexico
- The local offices of the New Mexico Oil Conservation Division

To further the widespread distribution of WIPP information, materials will also be offered to a number of libraries including:

- The New Mexico and Texas State Libraries
- The state libraries of the remaining 48 states
- The City Libraries of population centers exceeding 15,000 within 150 miles of the WIPP site
- The 53 Federal Regional Depository Libraries
- The major universities of New Mexico and Texas

To ensure widespread distribution of location information of the WIPP site and the hazards associated with the emplaced waste, detailed maps and descriptions of the hazardous material will be sent to national and international professional societies of cartographers and geographers. Weitzburg (1982) suggests the following organizations and societies receive this location and hazards information:

- The American Congress on Surveying and Mapping
- The American Society of Cartographers
- The Commission for the Geological Map of the World
- The International Cartographic Association
- The American Geographical Society
- The Association of American Geographers
- The International Geographical Union
- The Society of Women Geographers
- The American Geological Institute
- The American Geophysical Union
- The American Society of Professional Geographers
- The National Geographic Society
- The Federal Aviation Administration
- Mining, Oil, and Gas Professional Organizations

These organizations and societies can be supplemented by contacting the American Historical Association, the National Institutes of Health, and the Centers for Disease Control for guidance in the distribution of documents. The actual distribution of the information will depend on agreements worked out between the DOE and these organizations and societies.

Many members of these various organizations are employed in secondary and college education providing an opportunity for this information to become more widely disseminated among students during their formal education. In addition, companies providing energy and resource-related data to commercial ventures active in the Delaware Basin will receive location and hazardous record information. Examples of such companies include

- Midland Map Company of Midland, Texas
- Petroleum Information Corporation of Midland, Texas
- Tobin Data Graphics of Austin, Texas
- Dwight's Energy Data of Denver, Colorado

5.4.2 Historical Analogue: German Archives

The German archives discussed here (Brachmann et al., 1991) consisted of state, city, and church archives of the pre-WW II era. These archives contained one-of-a kind records pertinent to the location of the archives. During the course of the war most of the archives were moved in part or in whole in order to protect them from Allied bombing. The failure modes were from direct war damage (e.g., bombing, fire, or water from putting fires out), or from transit (vehicles were direct targets, vehicles broke down and were pillaged by the local inhabitants), and from alternate storage options (wine cellars were relatively inaccessible but damp, thus promoting the deterioration of the paper, and salt mines provided a dry, bomb-proof environment, but this environment resulted in the corrosion of any metals associated with binding the books or storage containers).

Extraordinary measures may be taken by at least some segments of society to protect documents perceived to be of value to society (including such things as church records of births, deaths, baptisms, etc.). For example, numerous archivists were killed trying to save records. and common individuals recognized the importance of the archives:

> "Putting individual material in private locations was considered 'billeting'. The question of moral or materialistic motivation of the individuals providing their property for storage purposes could be of significance. However, a large part of the population esteemed not only German archival material but also foreign and even enemy 'cultural assets.' Appeals for the protection of cultural assets found support, despite the tremendous existential problems of the period." (Brachmann et al., 1991, pt. II, p. 41)

Pillaging of the archives by the local population was generally driven by desperation caused by the shortages of basic goods necessary for survival. Even the 'enemy' valued the intrinsic value of archives and records. For example, after the war, the allied forces sent special commandos into occupied territory to protect the general cultural and archival materials.

Despite the ravages of war, a surprising number of archives remained relatively intact. According to Brachmann et al. (1991):

> "A number of archives suffered varying degrees of damage during WW II. Some archives did not suffer losses or damages, others were totally destroyed. However, the large part of archival materials in Germany survived the war without appreciable damages." (Brachmann et al., 1991, pt. I, p. 10)

5.4.3 WIPP Relevance: German Archives

This experience indicates that even in a "total" war, areas away from strategic targets and areas of troop engagements can remain virtually untouched. During periods of crisis and upheaval, some buildings and documents will be lost, and no way exists to predict what will constitute a target at any particular time.

The lessons learned from the German archives are that numerous copies of the WIPP records should be produced, these records should be widely distributed (i.e., to assure that at least some of the records are not in strategic locations), and an effort should be made to impart a sense of value to the records so that future generations will make the necessary effort to preserve them.

The experience of the German archives and the great effort that went into preserving the records and the lessons learned indicate that even with significant political and social upheaval, records can and are likely to be maintained.

5.4.4 Potential Failure Mechanisms and Design Solutions

Decay of paper. (1) *Archival paper. (2) Carbon black ink. (3) Controlled environment—even small records centers control temperature. Not withstanding the desirability of controlling the environment to increase durability, temperature and humidity will be controlled for the comfort of the individuals working in an archive.*

Theft. (1) *No original signatures, seals or other items to make the physical record salable on the black market. (2) Multiple copies—records can be recreated; reduces sale value.*

Misfiling. (1) *Indexing system created and agreed upon before records are ever sent to a records center or an archive. (2) Distinctive (inexpensive) binding for the records.*

Catastrophes (including fire, flood, tornadoes, earthquakes). *Multiple copies—records can be re-created.*

Recycling. (1) *Concise summary—reduces the shelf space required for the information and discourages the entire collection from being discarded. (2) Cover contains language about long-term importance of the information contained in the record (safety).*

Archivist deciding that records are no longer important. (1) *Concise summary—reduces the shelf space required for the information and discourages the entire collection from being discarded. (2) Cover contains language about long-term importance of the information contained in the record (safety).*

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Deliberate destruction (other than governmental actions). *Multiple copies—records can be re-created.*

Warning understood but believed to be for prior generations or other intruders. *Cover contains language about long-term importance of the information contained in the records (safety issues).*

Warning not understood. *(1) Endurance of English (see assumptions). (2) Communication through means other than language (e.g., pictures, graphs, figures, and maps) (see assumptions).*

5.5 Government Land Ownership and Control

5.5.1 Conceptual Design

The U.S. Government controls the 16 sections that are included in the WIPP Withdrawal (Figure 1-2). Within this Withdrawal, all land-use leases are also retained by the federal government with the exception of two, 129.5-hectare (320-acre), oil and gas leases in Section 31. Section 31 is the southwestern most section of the 16 sections withdrawn under the LWA. The two leases permit oil and gas development below 1,829 meters (6,000 feet) from the surface. Section 31 does not include the area planned for repository use. Government control is a passive control providing for the transfer of information on the status of land ownership. It is not an active control, in so far as the information does not overtly prevent intrusion. It is expected that government control of this area will be retained for as long as a U.S. Government exists. With government ownership of the resource leases for the withdrawn sections, commercial resource exploration and development entities cannot drill or mine in and immediately around the repository without receiving permission. Any organization contemplating resource exploration and development within the Withdrawal would learn of the government control immediately upon initiating search of lease availability within the appropriate records center(s) pertaining to Eddy County New Mexico.

In accordance with the LWA, the 16 sections at the WIPP were " . . . withdrawn from all forms of entry, appropriation, and disposal under the public land laws, the material sale laws . . . and mining laws" [Public Law 102-579, 1992, Sect. 3(a)(1)]. The objective of the DOE with respect to mining and oil and gas production is to ensure that the development of resource leases does not affect the integrity of the disposal system. Accordingly, no surface or subsurface mining unrelated to the WIPP construction, or oil or gas production, including slant drilling from outside the boundaries of the Withdrawal are permitted at any time, including post-decommissioning, with the exception of the two existing oil and gas leases. These leases prohibit drilling within the first 1,829 meters (6,000 feet) of the surface within the Withdrawal (DOE, 1993). The LWA does permit the Secretary of Energy to permit grazing, hunting, and trapping within the Withdrawal.

This prohibition is in direct contradiction to the PA assumptions that drilling will take place at historic rates for the 10,000 years of regulatory concern.

5.5.2 Historical Analogue

The search for historical analogues for land restrictions at the WIPP suggests examples such as the Boston Commons and the plaza in Santa Fe. These locations are both examples of areas that have been owned by a government and under government control for long periods of time. Both locations are areas of controlled public usage (some activities are allowed and some activities are prohibited), despite changes in the particular government. Boston Commons was created when the land was a part of the thirteen colonies of Great Britain (Boston was founded in 1630), and the public land use continued once it was a part of the United States. The plaza of Santa Fe was created under Spanish rule (Santa Fe was founded in 1610), remained as such under Mexican rule (1821-1846), U.S. rule, a brief occupation by Confederate forces (1862), and once again U.S. rule (Jenkins and Schroeder, 1974). The only period of unknown status was the period during and after the Pueblo revolt (1680-1692) until the location was reestablished as being a part of Spanish lands. More contemporary examples of areas of land being set aside for the public use/good are New York City's Central Park, the Mall in Washington D.C., and Balboa Park in San Diego.

A different type of government land for public use is Yellowstone National Park, established in 1890 as the United States' first national park. Park management allows access by the public, but with restrictions on the activities that can take place within the Park (e.g., no new leases for resource development). At the time of its establishment, Yellowstone was a remote area, with limited access to communication or transportation. Yellowstone was established to benefit the nation as a whole by preservation of our natural assets.

5.5.3 WIPP Relevance

Within our national history, governments have established and controlled areas for the greater good of the society by restricting the activities taking place there.

Even though the Boston Commons and the Santa Fe plaza could be of major financial benefit were they to be sold for private development, governments have chosen to retain ownership and control rather than short-term financial gain. As long as significant public pressure is applied that the value of safety is greater than the financial value of land or mineral resources, the Withdrawal, and especially the repository footprint will be maintained.

Throughout its history, Yellowstone has been located in an area more remote than the area surrounding the WIPP. The WIPP is not situated in as remote a location as it appears—people travel to the City of Carlsbad by plane and by private vehicle, and the WIPP is only 42 kilometers (26 miles) from the City of Carlsbad. Significant traffic is generated by trucks collecting oil from tanks and by gas lines being monitored periodically. Increased population and the ease of travel and communication cast doubt on the WIPP/Carlsbad area becoming more remote in the future.

5.5.4 Potential Failure Mechanisms and Design Solutions

Government considering opening up the Withdrawal to resource exploration and exploitation. *Wide dissemination of information about the safety issues associated with maintaining the integrity of the disposal system—wide distribution of the information will make it available to more of the general populace so that there continues to be pressure not to open up the Withdrawal.*

5.6 Other PICs

Other PICs may be incorporated to trigger society's awareness of the WIPP location and cautions regarding the maintenance of its integrity. These "awareness triggers," which will be discussed in Chapter 7, include

- Incorporation of the WIPP's location on various maps and road atlases
- Description of the WIPP's location and content within the subject matter of encyclopedias and common reference material
- Identification of the WIPP as a geographical name in dictionaries
- Descriptions of the WIPP incorporated within the text of high-school and college-level history and science books
- Development of a home page for the WIPP on the Internet (the current home page address for WIPP information is **http://www.wipp.carlsbad.nm.us**)

Examples of specific areas being identified on maps can be found in various road atlases. Gousha (1993) designates specific sites such as the "Nevada Test Site" and "Nellis Air Force Range" in Nevada, the "Chocolate Mountain Gunnery Range" in southern California, and the "White Sands Missile Range" in New Mexico. Certain areas in western Nevada are designated by the generic warning "Danger Area."

5.7 Materials Issues

Granite is an igneous rock that crystallized at depth within the Earth's crust. As a result, the minerals that compose granite are not thermodynamically and chemically stable in geologic timeframes at the lower pressures and temperatures at the Earth's surface. However, for the time frames of interest, the thermodynamic instabilities of the minerals in granite are much less important than physical properties (e.g., mineral solubilities and rock porosities) of other rock types used in buildings and monuments (e.g., marble, limestone, and sandstone). Because the minerals in granite are less soluble than those in marble and limestone, and have a lower porosity than sandstone to resist water intrusion with freeze and thaw cycles, granite is more resistant to weathering than these other rock types.

Selection of stainless steel for use as the radar reflectors is based on a combination of cost and corrosion resistance. The reflectors would be constructed of sections about 1.3 cm thick and approximately 0.9 m on a side and welded to form a trihedral. Berry (1983) reviews earlier studies of various stainless steel alloys in soils. Type 316 stainless is the most resistant of the steels covered in Berry (1983). In one study the weight loss extrapolated to penetrations of 0.0027 to 0.55 millimeters in 10,000 years. Encasing the reflectors in concrete should further enhance their survivability. Berry (1983) also provides data supporting much better corrosion resistance for titanium and hastealloy. However, both of these materials are more costly than stainless steel. A fourth material that may also prove acceptable for this application is monel. Testing during the operational and active-controls period after disposal will be utilized to determine whether or not protecting the stainless steel will improve its survivability sufficiently to justify its use instead of the more corrosion resistant materials available. Use of titanium or hastealloy may also increase the likelihood of future generations mining the reflectors for their commercial value.

The planned use of strontium ferrite magnets is based upon their retentive ability, strength, and cost. In discussions with a supplier, Magnet Sales & Manufacturing Co. of Culver City, California, it was stated that although strontium ferrite magnets are not quite as strong as samarium cobalt, there is significant cost differential (a factor of 7). Alinco magnets are the least expensive of the three materials but lose their strength at an almost linear rate of 0.1 percent per 10,000 hours. However, samarium cobalt and strontium ferrite magnets achieve a nearly asymptotic value in 10,000 hours. More extensive testing during the latter part of the operational phase and the active-controls phase will be conducted to determine the best alternative for the final design.

5.8 Conclusion

The historical analogues described above support the premise that our current society has the capability to develop systems composed of components that will endure and pass information on to succeeding generations. The use of large, massive structures provides the greatest chance for the survival and promulgation of information for thousands of years. By their presence, large structures will convey a Level I message that something made by humans is present. Information preservation is enhanced by engraving messages in stone and burying the information. However, this approach to preservation does pose the problem of discovery of the message by future generations. Alternatively, engraving on massive stone outcroppings, such as the Rock of Behistun, or on stone markers, such as the Code of Hammurabi stele, supports the premise that engraving can withstand the ravages of the environment for thousands of years. Although not as durable as stone, organic-based materials such as vellum and papyrus have also been successful in preserving original records for more than 2,000 years. Not only have these ancient records survived, but also their languages can be understood today even though the languages may not be in use. The Vatican Archives demonstrate that records can be stored for centuries. An additional aspect supporting the preservation of information over thousands of years is that historians and archivists have had and continue to have an ongoing interest in the preservation of information and documents. An example of this is Herodotus' history (written in the 5th century B.C.) of the Pyramids, which were built about 2,000 years before his time. His descriptions have survived to our time through additional historical documentation efforts even though the original materials upon which he described the individual events may not have survived. Thus, even if original documents do not survive, the information contained in them can survive through the efforts of historians and archivists.

The use of these historical analogues as models for the PICs system support the concept that the WIPP warnings will be successfully conveyed to the future. Historically, some monuments have ceased to exist. However, the permanent marker design concept has focused on successful monuments that have withstood time and provide support for the "reasonable expectation" that the WIPP's PICs will endure for thousands of years and may even surpass the 10,000-year regulatory time frame.

The single most significant feature of the PICs for the WIPP is the widespread distribution of information describing the history, design, location, and hazards associated with WIPP's storage of transuranic and hazardous wastes. No historical analogue replicates the degree of effort represented in the WIPP PICs in communicating with future generations. The widespread distribution of WIPP information in archives, records centers, and other published media gives ample justification for a reasonable expectation that future generations will have information in an understandable format regarding the hazards associated with intruding into the WIPP repository and its location.

6.0 EFFECTIVENESS OF PICS IN REDUCING THE FREQUENCY OF INADVERTENT HUMAN INTRUSIONS AT THE WIPP

The previous chapters to this report have discussed the regulatory constraints on assessing the effectiveness of PICs in deterring inadvertent human intrusions, the assumptions used by the PTF in estimating this effectiveness, the conceptual design of the PIC components, the historical analogues that provide insight into how long structures and materials can last and information can be understood, possible failure mechanisms for each component and how the conceptual design for each component counteracts these mechanisms, and the redundancy and reinforcement between PIC components. This chapter integrates the information in these earlier chapters and provides the PTF's estimates of the effectiveness of PICs in discouraging inadvertent human intrusion into the repository footprint and the Withdrawal as a function of time. These inadvertent human intrusions, as guided by 40 CFR Part 194, are drilling for and the mining of natural resources. This chapter also includes arguments supporting these estimates.

6.1 PTF Estimates of PIC Effectiveness in Deterring Future Inadvertent Human Intrusions

The PIC system consists of integrated components some of which act as "awareness triggers" designed to encourage an investigator or potential intruder to obtain additional information before engaging in potentially disruptive actions at the repository footprint or within the Withdrawal. These awareness triggers by themselves have no deterrent value. Other components, both alone and in combination, are designed to act as deterrents to potentially disruptive actions. The following discussion examines each of the components from the point of view of effectiveness as a function of time.

6.1.1 Deterrence of the Marker System at the Repository Footprint

Each of the markers at the repository footprint has been specifically designed for durability. Durability will be achieved by the choice of construction material used along with the size of the marker and/or placement (i.e., exposed versus buried). In estimating deterrence for this component, the marker system is considered as a whole to account for its Gestaltic nature rather than as individual markers

6.1.1.1 Berm

The berm surrounding the repository footprint is intended to convey a Level I message that something built by humans is present. A Level I message is an awareness trigger rather than a deterrent. As a result, this particular marker has no deterrent value, although the presence of the berm may enhance the deterrence of the other markers by making the potential intruder aware that the repository site is different than the surrounding area and more information is needed prior to the initiation of intrusion activities. The historical analogues used to estimate the durability of the berm are the earthen banks surrounding the monoliths at Stonehenge (see Chapter 6). These banks were constructed as piles of earth with no reinforcement or other features designed to extend their lifetime. Based on the assumption that current science and technology has the capability to construct an earthen structure at least as durable as the banks at Stonehenge (Assumption 22) and the belief that this capability is represented in the conceptual design of the berm (Assumption 21) , the PTF concluded that the berm will survive for at least 4,700 years after disposal, which is the minimum lifetime of the banks at Stonehenge. The size, the layered structure, and the selected materials of the berm will ensure that this structure has a high probability of surviving far longer than the Stonehenge banks have survived to date. Because of the volume of the various materials in the berm, recycling of any of these materials in the future will result in large volumes of the other materials (e.g., mining the salt) being left behind (e.g., the ripramand caliche) , which will continue to convey the Level I message.

6.1.1.2 Monuments Outlining the Repository Footprint

The monuments that contain Levels II, III, and IV messages will be composed of granite. Based on the historical analogues of the monoliths at Stonehenge and the Rock of Behistun, (see Chapter 6), these monuments at the WIPP will be able to remain intact for at least 4,000 years, which is the minimum lifetime of the Stonehenge monoliths, and the engraved messages on the monument will be legible for at least 4,000 years, which is the minimum lifetime of the engraved messages on the Rock of Behistun. Because these ages are minimums, a life expectancy for the inscriptions on the monuments substantially longer than 4,000 years after disposal is realistic and highly probable.

Estimates of the ability of future generation to read and understand the warnings on the monuments are based on the assumptions that current English will continue to be readable by individuals working in the natural-resource industries (possibly as a specialized second language) due to the nearly continuous resource exploration and exploitation in the WIPP area and the Delaware Basin (Assumption 13) and that pictures will be able to convey meaning independent of or as a supplement to written warnings (Assumption 4) (e.g., facial expressions representing emotions and pictographs representing potentially harmful activities). Based on these assumptions, the warnings inscribed on the monuments will be understood by individuals within the natural-resource industries for thousands of years after disposal

The number of monuments within the relatively small repository area provide a level of redundancy that suggests that the monuments will remain an effective deterrent to inadvertent human intrusion into the repository in the event that one or several of the monuments are deliberately destroyed or removed.

6.1.1.3 Information Center

An Information Center will be constructed in the center of the footprint. This center will have granite walls set into caliche, and these walls will be inscribed with Level IV information. The lack of a roof for this room provides natural lighting but also allows for the walls to be exposed to a limited amount of weathering and for wind-blown sand to settle into the room. The historical analogues used by the PTF for the Information Center are the Acropolis for the durability of the structure and Australian rock art for the partially exposed engravings. Based on the assumption that today's scientists and engineers, through engineering design and selection of materials, can built a rock structure that endure for at least as long as the structures at the Acropolis (Assumption 22), the PTF concluded that the Information Center will survive for at least 2,400 years after disposal, which is the minimum age for most of the structures at the Acropolis. The much-older Egyptian pyramids were not used as an analogue for the Information Center, because the pyramids are massive structures, which are not structurally analogous to the Information Center, whereas buildings at the Acropolis were designed for human use and structurally more analogous to the Information Center.

Inscriptions on the walls within the Information Center will be partially protected from wind-driven rain, snow, and sand by the outer walls. This configuration is similar to the Australian rock art consisting of paintings, engravings, and peckings located on partially protected surface. The fact that this rock art has been able to survive for tens of thousands of years indicates that the inscriptions in the granitic rock of the Information Center will endure for as long as the inscribed surfaces are protected (Assumption 22) (including walls knocked over in a face-down position or buried by drifting sand). Even if the structue of the Informaiton Center fails, the protected insriptions could survive for tens of thousands of years.

The Level IV messages within the Information Center will consist of both written messages and pictures. Estimates by the PTF of the interpretability of the warnings within the Information Center were based on the following assumptions: (1) future generations will continue to use writing as a means of communication (Assumption 2), (2) future generations will continue to be curious about the meaning behind unfamiliar structures and writings (Assumption 1), (3) current English will continue to be understood by individuals within the natural-resource exploration and exploitation industries or governmental agencies (Assumption 13) (possibly as a specialized second language), and (4) pictures will be able to convey meaning independent of or as a supplement to written warnings (e.g., facial expressions representing emotions and pictograph representing potentially harmful activities). Based on these assumptions, the PTF concluded that the inscribed warnings on the walls of the Information Center will be understood by individuals within the natural-resource industries or governmental agencies for thousands of years after disposal.

6.1.1.4 Buried Storage Rooms

The two buried storage rooms also will be constructed of granite. One room will be buried in the berm as protection during the early times of the regulatory time frame. As the berm ages and erosion occurs, portions of the buried room (e.g., a corner, edge, or wall) may become exposed at the surface thereby informing future generations of the existence of another source of information, and adding another source of warning messages to potential intruders. Exposure of the buried room would occur later in the regulatory time frame after the monuments and the information center have been exposed to surficial erosion processes and may undergo some surficial degradation. Although both the monuments and the Information Center are expected to remain intact for at least several thousand years, the exposure of the buried room will reveal another source of detailed information as to why human intrusion should not be attempted. The other room will be buried below grade outside the berm. This room is not expected to be exposed by natural processes, but its location will be described in the archives and in the Information Center. Future generations may choose to excavate this room to obtain Level IV information.

The historical analogues for the buried rooms are Newgrange and the rooms within the Egyptian pyramids. Based on the assumption that current science and technology have the capability to construct buried rooms at least as durable as these analogues, and the belief that this capability is represented in the conceptual design of the buried rooms, the PTF concluded that the buried rooms will survive for at least 5,000 years after construction, which is the minimum age of Newgrange.

Inscriptions in the walls of the buried rooms will be completely protected from weathering and erosion for as long as the rooms remain buried. The inscriptions in the walls of the rooms contained within the Khufu pyramid exhibit no signs of deterioration 4,500 years after being carved into the rock, and the broader patterns engraved in the interior walls of Newgrange exhibit no signs of significant deterioration after 5,000 years. Based on these analogues, the PTF concluded that the inscriptions in the walls of the buried rooms at the WIPP will endure for at least 5,000 years.

The Level IV messages within the buried rooms will consist of both written messages and pictures. Estimates of the interpretability of the warnings within the buried rooms were based on the following assumptions: (1) future generations will continue to use writing as a means of communication (Assumption 2), (2) future generations will continue to be curious about the meaning of unfamiliar structures and writings (Assumption 1), (3) current English will continue to be understood by individuals within the natural-resource exploration and exploitation industries or governmental agencies (possibly as a specialized second language) (Assumption 13), and (4) pictures will be able to convey meanings (Assumption 4) independent of or as a supplement to written warnings or by themselves, if the buried rooms are exposed or exhumed far enough into the future when an understanding of current English is lost by the general populace. Based on these assumptions, the PTF concluded that the inscribed warnings on the walls of the buried rooms will be understood by individuals within the natural-resource industries or governmental agencies for thousands of years after disposal.

6.1.1.5 Small Buried Markers

The conceptual design for the marker system includes a relatively large number of small markers that will be buried at random intervals and depths across the area of the repository footprint. By design, these markers will be encountered during the preparation of any location within the footprint for drilling operations (e.g., digging a mud pit). The material used to construct these markers will be selected through an experimental program to assure that the markers will not undergo significant chemical alterations from contact with the enclosing sediments and soils within the regulatory time frame, thereby ensuring that these markers will endure.

The historical analogues for the buried markers are the diorite stele that contains the inscriptions of the Code of Hammurabi and the artifacts found in Mesopotamian tells and tombs. Based on the assumption that the materials selected through the experimental program for these markers will survive with no significant deterioration of the inscriptions for at least as long as the stele and the artifacts (Assumption 22), the PTF concluded that the buried markers will survive for at least 3,700 years, which is the approximately the time frame during which the stele was buried, with a high probability of surviving longer than 4,500 years, which is the minimum age of some of the older Mesopotamian artifacts.

Buried markers will contain a Level II message. Estimates of the interpretability of the warnings on these markers were based on the following assumptions: (1) future generations will continue to use writing as a means of communication (Assumption 2), (2) future generations will continue to be curious about the meaning of unfamiliar objects and writings (Assumption 1), (3) current English will continue to be understood by individuals within the natural-resource exploration and exploitation industries or government agencies (possibly as a specialized second language) (Assumption 13), and (4) pictures will be able to convey meanings (Assumption 4). Because the buried markers will contain symbols instead of pictographs, the effectiveness of this portion of the message may be less than the higher-level messages conveyed by the figures and pictographs on the markers and in the buried rooms and Information Center. The PTF concluded that the basic message of danger conveyed by the text inscriptions will be understood by individuals associated with natural resources for the sands of years after disposal. If the symbols cannot be understood, the inherent curiosity of future generations will make the symbols awareness triggers.

6.1.1.6 Effectiveness and Endurance of the Repository Marker System

Each marker component, except for the berm which is an awareness trigger, will have the capability to independently deter future inadvertent human intrusion. Failure of the marker system requires the failure of all of the components of the system. No failure mechanism for all of the components has been identified. Based on the materials to be used to construct the various types of markers, the redundancy of the warning messages at the various message levels, the numbers of markers, and the marker distribution, the marker system at the repository footprint (approximately 0.5 square kilometers [0.2 square miles]) will completely deter inadvertent human intrusions within the repository footprint for thousands of years based on the assumptions previously discussed about the nature of people and society and the use of historical analogues.

6.1.2 Monuments at the Land Withdrawal Area Boundary

An additional set of monuments is to be placed along the boundary of the Withdrawal (approximately 41 square kilometers [16 square miles]). These monuments have the same design specifications as the monuments at the boundary of the repository footprint, although the warning message on these outer monuments will place more emphasis on deterring intrusion into the Withdrawal outside of the repository footprint. Because these outer monuments will be compositionally and dimensionally the same as the inner monuments, the estimates of durability for these two sets of monuments is the same. The warning message on these outer markers will be a little less emphatic than the one on the inner markers. A warning to not disturb the ground-water flow system is abstract and is unlikely to have the same sense of importance as a warning against activities that could result in the release of radionuclides from a buried storage facility. In addition, the area of danger clearly will be the one marked by the berm, the inner monuments, and the information center based on the greater level of effort in constructing markers. This lack of compelling reason not to intrude along with an absence of redundancy of the message on other markers will likely result in less deterrence than the message to be conveyed by the repository markers, especially if the other confirmatory components (e.g., records and government control) of the importance of the entire Withdrawal begin to fail. For these reasons, the marker system at the Withdrawal boundary is assumed to be less effective than the markers at the repository footprint, although this decrease in effectiveness will not occur until at least a 1,000 years after disposal, which is equivalent to the time between current and Old English.

6.1.3 Records Centers

For the purpose of estimating the effectiveness of records in deterring intrusion, the records are considered in two types of records centers. One type of records center consists of depositories at both the regional and national levels (e.g., regional depository libraries and the Federal Records Center in Denver, Colorado). The depositories hold a wide variety of information and documents among which the WIPP records would be just one more set of records. The other type of records center consists of agencies that deal with land use, especially in the areas of natural-resource exploration and exploitation (e.g., Bureau of Land Management and New Mexico Oil Conservation Division). In this second type of records center, the WIPP records would be more distinctive, because these records will deal with how the land can and cannot be used, in addition to containing potentially significant economic information.

Based on historical records, fragments of wood-based paper have survived for most of the nearly 2,000 years since its invention, and an uninscribed papyrus roll has been found in an Egyptian grave approximately 5,000 years old (Gaur, 1992). The volume of ancient documents that have survived to the present with no or limited attention to preservation indicates that the survivability of documents that are cared for will be high. These historical analogues suggest that the WIPP records printed on paper developed for an extended life expectancy and stored in records centers should be able to survive relatively intact for several thousand years. As a historical analogue for writing on an organic material, papyrus with written hieroglyphics dates to approximately 4,500 years ago (Gaur, 1992). This historical analogue indicates that printed WIPP documents can survive for as long as the paper. An additional factor that improves the survival of the records is the human habit of reproducing records. The PTF estimates have not included credit for future generations reproducing documents except in the case of restoration of a records center following catastrophic loss of records (e.g., fire or natural disaster).

The German archives during WWII serve as the historical analogue for the distribution of the WIPP documents in numerous records centers. The fact that the large part of these archives survived the war indicates that the distribution of WIPP records to a large number of records centers essentially guarantees that at least some copies of these records will survive for an extended period of time into the future.

The general records centers are and will be depositories for a wide variety of information and a large volume of documents. These records centers also will contain Level V WIPP messages. Over time, the importance of the normal records may be lost to individuals operating the records centers, and the records may be replaced with what are perceived to be more important records, in which case the records could be destroyed or relegated to a less prominent area within the records center. The conceptual design for the WIPP records contain provision for making them distinctive, concise, and of readily recognized value. Estimates of the effectiveness of the general records centers in deterring inadvertent intrusion were based on the following assumptions: (1) future generations will continue to use writing as a means of communication (Assumption 2), (2) future generations will continue to be curious about unfamiliar writings and structures

(Assumption 1), and (3) current English will continue to be understood by individuals within the natural-resource exploration and exploitation industries and government agencies (Assumption 13) along with those individuals in other fields of endeavor in which historical documents are important (Assumption 12). Because of the prominence of the WIPP records, the PTF concluded that the warnings contained in the WIPP records of the general records centers will be completely effective deterrents for anyone checking these records centers for possibly 1,000 years or more after disposal. Beyond this time, the records begin to decrease in deterrence value because of the likelihood of these records will be lost within the records centers. In the vicinity of 4,000 years (i.e., twice the lifetime of the oldest existing paper fragments and approximately the lifetime of some of the older papyrus), the possible deterioration of the original records may begin to be a factor. This deterioration combined with the possible loss of records in the records centers may result in a rapid decrease in the deterrence value of the general records centers. Because of the wide-spread distribution of general records centers and the diverse nature of the types of records centers, no pattern of document survival or effectiveness is applicable to all records centers.

The resource records centers are and will be the depositories for more specialized documents and information related to resource and land ownership and use. Based on the same assumptions used for the general records centers and the addition assumptions that resource exploration and exploitation will continue for the entire regulatory period (Assumptions 16 and 17) and government in any form will require record keeping and consultation of records (Assumptions 8, 9, and 10), the PTF concluded that resource records centers will remain active throughout the regulatory period. Because of this activity and the importance of the WIPP records, these records will be consulted by individuals associated with natural resource exploration and exploitation (Assumption 18) and will be highly effective deterrents to inadvertent intrusion (Assumptions 6, 8, and 10) for at least a couple of thousands of years after closure. Failure of the WIPP records to deter will be the result of catastrophic record destruction and the physical deterioration of the records. The wide distribution of the WIPP records in numerous records centers virtually assure that at least some copies of these records will survive for an extended time and that lost records can be reproduced.

6.1.4 Archives

Archives are designed to preserve historically significant documents. In this capacity, the role of archives is preservation rather than the dissemination of information. As a result, the WIPP records will be stored under conditions that will extend their life expectancy relative to documents in records centers. The PTF considered the Vatican Archives as a historical analogue for the durability of an archive as an institution and the ancient paper, papyrus, and other documents as historical analogues for the WIPP documents to be stored in the archives. The assumptions used by the PTF to estimate the effectiveness of the archives in deterring inadvertent intrusion were basically the same as for the records centers (see Section 7.2.3).

Using the Vatican Archives as a historical analogue, the PTF concluded that the archives in which the WIPP records will be stored have the capability to survive as institutions for at least 1,100 years, which is the minimum age of the Vatican Archives. Because of the seemingly universal recognition of the documents in archives as historically important, the PTF concluded that future societies will go to great lengths to preserve the documents within an archive, even though the structure housing the documents is expendable and replaceable. The limiting factor is the life of the paper, because the institution or a successor was assumed to last indefinitely. With optimum storage conditions and limited use, the documents within the archives, and especially the WIPP records, will last substantially longer than the records in the records centers. Documents in the archives should last as long as the ancient documents considered as historical analogues described above even if the physical structure housing the documents do not. The PTF concluded that the WIPP records in archives will survive in at least some of the archives for at least 5,000 years. Archives suffer some of the same problems as records centers in that documents can be "lost" through such actions as misfiling, reshelving, and in some cases, destruction or theft.

The WIPP records in the archives will contain Level V messages. Estimates of the effectiveness of the archives in deterring inadvertent intrusion were based on the following assumptions: (1) future generations will continue to use writing as a means of communication (Assumption 2), (2) future generations will continue to be curious about unfamiliar structures and writings (Assumption 1), and (3) current English will continue to be understood by individuals within the natural-resources exploration and exploitation industries and government agencies (Assumption 13) along with those individuals in others fields of endeavor in which historical documents are important (Assumption 12). For the potential intruder or the site investigator who visits an archive, the warnings within the WIPP records will be readily understood for more than 1,000 years after disposal because of the specialized vocabulary based on current English associated with natural resource and land use. Because of the large volume of records and document in current English within an archive, a high probability exists that someone working at the archive will be able to translate current English into the future dialect of the time for anyone unfamiliar with current English. Readily available translation will be available for a much longer period beyond 1,000 years after disposal, which is equivalent to the time between current and Old English.

In a regional sense, the deterrence value of the archives compared to records centers will be relatively low in the early part of the regulatory time frame, because the archives will be farther away from the WIPP than the records centers, which are the traditional sources of land-use and natural-resource information to the natural-resource industry. As the documents in the records centers start to deteriorate and/or become lost in the volume of records that will be submitted, the reliance on the archives will increase because of the better preservation of the documents. The level of deterrence of the archives will not reach the peak levels achieved by the deterrence of the records centers because of the remoteness of the archive sites from the WIPP, and the possibility of archives losing the records.

6.1.5 Government Control of Land Use

Government control of land use consists of written instructions in any government-agency offices where land-use determinations are and will be made specifying the prohibited uses, and covenants on land use written into surface- and resource/mineral-rights leases. A basic assumption used by the PTF is that any prudent extrapolation of the current form of government (Assumption 7) will continue some form of land-use control (Assumption 8), especially in those areas having natural-resource potential (Assumption 10). These offices are one of the types of records centers discussed in Section 7.1.3.

The PTF concluded that land-use restriction will be completely effective deterrents against inadvertent human intrusion for as long as the paper recording these restrictions lasts. Because of the specialized and limited vocabulary associated with land-use restrictions, these restrictions will be interpretable by individuals in the natural-resource industries and/or government agencies (Assumption 13) for thousands of years. The PTF assumed no credit for the land-use restrictions being transcribed to other copies of documents.

6.2 Awareness Triggers

Several of the components described in Chapter 6 have no deterrent value on their own, but may contribute to the effectiveness of the PICs system. These components have been labeled as "awareness triggers," because each of these components has the potential to make a potential intruder or site investigator aware of the existence of the WIPP, and therefore aware that additional information about the WIPP should be obtained. These awareness triggers are:

- berm
- government ownership of the Withdrawal
- incorporation of the WIPP's location on maps and road atlases
- description of the WIPP in encyclopedias
- identification of the WIPP in dictionaries
- description of the WIPP in science and history textbooks
- a WIPP homepage on the Internet

Although these components will contribute to the effectiveness of the PICs system, the PTF has taken no credit for these components in the effectiveness estimates presented in Section 7.4 below.

6.3 Effectiveness of PICs System in Deterring Inadvertent Human Intrusions

The PICs components are an integrated system that includes redundancy in the ability to deter future inadvertent human intrusions within the Withdrawal. System deterrence is as effective as the most effective component. As long as the most effective component does not fail, total or partial failure of one or more of the other components will not compromise the effectiveness of the overall PICs system. Based on the above analyses, the PICs system will offer virtually complete effectiveness in deterring inadvertent human intrusions within the repository footprint for as long as the marker-system components at this location are in place. The effectiveness of the PICs system in deterring inadvertent human intrusions within the Withdrawal outside the repository footprint will offer virtually complete effectiveness for the period from 100 years (when the PA can no longer take credit for AICs) after disposal to at least a couple of thousand years after disposal. Over time, the PTF believes that the effectiveness of the PICs in protecting the Withdrawal outside of the repository footprint will not be as high as the effectiveness for the smaller, more highly marked footprint. The primary function of the PICs for the Withdrawal outside of the footprint is to protect the integrity of the disposal system rather than protecting a driller, which is the primary function of the PICs at the footprint. The difference in the level of effectiveness will not manifest itself until some thousands of years after disposal.

6.4 Conclusions for Use in PA

As noted in Section 1.5 of this report, the EPA states that for the PAs, PICs cannot totally deter inadvertent human intrusion for even a short period of time after active controls are assumed to end and cannot deter for more than several hundred years. Looking at the historical analogues and potential failure modes for the PICs components, the PTF ascertained that the PICs will be highly effective for periods of time much longer than several hundred years. The attempt to quantify "highly effective" in order to provide input to the PA calculations focused on possible failure mechanisms. Designing physical monuments and markers and establishing institutions for control based on historical analogues leads the DOE to assert that for the time period of interest to PA, these PICs will perform virtually perfectly in enduring and preserving messages for interpretation. The assumptions developed in Chapter 3 lead the DOE to assert that current English will be decipherable by the resource community for the entire period of interest to PA. Thus, the only allure mechanisms of the PICs for communicating with a potential driller/intruder centered around human error in the permitting process (retaining knowledge of the prohibition of drilling and mining, and correctly preparing/rejecting permits) or in locating a permitted operation.

During the deliberation of the PTF, members of WID's Long-Term Regulatory Compliance Section have reviewed drilling records for the New Mexico portion of the Delaware Basin dating back to 1914 and located at the Hobbs and Artesia offices of the state of New Mexico's Oil Conservation Division. One aspect of this review was to determine if any of the well records identified a case or cases wherein the driller set up and drilled in a location other than that authorized. Similarly, the PTF could not locate any record or individual that could confirm that any of the 11,500 wells of the Delaware Basin were drilled at the wrong location. As a follow-up, members of each office were contacted by phone on April 4, 1996, (Johns, 1996) and asked if they recall any incidents of drilling in an unauthorized location. No incidents were recalled.

In a follow-up investigation, the PTF contacted four experts with a total of 106 years of field experience in the oil and gas industry (Rodriguez, 1996e; Rodriguez, 1996f; Rodriguez, 1996g and Rodriguez, 1996h). The experts could recall only five instances, all outside of the Delaware Basin, where someone had drilled a well at the wrong location; three occurred in Texas about 15 years ago and two near Eunice, New Mexico about 30 years ago (Rodriguez, 1996h). These five instances are out of the some 429,000 wells that have been drilled in the Permian Basin (29,000 in southern New Mexico and 400,000 in eastern Texas). Three of the five instances occurred thirty years ago during a period of high activity that the Permian Basin had not witnessed before or afterwards.

The error rate for drilling wells is 0.00 in the Delaware Basin and 0.00001 for a much larger area extending beyond the boundaries of the Delaware Basin. Other than the PICs of government control of land rise through records centers, no other PICs exist in the Permian Basin to deter drilling at any particular site. Yet only five out of hundreds of thousands of wells were drilled at the wrong location, and these wrong locations were still within established claims. The addition of PICs, such as restrictive government control of land use, extensive records, and elaborate monuments and markers would eliminate drilling error as a possible failure mode at the WIPP.

For the sake of addressing the needs of PA and to account for unidentified possible failure mechanisms and sources of human error that could result in reduced effectiveness of the PICs system, the PTF recommends that the failure rate for PA calculations (years 100 to 700 after disposal) be increased to a bounding value of 0.01. Thus, the PICs are to be 0.99 effective in successfully communicating about the WIPP. A 1-percent failure rate would mean that out of every 100 permit requests, one involved an unlawful permit, a location error on the permit itself, or the drillers setting up in the wrong location. This is not believed to be possible in the future because such a high error rate would be widely known within the drilling community, and thus would cause the implementation of stronger controls over drilling.

The numerical percentage by which the intrusion rate will be reduced in the PA calculations is taken to be the probability of successful communication of the information. This assumption is made based on the thought that, for example, if the PICs are effective in correctly transmitting the information 99 percent of the time, then 99 percent of the potential intrusions are either deterred or are made with full information and thus are not inadvertent (i.e., do not have to be considered in the PAs).

The PTF emphasizes that these accommodations to the regulation for both the repository footprint and the remainder of the Withdrawal are bounding values that underestimate the effectiveness of the PICs system in deterring inadvertent human intrusions under the assumptions established in Chapter 3.

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7.0 REFERENCES

Allison, R.W. 1996. "Summary Catalog of the Greek Manuscripts of Philotheou Monastery." Web Page http://abacus.bates.edu:80. Lewiston, ME: Bates College, Department of Philosophy and Religion. (Paper copy of web page on file in Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Berry, W.E. 1983. *Durability of Marker Materials for Nuclear Waste Isolation Sites.* ONWI-474. Washington, DC: Office of Nuclear Waste Isolation, Batelle Memorial Institute.

Bertram-Howery, S.G., and R.L. Hunter. 1989. *Plans for Evaluation of the Waste Isolation Pilot Plant's Compliance with EPA Standards for Radioactive Waste Management and Disposal.* SAND88-2871. Albuquerque, NM: Sandia National Laboratories.

BLM (Bureau of Land Management). 1992. "Legal Description of the Waste Isolation Pilot Plant (WIPP) Withdrawal; NM," *Federal Register.* Vol. 57, no. 227, 55277.

Brachmann, B., M. Herrman, and S. Pollert. 1991. *Archive Safety Analysis. Case Study: German Archives During the 20th Century.* NKS/KAN 1.3(91)5. [Stockholm, Sweden]: Nordic Nuclear Safety Research Programme. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Brausch, L.M., A.K. Kuhn, and J.K. Register. 1982. *Natural Resources Study, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico.* WTSD-TME-3156. Albuquerque, NM: U.S. Department of Energy, Waste Isolation Pilot Plant.

Crystal, D., 1994. *An Encyclopedic Dictionary of Language and Languages.* New York, NY: Penguin Books.

DOE (U.S. Department of Energy). 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026. Washington, DC: U.S. Department of Energy. Vols. I-II.

DOE (U.S. Department of Energy). 1989. *Draft Supplement Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026-DS. Washington, DC: U.S. Department of Energy.

DOE (U.S. Department of Energy). 1990a. *Final Safety Analysis Report, Waste Isolation Pilot Plant, Carlsbad, New Mexico.* WP 02-9, Rev. 0. Carlsbad, NM: Westinghouse Electric Corporation

DOE (U.S. Department of Energy). 1990b. *Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026-FS. Washington, DC: U.S. Department of Energy, Office of Environmental Restoration and Waste Management. Vols. 1-13.

DOE (U.S. Department of Energy). 1993. *Waste Isolation Pilot Plant Land Management Plan.* DOE/WIPP 93-004. [Carlsbad, NM]: U.S. Department of Energy, Waste Isolation Pilot Plant.

DOE (U.S. Department of Energy). 1995a. *Resource Conservation and Recovery Act Part B Permit Application.* DOE/WIPP 91-005 Revision 5. Carlsbad, NM: Waste Isolation Pilot Plant. Vols. I-X.

DOE (U.S. Department of Energy). 1995b. *Draft No-Migration Variance Petition.* DOE/CAO-95-2043. Carlsbad, NM: U.S. Department of Energy, Waste Isolation Pilot Plant, Carlsbad Area Office. Vols. I-VII.

DOE (U.S. Department of Energy). 1996. *Passive Institutional Controls Conceptual Design Report.* Carlsbad, NM: U.S. Department of Energy, Carlsbad Area Office. (Copy on file in Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Encyclopedia Britannica. 1994. *New Encyclopedia Britannica.* 15th ed. Chicago, IL: Encyclopedia Britannica. (Sections on "Behistun" and "Hammurabi, Code of" on file in Sandia WIPP Central Files.)

EPA (U.S. Environmental Protection Agency). 1978. "Criteria for Radioactive Wastes," *Federal Register.* Vol. 43, no. 221, 53262-53268.

EPA (U.S. Environmental Protection Agency). 1985. "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule," *Federal Register.* Vol. 50, no. 182, 38066-38089.

EPA (U.S. Environmental Protection Agency). 1993. "40 CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule," *Federal Register.* Vol. 58, no. 242, 66398-66416.

EPA (U.S. Environmental Protection Agency). 1995a. "40 CFR Part 194: Criteria for the Certification and Determination of the Waste Isolation Pilot Plant's Compliance with Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Proposed Rule," *Federal Register.* Vol. 60, no. 19, 5766-5791.

EPA (U.S. Environmental Protection Agency). 1995b. "Part 192—Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings," *Code of Federal Regulations 40 Part 192.* Washington, DC: U.S. Government Printing Office, Superintendent of Documents.

EPA (U.S. Environmental Protection Agency). 1996a. *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations. Background Information Document.* EPA 402-R-96-002. Washington, DC: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air.

EPA (U.S. Environmental Protection Agency). 1996b. *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191*

Disposal Regulations. Response to Comments Document for 40 CFR Part 194. EPA 402-R-96-001. Washington, DC: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air.

EPA (U.S. Environmental Protection Agency). 1996c. "40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance With the 40 CFR Part 191 Disposal Regulations; Final Rule," *Federal Register*. Vol. 61, no. 28, 5224-5245.

EPA (U.S. Environmental Protection Agency). 1996d. *Compliance Application Guidance for 40 CFR Part 194.* EPA 402-R-95-014. Washington, DC: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air.

Fagan, B. 1994. "Neolithic Newgrange," *Archaeology*, Vol. 47, no. 5, 16-17.

Frimmer, S. 1969. *The Stone That Spoke, and Other Clues to the Decipherment of Lost Languages.* New York, NY: Putnam Publishing Co. 100-117.

Gaur, A. 1992. "The Process of Writing," *A History of Writing.* Rev. ed. New York, NY: Cross River Press, A Division of Abbeville Press. 35-48.

Gillis, D. 1985. "Preventing Human Intrusion into High-Level Nuclear Waste Repositories," *Underground Space*. Vol. 9, no. 1, 51-59.

Givens, D.B. 1982. "From Here to Eternity: Communicating with the Distant Future," *Etc. Et cetera.* Vol. 39, no. 2, 159-179.

Gousha. 1993. *New Deluxe 1993 Road Atlas. United States, Canada, Mexico.* H.M. Gousha, Simon & Schuster, Inc.

Guzowski, R.V. 1990. *Preliminary Identification of Scenarios That May Affect the Escape and Transport of Radionuclides From the Waste Isolation Pilot Plant, Southeastern New Mexico.* SAND89-7149. Albuquerque, NM: Sandia National Laboratories.

Hawkins, G.S. 1973. *Beyond Stonehenge.* New York, NY: Harper and Row.

Hora, S.C., and R.L. Iman. 1989. "Expert Opinion in Risk Analysis: The NUREG-1150 Methodology," *Nuclear Science and Engineering.* Vol. 102, no. 4, 323-331.

Hunter, D. 1978. *Papermaking: The History and Technique of an Ancient Craft.* New York, NY: Dover Publications.

IAEA (International Atomic Energy Agency). 1994. *Safety Indicators in Different Time Frames for the Safety Assessment of Underground Radioactive Waste Repositories.* IAEA-TECDOC-767. Vienna, Austria: International Atomic Energy Agency.

Jenkins, M.E., and A.H. Schroeder. 1974. *A Brief History of New Mexico*. Albuquerque, NM: University of New Mexico Press.

Johns, James. 1996. Telephone conversation with Paul Katz, Hobbs OCD, and Ray Smith, Artesia OCD. April 4, 1996. (Log copy on file in Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Kaplan, M.F. 1982. *Archaeological Data as a Basis for Repository Marker Design*. ONWI-354. Columbus, OH: Office of Nuclear Waste Isolation, Battelle Memorial Institute, Project Management Division.

Keesey, J.J. 1976. *Hydrocarbon Evaluation, Proposed Southeastern New Mexico Radioactive Material Storage Site, Eddy County, New Mexico.* SAND77-7033. Midland, TX: Sipes, Williamson, and Aycock; Albuquerque, NM: Sandia National Laboratories.

Kerr, R.A. 1989. "Oil and Gas Estimates Plummet," *Science*. Vol. 245, no. 4924, 1330-1331.

Kinder, H., and W. Hilgemann. 1974. *The Anchor Atlas of World History. Volume I. From the Stone Age to the Eve of the French Revolution*. New York, NY: Anchor Press.

Merriam-Webster, Inc. 1991. *Merriam-Webster's Ninth New Collegiate Dictionary*. Springfield, MA: Merriam-Webster, Inc. p. 101.

Mohen, J.-P. 1990. *The World of Megaliths*. New York, NY: Facts on File.

NEA (Nuclear Energy Agency). 1995. *Future Human Actions at Disposal Sites, A Report of the NEA Working Group on Assessment of Future Human Actions at Radioactive Waste Disposal Sites*. Paris, France: Nuclear Energy Agency, Organisation for Economic Co-Operation and Development.

NMBMMR (New Mexico Bureau of Mines and Mineral Resources). 1995. *Final Report Evaluation of Mineral Resources at the Waste Isolation Pilot Plant* (WIPP) Site. [Carlsbad, NM]: Westinghouse Electric Corporation; Socorro, NM: New Mexico Bureau of Mines and Mineral Resources.

Pasztor, S.B., and S.C. Hora. 1991. *The Vatican Archives: A Study of its History and Administration*. NKS/KAN 1.3(91)6. [Stockholm, Sweden]: Nordic Nuclear Safety Research Programme. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Powers, D.W., S.J. Lambert, S.-E. Shaffer, L.R. Hill, and W.D. Weart, eds. 1978. *Geologic Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico, Volume II*. SAND78-1596. Albuquerque, NM: Sandia National Laboratories.

Public Law 96-164. 1979. *Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980*.

Public Law 102-579. 1992. *Waste Isolation Pilot Plant Land Withdrawal Act*.

Rodriguez, R. 1996a. Telephone conversation with Miss Andrews of the British Museum. March 6, 1996. (Copy on file in Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Rodriguez, R. 1996b. Telephone conversation with Traianos Gagos of the University of Michigan. March 6, 1996. (Copy on file in Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Rodriguez, R. 1996c. Telephone conversation with Richard R. Navarro of the DOE Las Vegas, NV office. March 11, 1996 (Notes on file with Sandia WIPP Central Files.)

Rodriguez, R. 1996d. Telephone conversation with Roxanne Danz of Restoration Physics group at the DOE's Las Vegas, NV office. March 12, 1996 (Notes on file with Sandia WIPP Central Files.)

Rodriguez, R. 1996e. Telephone conversation with Larry Scott, Petroleum Engineer for Lynx Petroleum. May 8, 1996 (Notes on file with Sandia WIPP Central Files.)

Rodriguez, R. 1996f. Telephone conversation with Jack Ahlen, Consulting Geologist. May 8, 1996. (Notes on file with Sandia WIPP Central Files.)

Rodriguez, R. 1996g. Telephone conversation with Floyd Ferguson, Consulting Geologist. May 8, 1996 (Notes on file with Sandia WIPP Central Files.)

Rodriguez, R. 1996h. Telephone conversation with Ron Eidson, Supervisor of Surveyors, John West Engineering. May 8, 1996 (Notes on file with Sandia WIPP Central Files.)

Sullivan, G. 1987. "Vital Clue," *Treasure Hunt*. New York, NY: Henry Holt and Company. 56-63.

Tannenbaum, P.H. 1984. *Communication Across 300 Generations: Deterring Human Interference with Waste Deposit Sites*. BMI/ONWI-535. Columbus, OH: Office of Nuclear Waste Isolation, Battelle Memorial Institute.

Thue, H. 1991. "The Right to a Future," *Transmittal of Information Over Extremely Long Periods of Time, Proceedings from a Conference Arranged by Scandpower AS, Oslo, Norway, September 26-27, 1991*. NKS/KAN 1.3(91)9. Scandpower AS. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Trauth, K.M., S.C. Hora, and R.V. Guzowski. 1993. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant*. SAND92-1382. Albuquerque, NM: Sandia National Laboratories.

Waste Management Technology Department. 1987. *The Scientific Program at the Waste Isolation Pilot Plant*. SAND85-1699. Albuquerque, NM: Sandia National Laboratories.

Weitzberg, A. 1982. *Building on Existing Institutions to Perpetuate Knowledge of Waste Repositories*. ONWI-379. Columbus, OH: Office of Nuclear Waste Isolation, Battelle Memorial Institute.

WIPP (Waste Isolation Pilot Plant) Inadvertent Intrusion Advisory Panel and New Mexico Junior College. 1995. *Analytical Study of an Inadvertent Intrusion of the WIPP Site*. Westinghouse Electric Corporation Procurement Services, Waste Isolation Pilot Plant.

Woodard, L.L. 1996. "Appendix 12B: Letter to U.S. Archivist Transmitting WIPP Land Withdrawal Information," *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations. Background Information Document.* EPA 402-R-96-002. Washington, DC: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air.