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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United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

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ABSTRACT

The U.S. Environmental Protection Agency (EPA) requires the use of passive institutional controls (PICs) to discourage future generations from inadvertently intruding into the Waste Isolation Pilot Plant (WIPP) nuclear-waste repository and the contiguous 16 sections. The PICs are to include markers, records, archives, and government ownership and land-use restrictions, and other forms of communication. Credit may be allowed in performance assessment (PA) calculations for these PICs to reduce the frequency of inadvertent intrusion for up to 700 years after disposal.

A task force was formed by the U.S. Department of Energy (DOE) to estimate the credit for the PICs in PA calculations for the WIPP repository over the 700 years for which credit is possible. The estimate was constrained by the use of existing conceptual designs of these PICs, the use of design characteristics of historical analogues for the endurance of materials and structures, the consideration of possible failure modes for each PICs component, and the regulatory mandates established by the EPA for purposes of PA calculations.

Because of the durability of the PICs and the redundancy of messages and the PICs components, human error was identified by the task force as the only credible mechanism that could result in inadvertent intrusion for the 700 years under consideration. An examination of 80 years of drilling records for the New Mexico portion of the Delaware Basin identified no instances of drilling occurring in the wrong leases. Further investigation of errors for boreholes in other areas of the U.S. and Canada at least partially underlain by bedded salt resulted in an overall failure rate of 3.5×10^{-5}. The task force concluded that the most appropriate approach to the assessment of the effectiveness of PICs over 700 years was to develop a bounding value intended to account for possible error rates and failure mechanisms that the task force failed to identify. The overall

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observed failure rate was increased orders of magnitude to a level that would be unacceptably high (and which would induce corrective action) within the natural-resources and legal communities. For purposes of PA calculations, and consistent with EPA regulatory assumptions, the task force recommended that the failure of passive controls to correctly communicate the location and hazards of the waste, thereby deterring inadvertent intrusions for the first 700 years after closure of the WIPP, should be 0.01.

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PREFACE

The PICs Task Force (PTF) developed a process for estimating credit for PICs in PA calculations and documented the effort in Revision 0 of this report. Subsequently, Revision 0 of this report was reviewed by the PICs Peer Review Panel (PRP), which convened under the auspices of the Department of Energy (DOE). Revision 1 of this report addresses the issues raised by the PRP, in terms of the presentation of the process and the rationale for the process, although the process itself is the one originally developed by the PTF.

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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 Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, Final Rule 40 CFR Part 191* (EPA, 1985, 1993). 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" (EPA, 1985). 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* (EPA, 1996b). 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. Analyses supporting the dose limits to individuals (§191.15) and the protection of underground sources of drinking water (§191.24) do not include the assessment of human intrusion, and as a result, the credit for PICs in reducing the frequency of human intrusion is not a relevant issue.

The PICs have a dual role. The design of the PICs must accommodate the Assurance Requirements (§191.14) by being the most permanent practicable with no regulatory constraints on what the future of society and technology will be like. To comply with this requirement, the DOE has developed a conceptual design (DOE, 1996) that incorporates many of the communications concepts identified by the Markers Panel (Trauth et al., 1993), which was convened by the DOE to examine long-term communications concepts.

This conceptual design consists of several components. Markers at the WIPP are to include 32 granite monuments defining the boundary of the 16 sections defining the Withdrawal. Each monument will be 1.2 meters (4 feet) on a side, 7.6-meters (25-feet) high, and extend 5.2 meters (17 feet) into the subsurface. Messages and pictographs will be engraved on each above-surface and subsurface face of the monuments. A rectangular berm made of earthen materials will surround the footprint repository. This berm will have a trapezoidal cross section and will be 10-meters (33-feet) high and will have a 30-meter (98-feet) base and a 4-meter (13-feet) top width. Inside the boundary of the berm, 16 monuments will outline the footprint of the repository.

These monuments will be composed of the same material and will have the same dimensions as those monuments at the Withdrawal boundary. Each face of each monument also will be engraved with messages and pictographs. An Information Center will be located at the center of the repository footprint and will consist of four walls surrounding seven interior information walls. All of the walls will be embedded in the ground, and the room will not have a roof. Messages will be engraved on the interior side of the outer walls and on both sides of the interior information walls. The overall dimensions of the Information Center will be 12.2-meters (40-feet) wide by 9.8-meters (32-feet) deep by 3.0-meters (10-feet) high, and all of the walls will be composed of granite. Two closed rooms will be constructed that will be similar to the Information Center. One of these rooms will be buried in the southern segment of the berm, and the other room will be buried equidistant between the northern berm segment and the hot cell. Each of the buried rooms will contain seven interior information walls with each wall having messages repeated in a veneer wall. The dimensions of the buried rooms will be 11.9-meters (39-feet) long by 6.7-meters (22-feet) wide by 4.9-meters (16-feet) high, and all structural features and interior walls will be composed of granite. Relatively small markers composed of a variety of durable materials will be buried at random spacing and depths throughout the repository footprint.

Documentation about the WIPP will be sent to regional, national, and international records centers and archives. The specific documentation will depend on the specific type of records center and archive. General records centers both regionally and nationally—consisting of community and university libraries, federal and state agencies, professional societies, and natural-resources companies—will receive detailed documentation about the WIPP along with a summary document. Resource records centers are those centers specifically intended for use by the site investigator in the natural-resources industry. In addition to documentation about the WIPP, the surface and natural-resource leases in these records centers will be modified with covenants that will prohibit future intrusive activities. National and international archives will received a more extensive set of documents along with the summary document. Documents will be printed on archival paper with carbon-black ink with covers and bindings compatible with long-term preservation.

An "other" PICs component is designed for the general dissemination of information about the existence of the WIPP. This information will be incorporated into maps and road atlases, textbooks, dictionaries, encyclopedias, and other common reference sources. The purpose of these information sources is to perpetuate knowledge about something called WIPP and to stimulate interest about the WIPP so that other more detailed sources of information will be investigated.

Five levels of messages will be incorporated into and on the various components. Level I messages indicate that something made by humans is present. Each of the markers convey this level of message. Level II messages convey that something dangerous is present and the site should not be disturbed. Each of the monuments and the buried markers will include this level of message. Level III messages convey basic information about the WIPP, such as location, design, contents, and hazard. Each of the monuments will include this level of message. Level IV messages convey complex information about and related to the WIPP in multiple languages and through symbols and pictures. The Information Center and the buried rooms will contain

Level IV messages. Level V messages are the detailed documentation to be stored in records centers and archives.

Depending on the message conveyed, a PICs component can be classified as either a Deterrent Component or an Awareness Trigger. A Deterrent Component is one that contains a message and/or warning that will be sufficient to discourage a potential intruder from disturbing or intruding into the WIPP. Each of the elements of the markers system (except for the berm), the records centers, the archives, and the land-use controls are Deterrent Components. An Awareness Trigger is a component that contains a message about the WIPP without necessarily providing enough information to discourage inadvertent intrusion. The berm (a Level I message) and the "other" category of PICs are Awareness Triggers.

PICs also can be incorporated into performance assessments in the form of "credit" towards reducing the frequency of inadvertent human intrusion into the WIPP (§194.43). To address the issue of credit for PICs in performance assessments, the DOE created the PICs Task Force (PTF) with the charter of estimating the effectiveness of PICs in deterring inadvertent human intrusion under the constraints developed by the EPA to limit undue speculation in performance-assessment analyses about the future of society and technology. The EPA's constraints include limiting the period during which PICs can deter inadvertent intrusion to 700 years after repository closure and prohibiting the PICs from being completely effective for any time period after the assumed loss of active institutional controls.

A generic communications model consists of nine steps: (1) development of the intention, (2) identification of the audience, (3) encoding of the message in language, (4) capture of the message in media, (5) transmission of the message, (6) receipt of the message, (7) decoding of the message, (8) understanding the message, and (9) responding to the message. Steps 1 through 5 of this model have been or are being addressed by the EPA (through regulatory guidance) or the DOE (through the development of procedures that will ensure that the PICs will be correctly constructed and emplaced). The effectiveness of a message or warning in deterring a future action is dependent on the endurance of the message medium and the message being understood. The task of the PTF was to estimate how long the PICs would endure (Step 6—the PICs must survive in order for the message to be received) and how effective the messages will be in conveying their intended message (Steps 7 and 8). The response of future generations to a message that is understood (Step 9) was not a concern to the PTF. A warning that is understood and heeded results in no human intrusion in PA analyses, and a warning that is understood but ignored results in intentional intrusions, which are discounted from PA analyses.

The actions used by the PTF in estimating the effectiveness of the PICs are

1. Working premises were developed based on regulatory requirements and guidance along with logical deductions based on the regulations and guidance.

2. Historical analogues were examined to determine what design characteristics of the PICs components will contribute to their longevity and to determine how long the design characteristics can last.

3. Potential failure mechanisms for each PICs component were considered along with the identification of how the PICs design characteristics would counter these mechanisms.

4. Data was collected on the historical rates at which boreholes have been drilled on the wrong property.

5. An estimate was made of a bounding value for the failure rate of the PICs in deterring inadvertent intrusion for use in performance-assessment calculations.

In Action 1, the PTF relied on upon guidance that the EPA provided on how drilling for natural resources should be addressed in performance-assessment calculations (§194.33). This guidance states that drilling shall be assumed to occur during the regulatory time period (throughout the 10,000 years of concern to performance assessment) (§194.33(b)(2)), that the frequency of drilling for the Delaware Basin within the 10,000 years of concern to performance assessment should be based on historical drilling rates from the past 100 years (§194.33(b)(3)), and that future drilling practices and technology, including the sealing of boreholes, will remain consistent with the practices and technology at the time the compliance application is prepared (§194.33(c)(1)). Based on this guidance, the PTF concluded that for the 700 years after closure, government will continue to exist along with regulatory agencies and the associated permitting and record keeping for natural-resources exploration and exploitation. Exploratory and developmental drilling will continue throughout the Delaware Basin at such a high yearly rate that the records centers will remain active, and no time intervals will occur during which the procedures will be forgotten. A major premise that the PTF derived from this guidance is that the continuous natural-resources activity means that the information in current English will have considerable economic value far into the future, which means that current English will continue to be understood by personnel in the natural-resources industry for the entire 700 years of concern to PICs effectiveness.

An examination of the durability of design characteristics in historical analogues to the PICs components (Action 2) allowed the PTF to conclude that each of the PICs components is virtually certain to survive for the entire 700 years of concern to PICs effectiveness. Both the materials to be used and the component designs, especially the redundancy, virtually eliminate any credible mechanism within the regulatory guidance for performance assessments for a single PICs component to fail, let alone all of the PICs components that would have to fail in order for inadvertent intrusion to occur.

Each of the potential failure mechanisms identified in Action 3 for each PICs component is countered by the materials selected and the design for each component.

In Action 4, an examination of drilling records and personal interviews with individuals having extensive experience with drilling in the Delaware Basin revealed no instances of wells being drilled in the wrong location in the Delaware Basin (i.e., failure of 0.0). When the survey was extended to the much larger area of the Permian Basin in New Mexico and Texas, five instances of wells drilled in the "wrong" location out of some 429,000 wells drilled in total were identified (i.e., failure of 0.00001). Further investigation of errors for boreholes in areas of the U.S. and Canada at least partially underlain by bedded salt resulted in an overall failure rate of 3.5×10^{-5}

(20 errors out of at least 564,700 wells drilled). The fact that this failure rate is higher than the rate for the Permian Basin is largely due to an anomalously high failure rate for one Canadian province.

In Action 5, the PTF examined the ways in which the components of a PICs system can interact, depending on how the messages are conveyed: (i) if each component has a complete message, each component can independently convey the complete message, (ii) if each component contains a part of the message and understanding the message requires all the parts, loss of any component means failure for the entire system, (iii) if each component contains a part of the message that contributes to the complete message, loss of a component will reduce the effectiveness of the message, and (iv) if each component contains a message and also reinforces the other components (i.e., a Gestalt—the total effectiveness is greater than the combined component effectivenesses), the effect of the loss of a component on the system's performance is dependent the contribution of the component to the Gestalt. Although the PTF concluded that the PICs system for the WIPP will be a Gestalt (i.e., a (iv)), the decision was made to consider the PICs components to be independent (i.e., a (i)) for ease of analysis and to underestimate the PICs effectiveness.

The PTF also took into account the fact that the failure rates in Action 4 were for the single PICs component of government control of land use. The working premises in Action 1, which were derived from the EPA's regulatory guidance, indicate that the other PICs components would be at least as effective as the government control of land use. 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 decided to bound the problem and increased the observed failure rate by orders of magnitude to a level that would not be consistent with the regulatory assumptions established by the EPA (i.e., the bounding value is so high that it is not consistent with EPA's statements that drilling procedures will be similar to today's procedures). The PTF thus 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. Because the premises under which the PTF worked apply equally well to mining as to drilling, the PTF recommends that the failure estimate developed for inadvertent drilling also be used for potential mining intrusions.

ACRONYMS/INITIALISMS

AIC	active institutional controls
BID	Background Information Document
BLM	Bureau of Land Management
CAG	Compliance Application Guidance
CAO	Carlsbad Area Office, DOE
CCA	Compliance Certification Application
CCDF	complementary cumulative distribution function
CDR	Conceptual Design Report
CFR	Code of Federal Regulations
CTAC	Carlsbad Technical Assistance Contractor
DOE	Department of Energy
EPA	Environmental Protection Agency
FR	Federal Register
FSAR	Facility Safety Analysis Report
IAEA	International Atomic Energy Agency
LWA	Land Withdrawal Act
PA	performance assessment
PICs	passive institutional controls
PRP	PICs Peer Review Panel
PTF	PICs Task Force
QA	quality assurance
RCRA	Resource Conservation Recovery Act
SAIC	Science Applications International Corporation
SI	Supplementary Information
SNL	Sandia National Laboratories
TRU	transuranic
USDWs	underground sources of drinking water
WID	Westinghouse Waste Isolation Division
WIPP	Waste Isolation Pilot Plant

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 (TRU) 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 the 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 40 CFR Part 191 contain four main provisions related to disposal of radioactive waste in a repository. Firstly, Subpart B requires the use of performance-assessment (PA) analyses to calculate the performance of a disposal system for 10,000 years and to 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 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" (in 40 CFR Part 191) (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 deter to potential intruders by providing information about the existence and location of the repository, the wastes buried there, the nature of the hazard the wastes represent, and the necessity of not disturbing the disposal system. The use of PICs is based on a fundamental assumption about nuclear-waste disposal 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) includes both the requirement for PICs and the permission for the PA calculations 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 to the EPA. 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 framework (61 FR 5231/EPA, 1996c).

The EPA's regulations, both 40 CFR Parts 191 and 194, establish the framework for the consideration of PICs in PA (i.e., defining what is to be considered and how) with the intent of limiting undue speculation about the future. For PA purposes, PICs are intended to deter inadvertent human intrusion by the natural-resources industry anywhere within the Withdrawal. The consideration is only for 700 years after closure, and the current procedures and technologies of the natural-resources industry are assumed to be used for the entire 700 year period.

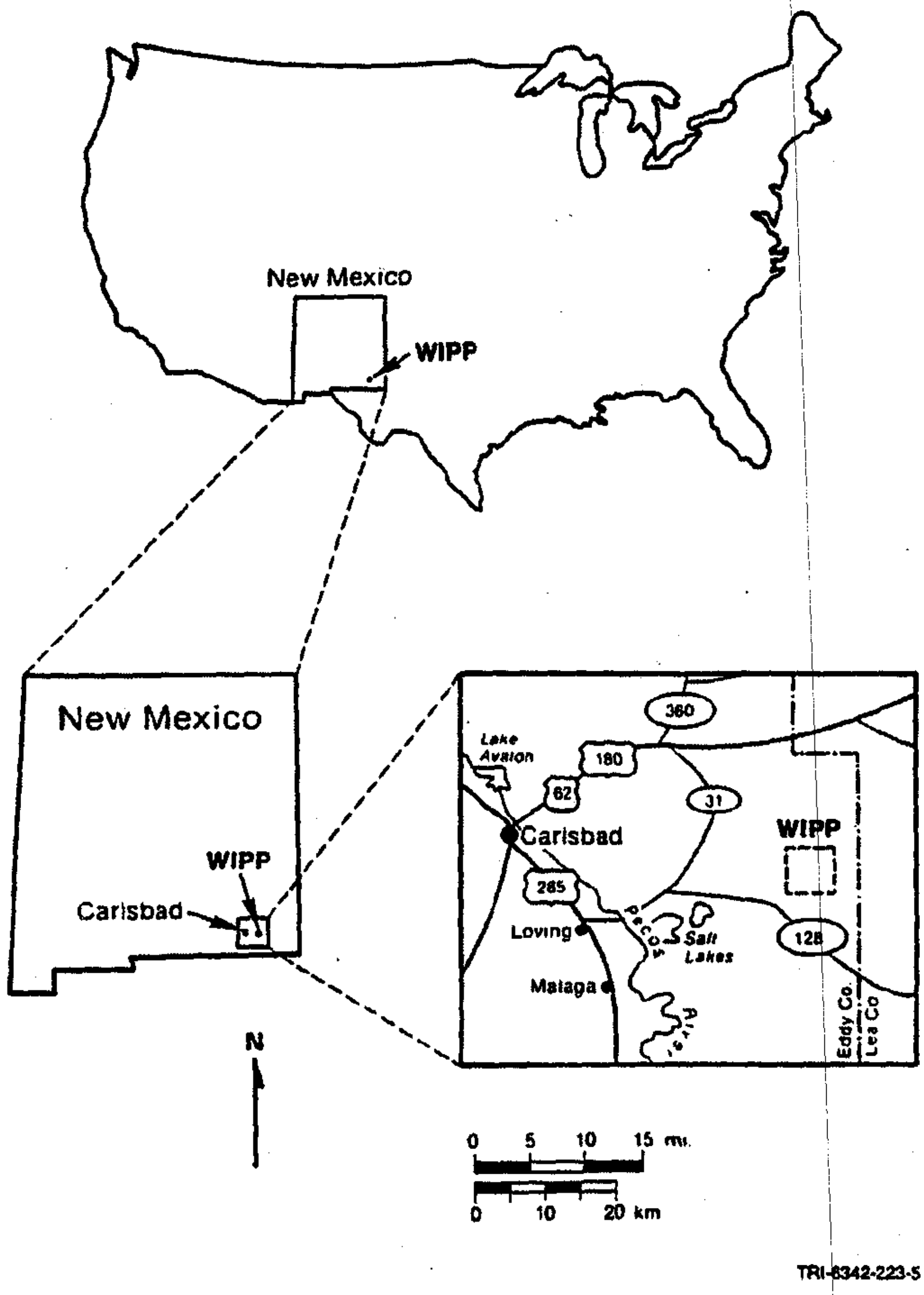

Figure 1-1. Location of the WIPP (after Bertram-Howery and Hunter, 1989).

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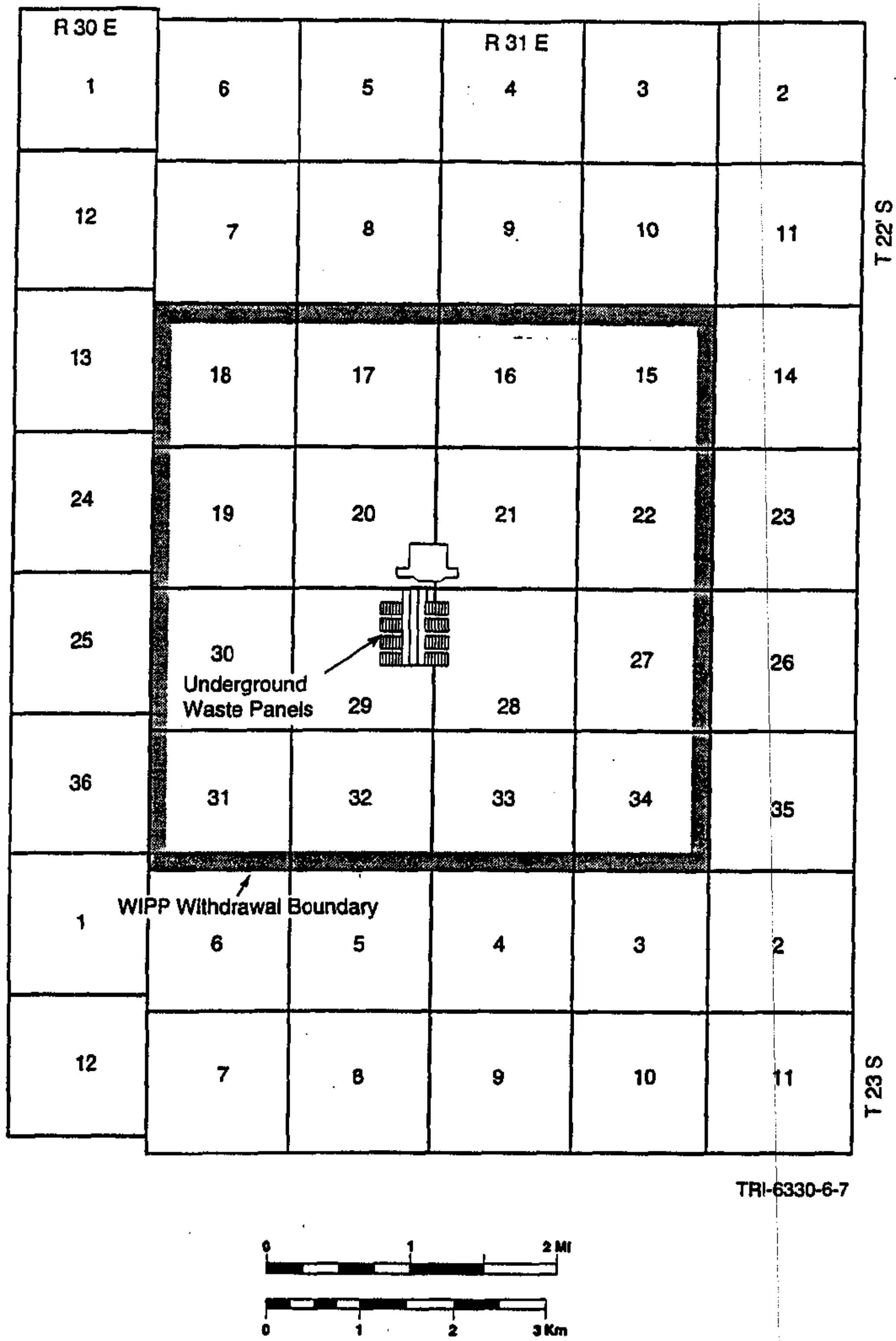

Figure 1-2. Position of the WIPP waste panels within the Withdrawal (DOE, 1990a).

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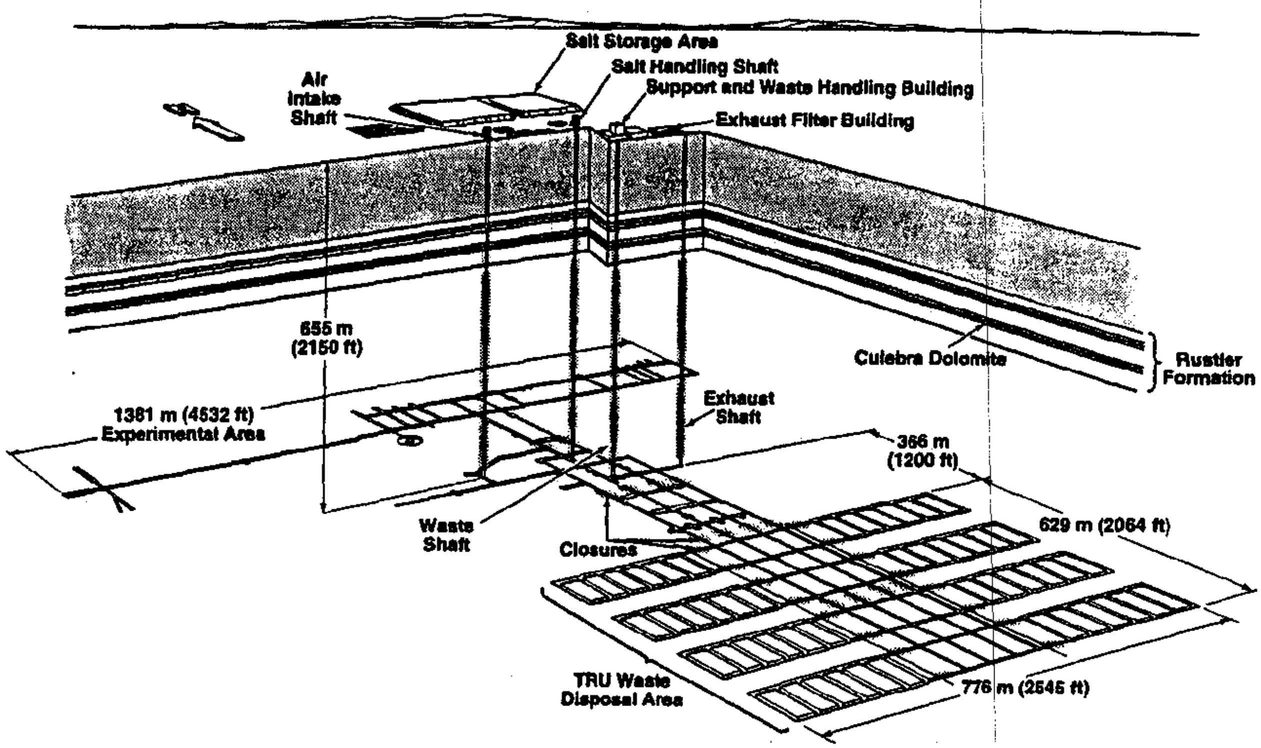

Figure 1-3. Relationship between the WIPP surface and subsurface facilities (after Waste Management Technology Department, 1987).

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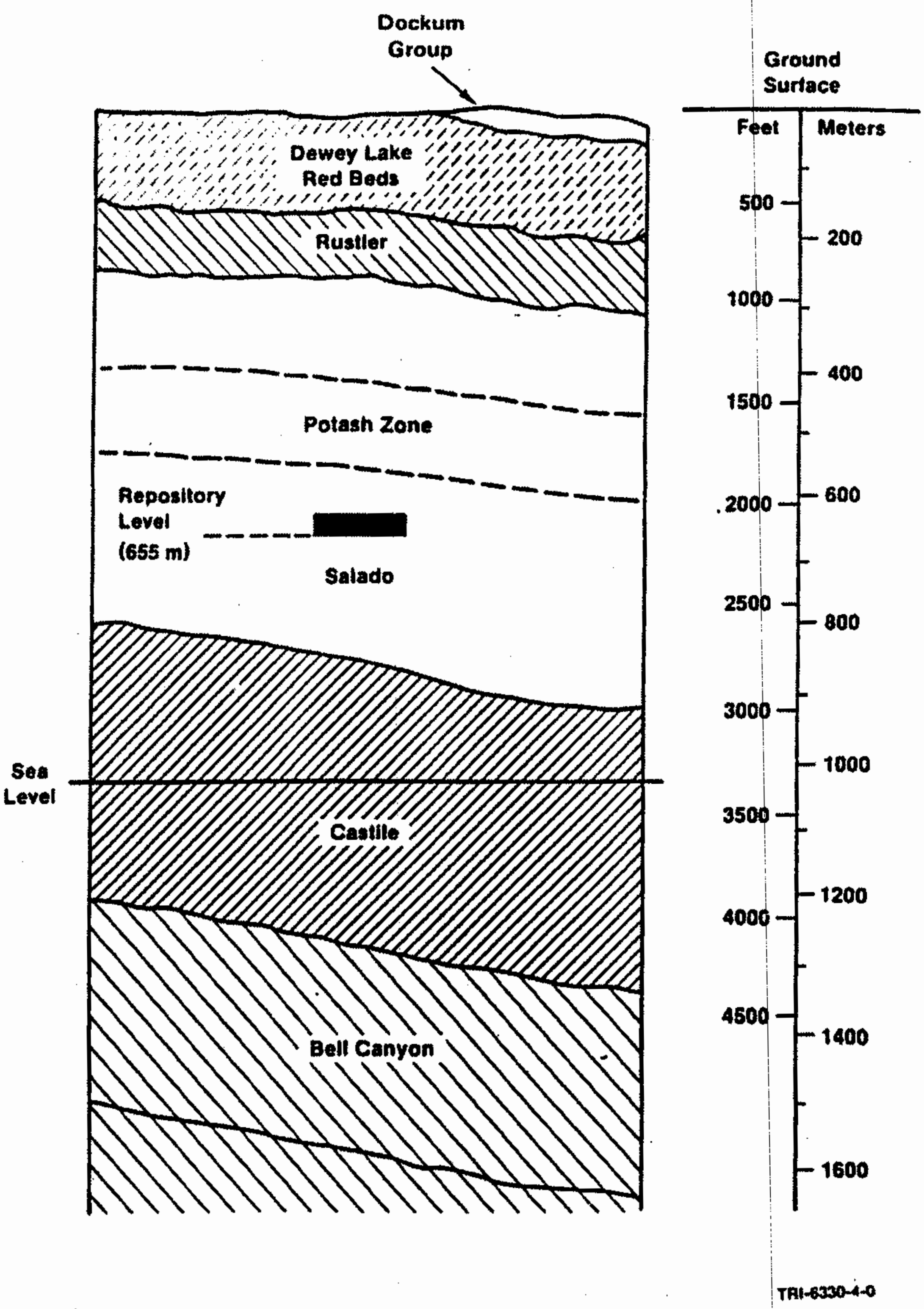

Figure 1-4. **Generalized stratigraphy at the WIPP (after Waste Management Technology Department, 1987).**

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1.3 PICs Task Force Objectives

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

As described in Section 1.4, the deliberations of the PTF were followed by external peer review of the results and the process by which the results were developed. As such, the PTF provided input materials for the peer review—supplying the effectiveness estimates and supporting arguments, and providing the PICs Peer Review Panel (PRP) with answers to questions or concerns. This report does not address the conduct of the external peer review, which was conducted within the DOE's peer-review process. This version of the report does, however, address issues raised by the peer review.

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 developed a four-step approach to achieve these goals. The first step was to convene the Markers Panel in 1991 (Trauth et al., 1993) using a process that followed the steps refined in NUREG-1150 (Hora and Iman, 1989). A comparison between the process for convening the Markers Panel in 1991 and the 1996 requirements of §194.26 Expert Judgment leads the DOE to conclude that the processes 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 was to submit the report of the PTF to external peer review (the PRP). The results of the PTF analysis were 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 with SNL having the lead responsibility. The following is a list of the PTF members:

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David Givens - American Anthropological Association
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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), the Background Information Document [BID] [EPA, 1996a], and the Compliance Application Guidance (CAG) (EPA, 1996d) 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 framework of premises for the PICs must be consistent with current drilling procedures and technology in §194.33. 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, consistent with the 700 year limitation.

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 (CDR) (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 Approach to PICs Effectiveness

The PTF examined 40 CFR 194.33 as providing the regulatory context for addressing the resource exploration and exploitation procedures and technology, and the means of deterring intrusion for PA. The individual boxes in Figure 1-5 represent conditions or activities that contribute to the three key elements of deterrence: (1) to endure for the required 700 years, (2) to be encountered by potential intruders (i.e., the natural-resources industry), and (3) to be understood by that same industry. The diagram starts out with General Societal Behavior [Box 1], realizing that society and the needs of society dictate the existence and operation of the

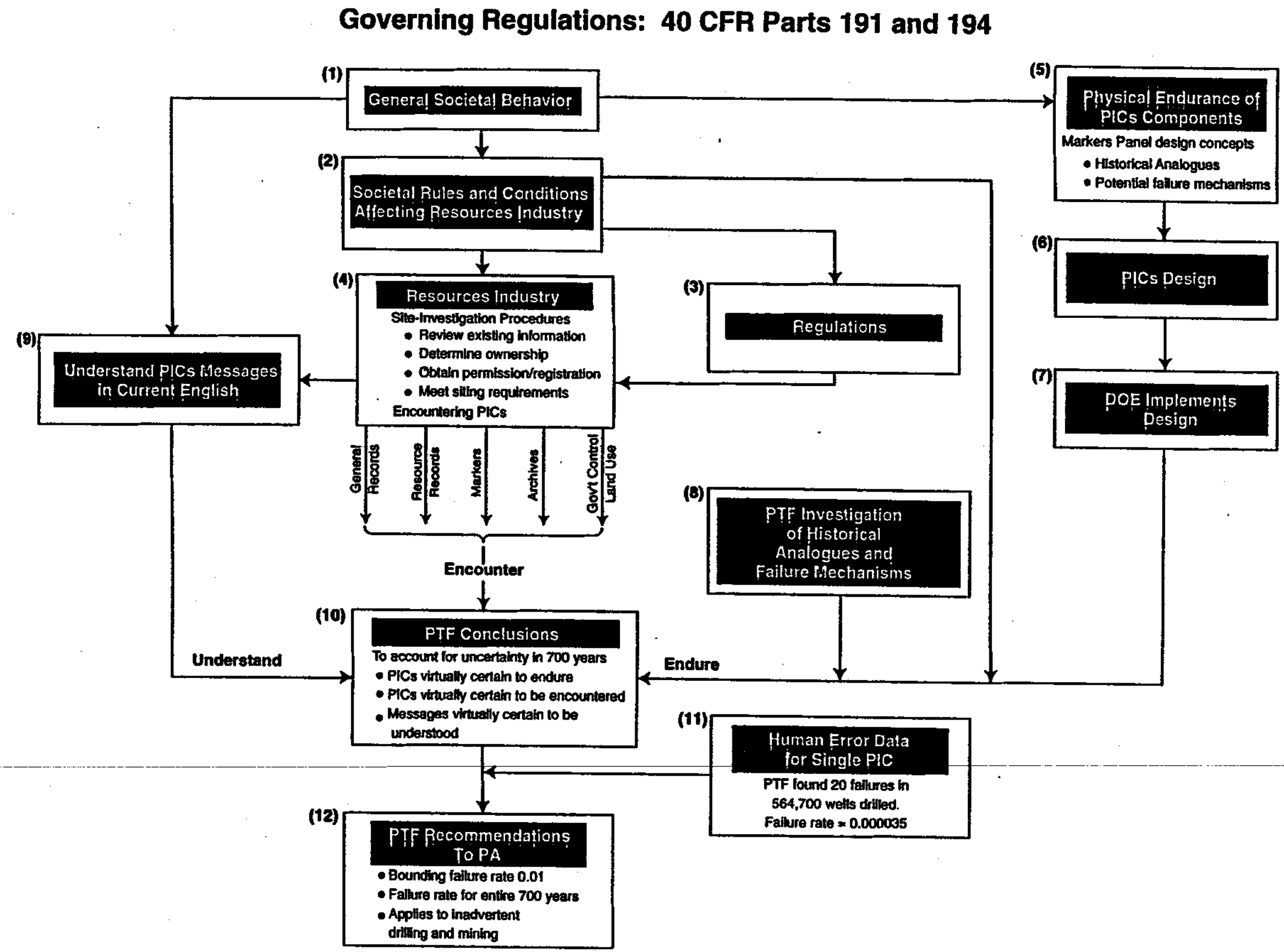

Figure 1-5. Flow diagram of PICs effectiveness (deterring inadvertent intrusion by the natural-resources industry for 7[illegible]ears). TRI-6342-4760-0

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natural resources industry [Box 2]. Regulatory guidance provided by the EPA limits the scope of the societal changes to consider for PA calculations in order to limit speculation about an unknowable future. Additional guidance provided by the EPA also limits the speculation about the future of the natural-resources industry [Box 3]. Guidance from EPA through the societal rules and conditions [Box 2] and regulations [Box 3] establishes that in the future the natural-resources industry will operate in a fashion similar to that of today (as of the date the application was submitted) [Box 4]. This industry will use site investigation procedures that are basically the same as today before drilling a borehole; industry will (a) review existing information on geology and resource potential of an area, (b) determine ownership of the property of interest, (c) go through proper channels to obtain ownership or lease, and (d) meet siting requirements for the operation of the drilling procedure.

The objective of the DOE is to provide a mechanism for preventing the natural-resources industry described in the above paragraph from intruding into the Withdrawal. Typical site investigation involves activities that will encounter the following: (a) general records centers, (b) archives, (c) resource records centers, and (d) government agencies controlling land use. In addition, this investigation is likely to include a visit to the site of interest (roads). To communicate the hazards associated with the WIPP, the EPA has identified passive institutional controls that must be implemented by the DOE, and these PICs are the same sources of information that would be utilized by the site investigator. These PICs will be encountered by the natural-resources industry in the normal conduct of their operations.

To ensure that the markers will endure in order for site investigators to encounter WIPP information, the DOE (1) convened the Markers Panel that identified design concepts for long-term communication taking into account historical analogues and potential failure mechanisms [Box 5]; (2) developed a conceptual design based on the recommendations from the Markers Panel and expanded it to include archives and records centers (incorporating features more durable than those in the historical analogues—size, number, materials, etc.—to improve durability) [Box 6]; and (3) is developing plans for implementing the designs [Box 7]. The PTF, in its deliberation, has investigated the durability of design concepts from historical analogues along with potential failure mechanisms within the 700-year regulatory time frame [Box 8]. In addition, the PTF considered those societal rules and conditions the contribute to the endurance of structures and institutions. Because the durability of the WIPP PICs is expected to exceed the durability of historical analogues and the redundancy designed into the PICs system will counter potential failure mechanisms, the PTF has concluded that the PICs will survive long enough to be encountered by the natural-resources industry for hundreds and possibly thousands of years.

To ensure that the PICs will be understood, the PTF has identified those characteristics of society that will enable current English incorporated into the PICs to be understood by future generations [from Box 1 to Box 9]. Society has developed such that current English is the international language of science, technology, commerce, and diplomacy. Wholesale, rapid changes in current English would be counter-productive for these enterprises. In addition, the PTF examined the history of English and determined that older versions of English can be read today by various individuals. Thus, this suggests that various individuals far into the future will be able to read current English. The potential economic benefit to be derived by the natural-resources industry from the information located in documents (i.e., locations of previous exploration and

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 in preventing human intrusion 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)

While credit for AICs in preventing intrusion at the WIPP cannot be taken for more than 100 years, 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. 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 institutional controls centers primarily around issues of maintenance and whether activities are directed specifically at the WIPP. Active institutional controls include physical components that will need maintenance (e.g., fences and signs) by someone who is visiting the site because it is the WIPP, who either initiates or makes arrangements for corrective actions. The medic of the passive institutional controls, including the granite of the site markers, and the paper records, and the written text, in the records centers and archives, will need no maintenance efforts. Other than the markers, the PICs "plug in" to existing societal institutions/activities (e.g., libraries, resource-development activities and government control of land use). While these institutions/activities may require the maintenance of their individual records centers or archives, this maintenance is not directed at the WIPP-specific records, and would be conducted whether or not the WIPP exists. In contrast, AICs, such as a guard driving around the perimeter of the Withdrawal, are undertaken specifically because the WIPP exists.

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 (Trauth et al., 1993).

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; (2) placement of records in the archives and land record systems of local, State, and Federal governments, and international archives, that would likely be consulted by individuals in search of unexploited resources . . . (3) other passive institutional controls practicable to indicate the dangers of the waste and its location."(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 receive 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 of §191.14, the PICs were intended to be a part of determining compliance with the Containment Requirements of §191.13. The PTF was convened to estimate the credit for PICs in PA. This report does not address the issue of the compliance of the WIPP PICs with the Assurance Requirements.

While the EPA stated the necessity of including PICs in the compliance application, 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 concerns are outside the context of credit for PICs in PA.

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 calculations 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 may 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. 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 societies or the actions of individuals (e.g., level of technology, language, culture, and natural-resource usage), only that they would be human beings with mental capabilities and bodies much like today's humans. 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 B, "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 thus 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 the Assurance Requirements of §191.14. Assessing PICs for efficacy in deterring inadvertent human intrusion over the 700 years for which credit is possible, and providing appropriate justification is wholly within the tasks associated with compliance with the Containment Requirements of §191.13.

2.11 Summary of Application Regulations

For the benefit of the reader, the major regulatory points identified in this chapter are listed below.

- AICs can be effective in deterring inadvertent human intrusion for no more than 100 years after closure.
- Implementation of PICs is required to address the Assurance Requirements.
- EPA may allow credit in PA for PICs deterring inadvertent human intrusion within the Withdrawal.
- The proposed period of time must be technically supportable, not to exceed 700 years after closure.
- Credit may be a constant or tapering reduction in the rate of human intrusion for the proposed time period.
- Credit for the PICs is to be based on a reasonable expectation that the information will endure and be understood for the proposed time period.
- The intent of PICs is to deter inadvertent human intrusion rather than intentional intrusion.
- Intrusion into the entire Withdrawal, not just the repository footprint, is a concern.
- For PA purposes, human intrusion is limited to drilling and mining.

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

3.1 Introduction

The Markers Panel identified design characteristics for the PICs to communicate with future societies of unknown social structures and technologies. This panel recommended messages and communication techniques ranging from simple warnings about the dangers associated with intruding into the WIPP to technical information that would help reestablish the technical basis of radiation and the health hazards associated with radiation exposure. Most of the Markers Panel's recommendations were incorporated into the PICs conceptual design that has been developed for the WIPP Project.

Consequence analyses of human intrusion with no constraints on the mechanisms by which this intrusion may occur presents major problems to the analysts who are trying to do complete analyses and to the regulator who must evaluate the adequacy of the analyses. To address these problems, the EPA has provided guidance designed to limit the speculation that must be incorporated into these analyses. This guidance was originally manifested as Appendix C of 40 CFR Part 191, which was replaced by the requirements in 40 CFR Part 194. Information in the CAG provides an additional view of the intent of the EPA in limiting speculation about the future.

This chapter discusses what the PTF established as the future framework of society and technology based on the regulatory guidance provided by the EPA and logical deductions following from this guidance. *The EPA's regulations, both 40 CFR Parts 191 and 194, establish the framework for the consideration of PICs in PA (i.e., defining what is to be considered and how) with the intent of limiting undue speculation about the future. For PA purposes, PICs are intended to deter inadvertent human intrusion by the natural-resources industry anywhere within the Withdrawal. The consideration is only for 700 years after closure, and the current procedures and technologies of the natural-resources industry are assumed to be used for the entire 700-year period.*

3.1.1 Regulations

The PICs are intended to convey a convincing message to future generations that deters 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 of 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)

3.1.2 Compliance Application Guidance

With regard to PICs, the EPA's 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)

The EPA does provide an approach to dealing with the issues of how PICs can be addressed in the context of PA by establishing guidance in the CAG with regard to assumptions and societal "common denominators." Guidance for the assumptions that can be used states that:

> "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 an example provided on what will and will not be accepted in the context of the future state of society, the EPA states that government regulations will remain in force, but the exact form and content of the regulations cannot be identified with certainty. In continuing the guidance, the EPA does not require justification for the existence of government but does require justification why any assumptions about the regulations are sound. The treatment of government in this example is consistent with the paragraph in the CAG following this example that discusses societal "common denominators."

Societal "common denominators" are described as:

> ". . . patterns of human behavior that may be detected throughout history and around the world." (EPA, 1996d)

Nowhere in this paragraph are these common denominators described as "assumptions," nor is there any suggestion that the discussion of assumptions in the previous paragraph applies to common denominators. This approach is consistent with the view that basic human characteristics (i.e., societal common denominators) are facts and not assumptions. In addition, nowhere in this paragraph does the EPA state or imply that these societal common denominators need to be justified by the DOE.

The guidance provided in the CAG about the prudent extrapolation of the future states of society and technology are more speculative than the current conditions of society and technology described in the future-state assumptions of §194.25. As a result, estimates of PICs effectiveness based on the guidance in the CAG would be more conservative than estimates based on the future-state guidance in §194.25.

3.2 PTF Approach

The PTF did not use or rely on the future-state assumptions of §194.25 in the development of estimates of effectiveness of PICs in deterring inadvertent human intrusion for PA calculations.

While §194.25 mandates the use of future-state assumptions, EPA's Response to Comments states that the future-state assumptions do not apply to work on PICs;

> "Future states assumptions do not apply to passive institutional controls. The final rule states that conditions will be assumed to be the same as the present unless otherwise specified in the rule. The final rule also clarifies that such assumptions apply in performance assessments and in compliance assessments; they are not to be applied to assurance requirements." (EPA 1996b, p. 7-7)

The PTF relied upon the language in §194.33 as the primary guidance for assessing the effectiveness of PICs in deterring inadvertent human intrusion for PA calculations.

In addition to guidance on future-state assumptions and common denominators, the EPA provides additional specific guidance in §194.33 and the related Supplementary Information for the treatment of future drilling practices and technology. Because the requirements of §194.33 and their basis are not part of the EPA's future-state assumptions in §194.25, there is no apparent prohibition from applying this guidance to PICs. The PTF therefore considers that current drilling practices in the Delaware Basin are activities that fall within the scope of PICs.

The EPA states that

> "Future drilling practices and technology will remain consistent with practices in the Delaware Basin at the time a compliance application is prepared. Such future drilling practices shall include, but shall not be limited to: The types and amounts of drilling fluids; borehole depths, diameters, and seals; and the fraction of such boreholes that are sealed by humans;" (61 FR 5242c/EPA, 1996c)

This statement has widespread implications for the consideration of PICs as deterrents to future inadvertent human intrusion into the WIPP in PA. The guidance that future drilling practices and technology will remain consistent with current practices (as of October 30, 1996) implies that basic human attributes regarding natural resources will not change over the period of regulatory concern (i.e., 700 years in the case of PICs). In addition, the PTF interprets the term "practices" to include those typical procedures employed by the natural resources industry prior to drilling (e.g., site investigations and lease acquisitions). Guidance with regard to borehole sealing, which is an activity that is regulatory driven to protect public safety and site preservation rather than something a company would normally do as part of resource development, requires the existence of a regulatory body (i.e., government) and the accompanying tools to ensure compliance with the regulations.

With respect to the appropriate treatment of the non-binding guidance in the CAG, the PTF notes that the CAG (on PICs issues) and §194.33 are consistent. The PTF interprets this consistency as resulting from the fact that the CAG (with regard to societal common denominators derived from historical and world-wide observations) is an expansion of the intent represented in §194.33. Language in the CAG describing the situation established by §194.33 as a "prudent extrapolation" was retained by the PTF because it very succinctly describes the relationship between §194.33 and the PICs. The PTF has likewise retained the CAG terminology of "common denominator" because this term describes the historical and societal conditions implicit in §194.33.

Examples of the consistency between §194.33 and the CAG include the existence of some form of government and regulations dealing with natural resources. The EPA has classified the existence of government as a societal common denominator, but the specific contents of regulations may vary and require justification. In a broader context, the existence of regulations and procedures associated with drilling also ensures that site characterization will continue to be required before drilling can begin.

The following sections list and the explain premises that the PTF used in estimating the effectiveness of PICs in deterring inadvertent human intrusion. To avoid possible confusion in terminology and/or origin of these working assumptions, each one is labeled as either a Common Denominator, a Regulatory Assumption, a PTF Assumption, or a PTF Conclusion (derived from the PTF Assumptions). Human attributes listed in Section 3.2.1 were derived from the regulatory guidance provided by the EPA on drilling procedures and technology in §194.33. Because these human attributes are basically the same as those identified by the EPA in the CAG, the PTF has labeled these attributes as Common Denominators. Section 3.2.2 deals with government. The continued existence of government and government regulatory controls also are Common Denominators and are implied in §194.33, although the PTF Assumptions related to government and controls were logical deductions based on the operations of governments. PTF Assumptions about the future of language (Section 3.2.3) were logical deductions based on the worldwide use of current English, the reduced rate of structural change in recent centuries, and the economic value of information written in current English to the natural resources industries. The PTF also has listed Regulatory Assumptions in the area of natural resources (Section 3.2.4) that were derived from §194.33 and the relevant material in the Supplementary Information to 40 CFR Part 191. PTF Assumptions and a PTF Conclusion that had a major impact on the PTF's estimate of PICs effectiveness are described in Section 3.2.5.

3.2.1 Basic Human Attributes

Common Denominator (1): Humans will continue to be curious.

People will continue to be curious about writing, pictures, symbols, and structures, and they will attempt to decipher them or have them deciphered. This common denominator is especially prevalent in the natural resources industry (and over the 700 years under consideration) where site investigators are paid to be curious in order to obtain as much relevant information about the possible presence of natural resources as possible prior to drilling operations and to secure the legal rights to the natural resources being sought. The PTF believes that curiosity will continue to be a trait of individuals in this industry, and this belief is consistent with §194.33.

Common Denominator (2): The use of the written word to transmit information and concepts will continue.

As Gaur (1992, p. 14) has stated, "All writing is information storage." The primary advantages of written information over other forms of information storage are that, at least theoretically, no limit exists on the amount of information that can be stored and written information can be manipulated (Gaur, 1992). Written information about potential natural resources in an area (as recorded in written records and documents) has widespread economic value. This ability of the natural resources industry to record and manipulate written information will not be replaced unless an entirely new technology is developed to replace writing. In addition, writing has been and is used to establish and communicate property ownership, contracts, and governmental control through regulations.

Common Denominator (3): Storytelling or the generational "passing down" of history will continue.

People will continue to be interested in their history and will continue to pass it down to future generations through writings and storytelling. In the natural resources industry, this passing down of history has included and will continue to include stories about the "big strikes" and the major financial and legal disasters of the past because of the potential economic benefit from undertaking certain activities and not undertaking other activities.

Common Denominator (4): The ability of pictures to convey meaning will continue.

In the natural resources industry, pictures include maps (e.g., geologic and geophysical maps), cross sections, fence diagrams, and well logs, all of which have economic value in the areas of natural-resource exploration and site evaluation. Pictures are currently used to store and communicate information and will continue to do so in the future because of the potential economic benefit to be gained through the use of the information.

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

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. The tendency of people to avoid governmental controls has led to an extensive regulatory structure established by governments to control the impulses of individuals or companies in the natural-resource industry (and other industries) to "take advantage of the situation." In addition to the regulatory structure, established legal remedies and penalties for non-compliance have been implemented throughout history. The existence of prisons is a basic example of the fact that some people do avoid or ignore controls.

PTF Assumption (1): Individuals will continue to look out for their own interests in the economic arena.

Individuals will continue to monitor the activities of their competitors in order to gain a personal benefit from competitors' actions or to prevent the competition from gaining a perceived unfair advantage. In the natural resources industry, individuals have a vested interest in obtaining information as economically as possible and estimating the risk (cost versus benefit) of an endeavor before investing large sums of capital. If the risk is too large (e.g., the cost of development is too high or ownership cannot be obtained), the investment will not be made. "Individual" can mean a single person, a corporation, or the State.

This assumption is focused on behavior related to locating and acquiring natural resources and does not address either individual, corporate, or government altruism with regard to the treatment of individuals in need or danger or charitable causes.

3.2.2 Government

Common Denominator (6): The existence of some form of government will continue.

Governments have existed throughout recorded history and worldwide. The functional nature of government indicates that government will exist in some form for the entire regulatory period. Government by definition means "the control and administration of public policy" (Houghton Mifflin Company, 1991). 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. In the area of natural resources, some form of regulation is required for dispute resolution and maintenance of public safety (e.g., borehole sealing) for as long as natural resources have value and attract exploration and exploitation activities. The guidance in §194.33 that drilling procedures will continue requires the existence of government, because some of these procedures involve economic matters and conflict resolutions.

Common Denominator (7): Government will exert some level of regulatory control over the exploration for and development of resources.

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 (e.g., legal procedures, armed force, penalties) to enforce the regulations (e.g., borehole sealing) or edicts. Because borehole sealing requires financial expenditures that have no immediate returns, regulatory authority will be used to ensure the "public good," along with governmental ability to enforce the regulations.

PTF Assumption (2): Governments will require and maintain records as part of the procedure to maintain controls.

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. Governments currently require record keeping and will continue to do so in the future. In dealing with natural resource, governments require and maintain records to ensure proper ownership of the resources at specific locations, to ensure the payment of rents, royalties, and taxes and to ensure that procedures have been followed (e.g., boreholes are located, cased, and sealed correctly).

PTF Assumption (3): Governments will continue to protect property rights.

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 ensure 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 Common Denominator 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).

3.2.3 Language

PTF Assumption (4): Current English will continue to increase in the size of its vocabulary and areas of use, but the basic vocabulary and structure will resist change.

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 worldwide range from 800,000,000 to 1,500,000,000, and English has official status in more than 60 countries (Crystal, 1994). Because of this widespread use and official status, at least a portion of both government records and those private records having a connection to the government in non-English-speaking countries are and will be in English. In order for government regulations to take place and for contracts in the private sector to be fulfilled, participants must be able to understand the language of the regulations and contracts even over long periods of time. Translating large volumes of documents in current English to another language would require considerable effort and would require negotiating precise meanings to words and concepts in the translations. As a result, retaining a knowledge of current English is an economic benefit.

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.

PTF Assumption (5): Current English will remain decipherable by future generations of English readers for at least 1,000 years after disposal.

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).

This PTF assumption is consistent with the conclusion of Team B of the Markers Panel (Trauth et al., 1993).

PTF Assumption (6): Current English will continue to be read by the natural resources exploration and exploitation industries.

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. For an example of an "industry"-specific language being resurrected and maintained, refer to the discussion on the *Atocha* (Sullivan, 1987) in PTF Assumption 5.

3.2.4 Natural Resources

Regulatory Assumption (1): 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 5242c)
>
> 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 also 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)

Regulatory Assumption (2): 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. (Supplementary Information corresponding to §194.33)

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 before the theoretical basis for nuclear reactions was developed. 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)

Regulatory Assumption (3): 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 not 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)

Regulatory Assumption (4): 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(b)(2) states that the drilling of exploration and exploitation boreholes is to be considered as random in time and space during the regulatory time frame for PA purposes (see Regulatory Assumption 3). Regulatory guidance also states that the rate of drilling of both deep and shallow boreholes is to be based on the rate of drilling for the previous 100 years (see §194.33(b)(3) and §194.33(b)(4)).

For the purposes of developing this regulatory assumption, only deep drilling is considered. This historical drilling record for deep boreholes in the Delaware Basin converts to a drilling rate of approximately 47 boreholes/km^2 for the 10,000-year regulatory time frame. This relatively high drilling rate virtually ensures that random sampling of the time of occurrence of drilling will result in boreholes being drilled throughout the regulatory period. If this sampling resulted in a uniform distribution of boreholes in time within the 23,100 km^2 of the Delaware Basin, this drilling rate would result in approximately 108 boreholes being drilled per year.

For a Poisson model, the probability (Pr) of drilling not occurring within a time interval (Δt) for a particular drilling rate per year (λ) can be determined with the equation

$$Pr = e^{-\lambda \Delta t} .$$

Using this equation with the regulatory-derived drilling rate (λ=108.57/yr), the probability of no drilling within the Delaware Basin in any year (Δt=1) is approximately 1×10^{-47}.

The point of this discussion is that the drilling rate that must be used in PA ensures that the drilling in the Delaware Basin will continue over the regulatory time period with no time breaks during which knowledge associated with natural resources can be lost. The records centers dealing with natural-resource exploration and exploitation will be busy processing and maintaining permits and records on a continuous basis, and these records centers will continue to be sources of information for the natural resources industry.

PTF Assumption (7): Resource exploration and exploitation are not casual activities.

Resource exploration and exploitation require 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 performing site investigations. All these steps occur prior to drilling.

3.2.5 Estimating PICs Effectiveness

PTF Assumption (8): 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.

For example, Congress has established the LWA, which 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. This assumption is an extrapolation of EPA's requirement that only inadvertent intrusion must be considered. This extrapolation is from the requirement of individuals to be responsible for their actions to governments that also must be responsible.

PTF Conclusion (1): Communicating with future societies using words, pictographs, symbols, and diagrams through a variety of media is possible.

This conclusion is derived from Common Denominators 2, 3, and 4.

PTF Assumption (9): Historical analogues of structures, media, and messages that have withstood the test of time represent design characteristics that allow the DOE to design for success.

Historians and archaeologists have observed that certain structures, media and messages have survived for long periods of time, whereas others have not. Such observations suggest that certain design considerations of structures, certain materials, and certain communication methods are more durable than others. The DOE can incorporate successful design characteristics to improve the prospects that PICs will endure and will be understood.

PTF Assumption (10): Today's scientific and engineering communities have the capability to create PICs that will perform at least as effectively as historical analogues.

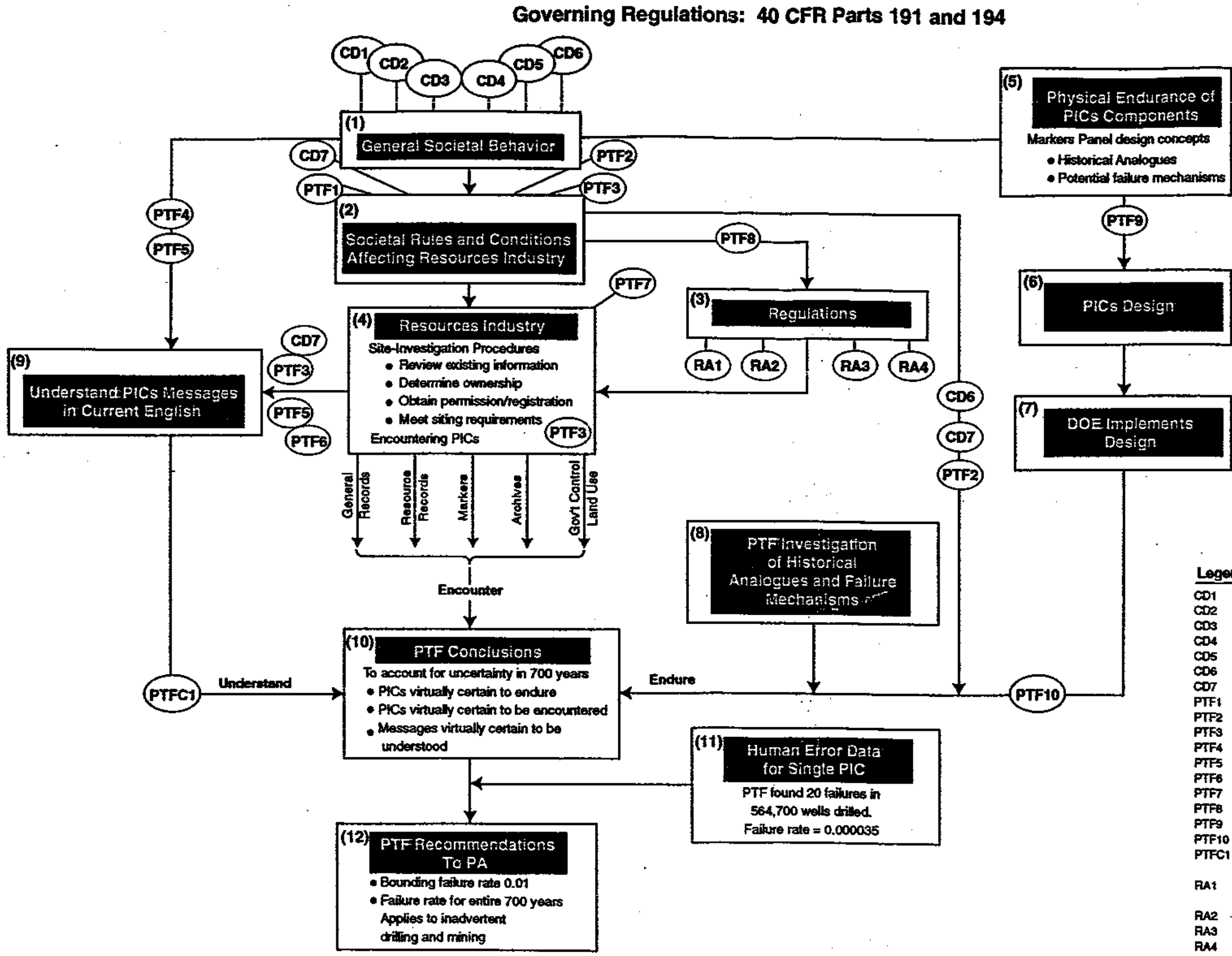
The technology used to construct the historical analogues was primitive by today's standards in that it was based on muscle power and the use of readily available materials. With the development of the PICs, the DOE is attempting to exceed the results of the historical analogues with a much higher knowledge base (why things survive) using much more advanced technology (e.g., mechanization, chemical composition of archival paper, environmental controls for records maintenance).

3.3 The Relationship Between PTF Working Premises and the Activities/Conditions Contributing to Deterrence

Figure 1-5, which is the flow diagram of PICs effectiveness, is reproduced as Figure 3-1 with the incorporation of the PTF's working premises to indicate how all the premises were used in the development of an estimate of effectiveness. Figure 3-1 indicates those premises upon which each of the activities/conditions were based. When a premise is repeated within the figure, the intent is to emphasize its importance for a particular activity/condition.

3.4 Summary

The EPA (1996b) states that the "future-state" assumptions in §194.25 do not apply to the PICs. As a result, the PTF relied on the EPA guidance in §194.33, which deals with the premises that the DOE can use in the areas of drilling procedures and technology to eliminate undue speculation about future states in PA, to establish societal framework for assessing the effectiveness of PICs. In addition to establishing the pertinence of various regulatory assumptions to PICs in PA, the PTF used §194.33 guidance and related Supplementary Information to establish common denominators and PTF assumptions that are consistent with the additional guidance that the EPA provided in the CAG. Each of these categories is numbered and italicized throughout this chapter. These premises provide a basis for the communication concepts discussed in Chapter 4, the PICs discussed in Chapter 5, and the estimate of PICs effectiveness presented in Chapter 6.



Legend

CD1	(Common Denominator 1) Curiosity
CD2	Written word transmits information
CD3	"Passing down" of history
CD4	Pictures convey meaning
CD5	Some people avoid or ignore controls
CD6	Government will exist
CD7	Government will exert regulatory control
PTF1	(PTF Assumption 1) Individuals look out for own interests
PTF2	Governments require records for controls
PTF3	Governments protect property rights
PTF4	Current English will resist structural change
PTF5	Current English decipherable ≥1,000 years
PTF6	Current English read by natural-resources industry
PTF7	Resource activities are not casual
PTF8	Individual and government responsibilities
PTF9	Historical analogues identify design concepts
PTF10	PICs perform better than historical analogues
PTFC1	(PTF Conclusion 1) Communicating through various media is possible
RA1	(Regulatory Assumption 1) Today's technology for natural-resources industry
RA2	Historical drilling rates surrogates for future drilling rates
RA3	Always resources of value in Delaware Basin
RA4	Virtually continuous natural-resources activity in Delaware Basin

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Figure 3-1. **Flow diagram of PICs effectiveness incorporating PTF premises (deterring inadvertent intrusion by the natural-resources industry for 700 years).**

4.0 BASIC COMMUNICATIONS CONCEPTS

The regulatory bases for PICs in PA are discussed in Chapter 2. In developing the conceptual designs for the PICs to address the Assurance Requirements (§191.14(c)), 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 PICs system for the WIPP consists of two types of components. Awareness Triggers are one type of component and are intended to alert the potential intruder or site investigator that something anomalous is present at the WIPP site, and that more information should be obtained before proceeding with the intrusion activity. In the search for additional information, the potential intruder or site investigator will encounter one or more Deterrent Components, which are the other type of components. Deterrent Components are designed to convey a warning to the potential intruder or site investigator that the WIPP site contains hazardous materials and drilling is not allowed.

4.1 Communications Model

4.1.1 Generic Communications Model

The PRP, in a review of an earlier version of this report, discussed the inclusion of a generic communications model. A model consisting of these steps is appropriate for anyone trying to communicate with anyone else. For example, these steps are as appropriate for writing a letter for someone who will receive it tomorrow as they are for PICs communicating with someone who will not be born for generations. The steps in the generic model discussed by the PRP are: (1) Develop Intention, (2) Identify Audience, (3) Encode In Language, (4) Capture In Media, (5) Transmit, (6) Receive, (7) Decode, (8) Understand, and (9) Respond (Glicken, 1996).

4.1.2 Generic Communications Model with Reference to WIPP PICs

Although no communications model was identified in the CDR for the PICs design, the PTF has identified the WIPP activities corresponding to each of the steps in the above generic communications model:

(1) Develop Intention

For PA calculations, communicate concepts of location, design, and content of the repository, and the hazard of the wastes in the repository.

For the Assurance Requirements, (a) communicate concepts of location, design, and content of the repository, and the hazard of the waste in the repository; (b) provide enough information to enable future societies to reestablish scientific basis for radiation and associated hazards (archives, general records centers, Information Center, buried rooms); and (c) provide enough information to reestablish knowledge of WIPP site, repository, ground-water flow, etc. (archives, general records centers).

(2) Identify Audience

For PA calculations, the audience is established in 40 CFR Part 194 as the potential intruder for resources (i.e., the natural-resources industry and not the individual drill-rig operator).

For the Assurance Requirement for PICs, EPA provides no guidance on what limitations DOE can assume about the future, so DOE cannot make any assumptions about the state of society or technology. As a result, the target audience cannot be identified.

(3) Encode In Language

For PA calculations, PTF Assumptions 4 through 6 in Chapter 3 established that current English is sufficient for correct communication.

For the Assurance Requirements, to accommodate the possible range of future societies, DOE will use five levels of messages ranging from a simple message that humans did something here to highly complex messages that can help to reestablish knowledge about radioactivity and possible health effects from exposure to radiation and detailed information about the WIPP facility, the contents, and the disposal system. Messages will be in the form of objects, text, pictographs, tables, and charts. DOE will test these messages by seeing if transcultural groups can understand the various messages in the different formats. These principles of communication were established by the Markers Panel (Trauth et al., 1993).

(4) Capture In Media—Selection of materials that are the most permanent practicable and placing the correct messages on the selected materials (e.g., granite and archival paper).

(5) Transmit—Physical markers are sent to the WIPP site and emplaced as per the design; paper records are sent to the designated records centers and archives and are incorporated into the collections per agreed upon indexing system; land use covenants sent to government agencies controlling land use and incorporated into the regulatory system; correct information sent to previously agreeable publishers of textbooks, reference books, and maps for publication and distribution through normal channels. Transmission occurs when the information gets into specific system above.

(6) Receive—PICs components endure for future generations to encounter.

(7) Decode—Warnings/messages are understood by future generations.

For PA calculations, this step requires that the potential intruder be able to understand the words of current English.

For the Assurance Requirements, this step requires that the potential intruder be able to understand either the written messages (in one of the languages used) or the pictographs.

(8) Understand—Future generations comprehend that the warnings/messages are directed at them.

DOE will have a testing program to ensure that the intended messages and warnings are captured in the text and pictographs.

(9) Respond

For PA, the response of future generations to the warnings/messages is not relevant—if warnings are ignored and intrusion occurs with knowledge of the possible consequences, the intrusion is intentional and is not part of PA.

For the Assurance Requirement, how future generations respond to the warnings/messages is not relevant to complying with this requirement.

4.1.3 PTF Focus for PICs Communication

EPA regulations identified the intentions of the PICs (Step 1); the Futures Panel (Hora et al., 1991) identified the audience in the Assurance Requirement arena whereas the rule identified the audience in the PA arena (a potential intruder in the natural resources industry) (Step 2); the Markers Panel identified the communications principles; and the DOE incorporated these principles into a conceptual design of the most permanent PICs practicable (Step 3).

The PTF dealt with the issues of how long the PICs would endure with their messages intact and whether the messages could be decoded (recognized) and understood in the 700 years of PA concern. The inappropriate response of future societies that have understood the messages was not a PTF concern.

The approach of the PTF was to focus on the EPA's two concerns of messages enduring and being understood (Steps (6) through (9) of the general communications model—see Section 4.1.1). Steps (3), (4), and (5) of the general communications model were assumed to be completed because the DOE has committed to implementing the PICs as described in the CDR.

QA procedures are being developed by the DOE that will ensure that Steps (3), (4), and (5) of the PRP's general communications model take place: (3) ensure that the linguistic and non-linguistic messages are developed to communicate the intended information, (4) the correct media are selected (e.g., correct paper, correct quality of granite), and the correct messages are captured in the appropriate media (e.g., the printer copies the correct messages on the correct paper, the engraver carves the correct messages at the correct locations in the granite monuments and walls), and (5) the completed PICs components will be transported to the correct locations (e.g., the records get to the correct records centers and archives, the granite monuments are delivered and emplaced in the correct locations).

Step (6) Receive—If the messages are to be received, they must endure (Step 6a) and be understood (Step 6b).

Step (6a) The PICs must endure for the regulatory time frame of interest.

An examination of historical analogues pertinent to certain design characteristics of the PICs identified physical characteristics that increase the likelihood that materials and structures will endure for extended periods of time. Among the characteristics identified were the use of durable materials and the development of multiple copies. The PICs planned for the WIPP were designed to take advantage of these characteristics using current design knowledge and technology to develop PICs that have a high probability of exceeding the performance of the historical analogues.

Step (6b) The PICs must be encountered.

When the DOE refers to a potential intrusion being deterred, the deterrence is not aimed primarily at the drill rig operator, but at other personnel involved in site investigations who are paid to be curious and find out all the pertinent facts about a site. Because resource exploration and extraction are not casual activities, decisions authorizing the expenditure of funds for drilling will be made by a senior official with the authority to commit the needed financial resources based on the site's geology, obtaining resource rights, and the probability of adequate financial return, and not made by the drill rig operators. As a result, the individual doing the site investigation must search records to establish ownership of surface and natural resource rights and may visit the site itself to determine the feasibility of drilling at the site. The locations of the PICs were selected to ensure that someone doing a site evaluation would encounter at least one of the Deterrent Components.

Step (7) Decode—The contents of the messages must be comprehended.

The PTF developed an assumption that current English will be understood by potential intruders (i.e., people involved in natural resource exploration and exploitation) for at least 700 years after disposal. This assumption was based on the ability of current societies to read and understand past versions of English, the volume of resource-related records and information that will be of economic importance to future societies, and the virtually continuous high level of resource-related activities in the Delaware Basin required by regulatory guidance. This assumption ensures that future societies will be able to read and understand the messages on deterrent PICs that survive intact (or relatively intact for some deterrent PICs).

Step (8) Understood—The messages are understood as a warning for the current reader.

When a message is comprehended as a warning, then a potential intruder recognizes the danger of intruding as a fact (not a myth) and knows that the warning is not just the remnant of a previous danger, but is intended to warn the current generation and future generations. The DOE will undertake a testing program prior to the implementation of the PICs to ensure that the messages can be understood as an ongoing warning.

Step (9) Respond—The warnings must deter future societies from inadvertently intruding into the WIPP.

For the purpose of this analysis and to be consistent with regulatory usage of the term "deterrence," the DOE assumed that deterrence would occur if the PICs endured long enough for future societies to encounter them and the messages could be understood. The DOE concluded that in the regulatory framework established by the EPA and the assumptions that could be developed from this framework, each of the Deterrent Components of the PICs contains sufficient warning in current English for a potential intruder to understand the potential dangers of the radioactive material.

4.2 Systems Approach for PICs Design

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. The PICs system is designed to include a wide variety of PICs components encompassing a variety of message levels (see Section 4.3) and using a variety of media for conveying the messages. 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 §191.14, the DOE has extended the systems concept to incorporate archives, records centers, government land ownership and control, and other means of communication into the total PICs design.

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 extent of changes in the future state(s) of society, technology, and language (i.e., one must design for the range of possibilities, but one can make the assumption that basic biological traits of humans will remain the same). With limited assumptions about the future, the systems approach means that (1) the multiple messages, levels of complexity, and communication media all reinforce each other to fill in gaps in communication and (2) the PICs are actually available and contain the necessary information 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 regulatory assumptions. Credit for PICs in PA is also limited to the much shorter time frame of 700 years. 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 that any one could correctly communicate the information and deter the potential intrusion.

4.3 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.

These different message levels are generally targeted at different audiences to address the Assurance Requirements rather than to address the credit for PICs in PA. Level II, and perhaps Level III, messages are targeted at people in societies that are not drastically different from our own who are involved in the natural resource industries that might be interested in locating or exploiting natural resources at the WIPP site. Levels III, IV, and V messages are designed to reestablish basic scientific concepts within societies in which these concepts have been lost or the social/technological/language changes have been so great that the connection between the text messages and the concepts have to be reestablished. In addition, these higher-level messages provide basic information about the characteristics of the WIPP site, the repository, and TRU waste.

4.4 PTF Approach to the PICs System for PA

The PICs components as a deterrent can be viewed in several ways:

(i) Each component is an independent deterrent whose effectiveness is uninfluenced by other components. The effectiveness of the PICs set or system is as effective as the most effective component that will be encountered by the potential intruder. Failure of one or more components could either reduce or leave unchanged the total effectiveness, depending on the differences in effectiveness of the components and the particular component(s) that fail. The message on each Deterrent Component conveys sufficient information so that comprehension precludes inadvertent human intrusion. As will be discussed in more detail below, this model is used by the PTF because of simplicity and conservatism.

(ii) The effectiveness of each of the components is dependent on the effectiveness of all of the other components. The effectiveness of the PICs system is the product of the effectiveness of each component in the system. Failure of any component to deter would mean that the entire PICs system fails.

(iii) The effectiveness of each component contributes to the effectiveness of the PICs system. The effectiveness of the PICs system is the sum of the component effectivenesses. Failure of one or more components would reduce the effectiveness of the PICs system.

(iv) The effectiveness of each component contributes to the effectiveness of the PICs system, but because of the Gestaltic nature of the system design, the effectiveness of the total PICs system is greater than the combined effectivenesses of the components. The effect of the failure of any component on the system effectiveness depends on the contribution of the component to the Gestalt.

A Gestalt is a system in which the whole cannot be determined by simply summing the parts within the whole. The Gestaltic nature of the PICs system refers to the PTF's belief that the effectiveness of the system cannot be determined by summing the estimated effectivenesses of the PICs components. The physical presence of the PICs components, the repetition of the warning over and over on different media and in different ways, the size of the markers, and the level of effort required to construct the markers and distribute the records will reinforce to the potential intruder the importance of the location, and thereby reinforce the importance of the messages and warnings to an extent that simply reading a single message is unlikely to convey.

The concept of Gestalt for PICs addresses the requirements of the Assurance Requirements; because of the potential for discontinuities in society and information, a future society might need to recreate all the information about the WIPP.

Team B of the Markers Panel discussed the relationship of the individual PICs components:

"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 PTF agrees with Team B that incorporating the impact of the Gestalt is appropriate and would result in greater probabilities of success, although representing such interactions would add additional controversy. An alternative that would introduce conservatism into the assessment of effectiveness would be to not take credit for the Gestalt, and view the components as acting as (i). The PICs for the WIPP for PA purposes are envisioned to operate as alternative (i) rather than alternative (iv) for the sake of simplicity and as a conservative action.

WIPP PICs components do not act either as alternative (ii) or (iii). Alternatives (ii) and (iii) would have portions of the messages or warnings on each of the components (i.e., no component contains the complete message or warning). For alternative (ii), the loss of any part of the warning or message means that the surviving parts are insufficient to construct the warning or message. In other words, loss of any component means that the entire system fails. For alternative (iii), each component contains a partially complete message or warning with the complete message or warning requiring all of the components. Loss of any component would reduce but not eliminate the effectiveness of the system.

Further, in an integrated system, where all of the components must be effective for the system to be effective, system effectiveness is controlled by the weakest link. An example of this would be a secret society where all members must maintain silence for the society to remain secret.

In a system where controls may reinforce each other, but essentially act independently, the most effective control determines effectiveness of the set of controls. An example of this case is the imposition of speed limits. A roadway sign indicating the legal speed limit is a control that contains sufficient information to keep a motorist from acting illegally by speeding. It may have varying effectiveness depending on the motorist and traffic conditions, for example. Police officers patrolling the highways is another means of controlling the illegal activity of speeding. If a police officer travels down the highway, then the probability of compliance with the speed limit will increase in most cases.

The PICs for the WIPP are akin to the second case, because each PICs component contains sufficient information to deter inadvertent human intrusion, and because while different components may have varying effectiveness, it doesn't matter as long as the activity is deterred.

Any one of the various PICs Deterrent Components that is encountered can deter the potential intrusion: (1) information encountered in any one of the records centers is sufficient to indicate to a site investigator that the Withdrawal is federally owned and has covenants to prohibit resources exploration or exploitation, and in addition, sufficient information is present to indicate the hazardous nature of the site and the personal hazards associated with intrusion; (2) information encountered in any one of the archives is sufficient to indicate to a site investigator that the Withdrawal is federally owned and has covenants to prohibit resources exploration or exploitation, and in addition, sufficient information is present to indicate the hazardous nature of the site and the personal hazards associated with intrusion; (3) prohibitions against drilling or mining attached to land records are sufficient to indicate to a potential intruder (even without being denied a lease) not to drill because they could not take advantage of anything they find; and

(4) information encountered at the site from the markers is sufficient to communicate that drilling is prohibited and they could not benefit from any drilling, and in addition, sufficient information is present to indicate the hazardous nature of the site and the personal hazards associated with intrusion.

Through the previous discussion of PICs, the reader should note that a "failure" for the purposes of PA is the inadvertent drilling of a borehole at a location where the driller does not own the property or lease (i.e., a "failure to deter" an inadvertent intrusion). In Chapter 5, the concept of a "failure mechanism" is introduced as a means by which the ability of a PICs component to endure and/or be understood is impaired or eliminated. The action of a failure mechanism to impair or eliminate a PICs component does not in and of itself constitute failure to deter for the entire system of PICs for the WIPP. Incorrect designation of the location of a borehole after it has been drilled in the correct location does not constitute either a "failure to deter" or a failure mechanism for the PICs for the purposes of estimating PICs effectiveness (signs after the fact are not a part of the PICs system and do not impact other boreholes).

4.5 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 natural resource potential, (2) evaluation of the natural resources in the areas, and (3) exploitation of the natural resources if the area-evaluation results confirm the presence of economically viable natural resources. Because of the high levels of expenses in evaluating resources through field work, the first step in locating areas with resource potential typically 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 to check 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 learn from the fact in property records that the land within the land-withdrawal boundary is owned by the 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. These warnings would 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.

Land-use restrictions and ownership do not depend on the existence of a particular records center but are established and maintained by government as a whole. As a result, even if a records center were to be destroyed, this destruction would not cancel existing property rights or existing regulations. Just as government would be obligated to maintain the previous property rights and regulations, anyone wanting to exploit natural resources would remain obligated to establish ownership of the natural resources and to obtain the necessary permits prior to starting the exploration or exploitation activities by checking with other records centers.

5.1 Potential Failure Mechanisms Eliminated From Consideration

The PICs PRP identified a number of potential failure mechanisms that needed specific treatment. Each of the potential failure mechanisms is discussed below to indicate how the topic was addressed in the Conceptual Design Report, why a potential failure mechanism is beyond the scope of credit for PICs in PA, or how the potential failure mechanism is subsumed into another failure mechanism already addressed.

5.1.1 Casual and Systematic Vandalism

Vandalism was taken into account in the designs. The PICs components are not replicates of the historical analogues examined, but take the basic design concept from the historical analogue that enabled these structures to endure and enhances them to compensate for natural and human factors that will tend to destroy the components. Specific examples of design solutions incorporated to counteract the effects of vandalism include: (1) selection of granite for the monuments and other markers as a durable rock that will resist chipping and limit damage from bullets; (2) use of multiple copies of the individual monuments and markers so the system will continue to communicate even if one or more individual monuments or markers are damaged or removed; (3) use of right angles and relatively large, flat surfaces in the shape of the monuments to reduce the amount of material that can be chipped away by someone hammering on a monument; (4) use of the large size of the monuments and the berm to make these components difficult to destroy or remove; (5) inclusion of two copies of the Level IV messages on the granite walls in each of the buried rooms; and (6) use of an irregular pattern of the spacing and depth of the small buried markers to make systematic collection of these markers difficult.

The PTF expects that the markers at the WIPP, with their multiplicity of copies, will be able to withstand casual vandalism and souvenir hunting (e.g., spray paint, bullet holes, chipping of edges) from 100 to 700 years after closure so that a sufficient number of components or pieces of components will remain to communicate their intended messages.

The PTF believes that systematic vandalism (e.g., the monuments and markers at the WIPP being caught in the middle of a tank fight, the target of a scorched earth policy of a retreating army, the target of rampaging renegade troops, the target of deliberate destruction by cults, or the development of new highly destructive technologies that can be owned by the general public) will be a low probability event at the WIPP from 100 to 700 years after closure. In addition, vandalism of this type is beyond the realm of a prudent extrapolation of today's societal conditions.

5.1.2 Collateral Effects of War

The collateral effects of war were not addressed and need not be addressed, because they would be such a low probability event. Collateral effects might destroy some parts of a component or some parts of several components, but would be unlikely to take out all of the markers at the site. It would take a very large bomb to destroy all of the markers to the point that pieces of text on monuments did not remain in pieces large enough to read. The trinitite produced from a nuclear device would itself be a marker. In discussing the impact of war damage, i.e., bomb damage on a repository, the EPA has stated that "Similar to the question of sabotage is the question of damage to the repository through some act of war. The only credible act that could even fracture the rock down to about 500 meters would be the detonation of at least a ten-megaton or larger nuclear device. During a war, it is hardly likely that bombs would be aimed at a repository. Cities and strategic installations are far more attractive targets. In addition, the effects on the biosphere from a damaged repository would be insignificant compared with the other damage inflicted in such a conflict" (EPA 1980). The WIPP is not a strategic target and is many miles away from any strategic targets. The probability of a stray missile in the expanse of southeastern New Mexico away from strategic targets, of a capacity large enough to destroy all the markers was below the regulatory cut-off for scenarios that had to be considered. In addition, to paraphrase the EPA, if a bomb that large did explode, it would disturb the repository, and that bomb would represent far greater impacts than the disruption of the repository itself. In addition, collateral effects of war at the WIPP would not destroy all of the records centers and archives containing WIPP information.

5.1.3 Horizontal Drilling for Resources

Horizontal drilling would be subject to the same regulations as vertical drilling, and as a result would be subject to the same procedures. Consistent with these procedures (including examining maps and other Awareness Triggers), horizontal drilling would require obtaining ownership or resource rights, both at the drill site and along the length of the drill string. There would be the same prohibitions on drilling into the disposal system from outside the Withdrawal as drilling vertically into the disposal system. As a result of being subject to the same procedures, the failure rate for horizontal drilling can be assumed to be the same as the failure rate for vertical drilling.

Horizontal drilling is required to go through the same site-evaluation procedures and permitting processes as vertical drilling. As a result, the PICs will be as effective in deterring inadvertent horizontal drilling into the Withdrawal as they will be in deterring inadvertent vertical drilling.

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 5-1 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 sand dunes cover the structure over the years. Sixteen large granite monuments outline the footprint perimeter. These monuments will include engraved warning messages in seven languages. Two large rooms are also buried. One room will be buried within the southern segment of the berm (Figure 5-1), 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 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

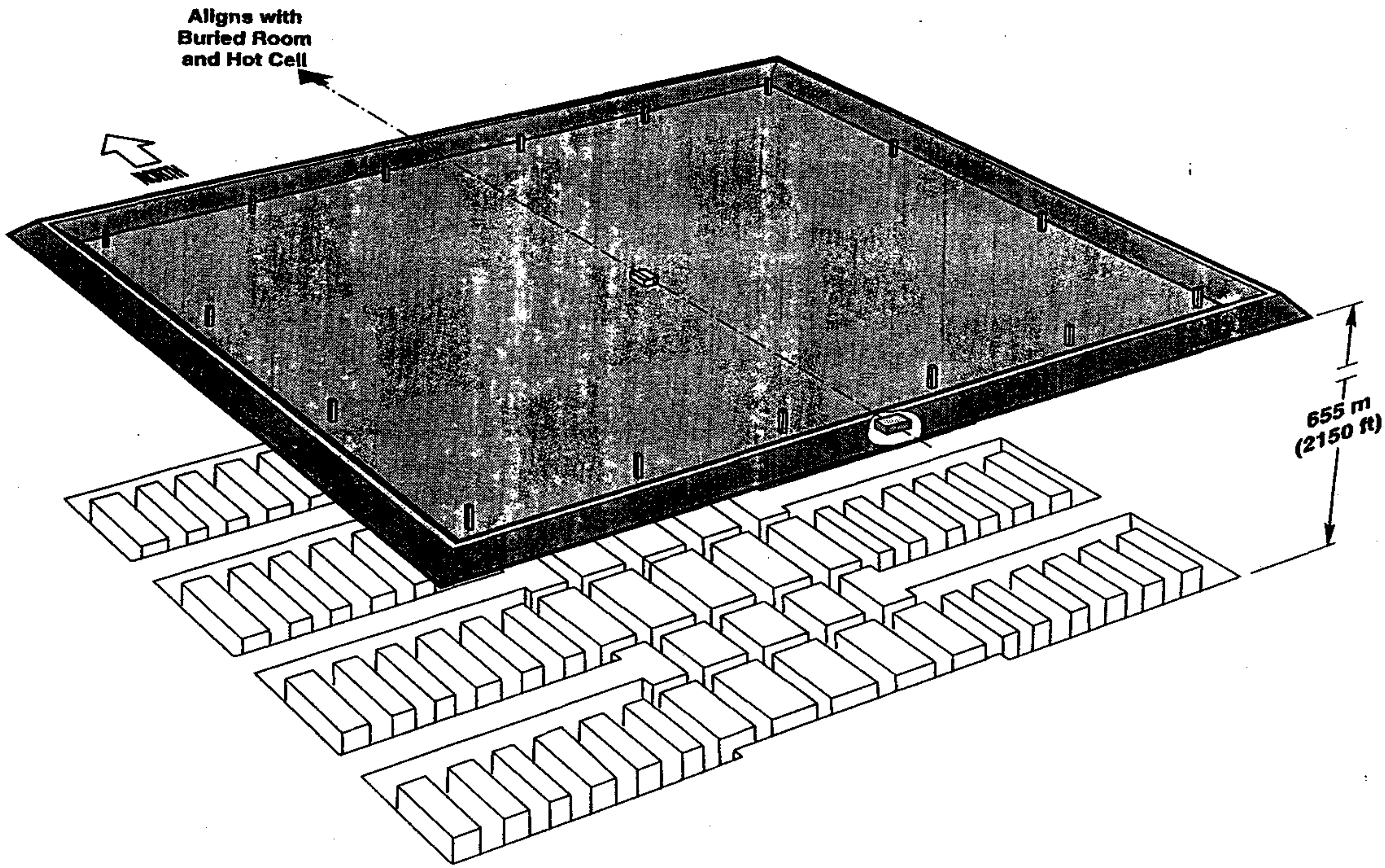

Figure 5-1. General layout of major components of the permanent marker system at the repository footprint.

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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, relatively small markers engraved with a warning not to drill or dig will be buried at randomly selected locations and depths (between 0.6 and 1.8 meters [2 and 6 feet] below the surface).

The conceptual design includes marking the 16-section Withdrawal with 32 granite monuments evenly spaced around the area perimeter (Figure 5-2). 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.

With regard to failure mechanisms and design solutions, climate is an issue that will potentially affect all of the markers at the site. The climate to which a historical analogue has been subjected versus the climate that the markers will experience at the WIPP will vary. In general, the climate at the WIPP is as dry or drier than the climate at the historical analogues. 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 the various 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.

5.2.1 Berm

5.2.1.1 Conceptual Design

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 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).

The survivability of earthworks 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 at the WIPP. 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 is virtually certain to 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 infiltrating 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 original shape, substantial quantities of 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 aerial extent that it all could not be entirely covered.

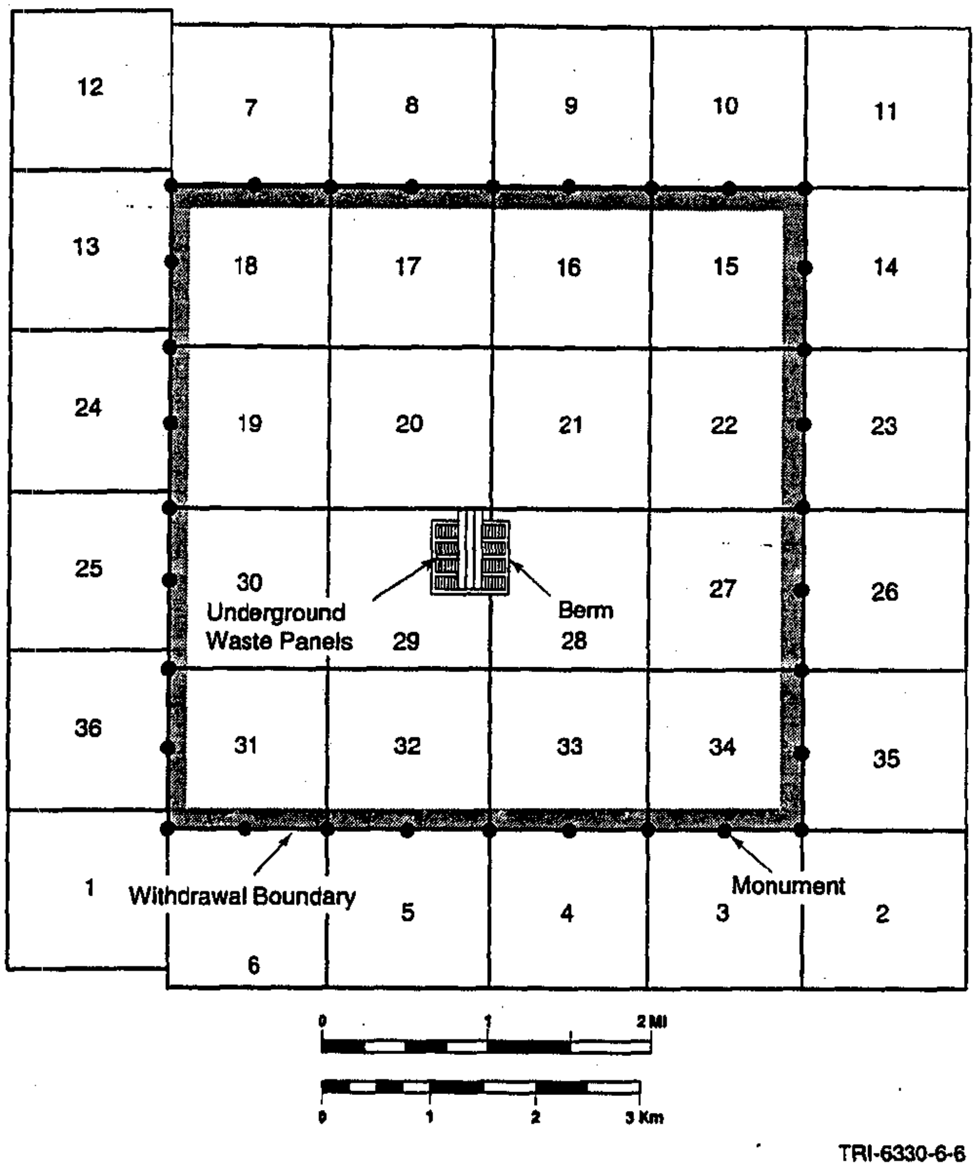

Figure 5-2. Proposed distribution of the permanent markers at the withdrawal boundary (modification of DOE, 1989).

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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 [see Figure 5-1]). Each of these monuments will extend 7.6 meters (25 feet) above the surface and 5.2 meters (17 feet) below the surface (DOE, 1996, Section V). Each monument will be comprised of 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 of the granite will include polishing so the surfaces will shed water rather than leaving the surface rough where small pits can serve as locations for water retention. Each stone will be engraved with Level II and Level III text messages and Level IV pictographs. Thirty-two monuments similar to the footprint monuments will outline the Withdrawal (see Figure 5-2) and convey the message that the entire area enclosed by the monuments should not be disturbed.

5.2.2.2 Historical Analogue: Stonehenge

Durability. Initial construction of Stonehenge included the placement of the 32 metric-ton (35 ton) "Heel Stone" (i.e., an upright monolith made of sarsen rock located outside the complex perimeter) 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., the Romans, the Jutes, the Angles, the Saxons, the Normans, the Danes, and the Norwegians) (Kinder and Hilgemann, 1974). There were also numerous episodes of internal strife (e.g., lines of successions, the War of the Roses) (Kinder and Hilgemann, 1974) that introduced political turmoil to the land.

After nearly 4,000 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 (1990). Thus, engravings can remain visible for thousands of years on exposed surfaces.

Communication. Stonehenge was no doubt useful to the society(ies) that used this structure in antiquity. Construction by humans is obvious (Level I message). 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. The PTF examined the physical endurance of Stonehenge as a historical analogue for a series of monuments. Stonehenge as a communications analogue (other than Level I) was not examined.

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 at least some of the WIPP monuments are virtually certain to 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 and transmit the engraved messages. 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 are virtually certain to 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

Durability. At the foot of the Zagros Mountains in the Kermanshah region of Iran, more than 2,500 years ago the Persian King, Darius I, inscribed a memorial 45.7 meters (150 feet) wide and 30.5 meters (100 feet) long (Frimmer, 1969) 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. Enormous bas-relief figures were 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. This memorial has withstood the rigors of time and weather in an exposed location so that its inscriptions can still be read today.

Communication. The accompanying text 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 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 in the case of 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 endure as long as the ancient inscriptions. This reasonable expectation provides further support for the DOE's previous assertion that monuments and their inscriptions are virtually certain to survive for at least 4,000 years, with a high probability of lasting beyond the regulatory period.

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 to address the Assurance Requirement for PICs.

5.2.2.6 Potential Failure Mechanisms and Design Solutions

Weathering (chemical alteration of rock). (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 collect. (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 that has not experienced weathering will be used. (2) Surface preparation — surfaces will be polished to remove all loose material and indentations where water could collect. (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 area outlined by 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 buried 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 area outlined 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, for all but the highest of the dunes.

Removal intact (museum). (1) Multiple monuments — some individual monuments can be removed and this PICs 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 this PICs component can still communicate effectively. (2) Size and weight — difficult to break up. (3) Government ownership and regulation — recycling efforts 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 that has not experienced weathering will be used. (2) Multiple monuments — some individual monuments can be removed or damaged and the component can still communicate effectively. (3) Government ownership and regulation—it is illegal to damage or destroy private or government property without permission. (4) Engraved messages — messages will still be readable under paint. (5) Design — monuments are designed to have *large flat surfaces that will be difficult to deface and sides that meet at right angles to limit the extent of chipping.*

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 exterior walls and seven parallel interior information walls but no roof. The sediments at the location of the Information Center will be excavated down to the level of the underlying caliche, and this excavation will be filled with caliche to the original land surface level. The overall dimensions of the Information Center are 12.2 meters wide by 9.8 meters deep by 3.0 meters high (40 feet wide by 32 feet deep by 10 feet high). The dimensions of the interior information walls are 5.2 meters wide by 2.1 meters high (17 feet wide by 7 feet high). These dimensions exclude 1.5 meters (5 feet) of each wall buried in the caliche. Level IV messages indicating the location, design, and hazards of the WIPP will be contained within the Information Center. The Level IV text information will be engraved on both sides of the seven granite information walls with one wall for each of the seven languages (the six official languages of the United Nations plus Navajo), while tables, figures, diagrams, and maps will be engraved on the interior side of the exterior walls.

5.2.3.2 Historical Analogue: Australian Rock Art

Durability. The EPA (1996a, p. 12-14) discussed ancient Australian rock art that includes paintings, engravings, and peckings located on protected surfaces (but not in enclosed rooms, etc.). 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 that it has endured the onslaught of wind-borne sand, and wide temperature fluctuations, without these processes destroying it.

Communication. This historical analogue was not examined for communication.

5.2.3.3 WIPP Relevance: Australian Rock Art

The relatively fragile media of Australian painted and pecked rock art has endured for thousands of years with only minimal effort towards long-term preservation, while the messages in the WIPP Information Center will be engraved to improve durability. Durability is increased by the selection of granite as the medium for the messages and the placement of the engraved messages within an Information Center designed to afford protection from weathering and erosion. The location of the Information Center within the berm offers additional protection against erosion. The DOE asserts that the performance of the Information Center is virtually certain to be as good as the endurance of Australian rock art and is virtually certain to be recognizable for the entire regulatory period.

5.2.3.4 Historical Analogue: The Acropolis

The Acropolis, which is 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 the 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-meters (34.5-feet) high, ring the building. At one time, metal "shields" were placed above the series of columns. 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. As noted above, most of the structures in existence today at the Acropolis date from the fifth century B.C., more than 2,400 years ago. The Acropolis has endured as a transcultural religious site (of importance to the Greeks, the Romans, Christians, and Muslims at various times), with many buildings that are analogues for the Information Center. While individuals/ museums wanted to remove pieces to their own countries, there was no desire then to destroy the original site. This removal to indoor museums has actually prolonged the durability of some friezes, statues, and columns, and also provided greater dissemination of information about the Acropolis, which has contributed to the Acropolis being seen as a cultural artifact worth preserving. The fact that no mortar was used would suggest that the structures would be relatively unstable, except for the fact that the building stones were extremely well dressed and afforded the structures greater stability. The building stone, while relatively soft and soluble, was not significantly degraded by natural weathering until the past 50 years when industrialization and automobile exhaust significantly increased the acidity of the rainfall. Even with some components being damaged or removed, the basic building structures remain distinguishable and these structures contain portions that include intricate carvings, some of which are in remarkably good condition even after weathering and periods of social chaos.

Communication. The PTF examined the physical endurance of the Acropolis as a historical analogue for a buried storage room. The Acropolis as a communications analogue (other than Level I) was not examined. The great detail that is known about the history of the Acropolis indicates that the long-term preservation of knowledge is possible, and this active transmission of information (historical records and translations) is discussed in the section on "Other PICs" (Section 5.6).

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. History provides information about what did not survive at the Acropolis, namely metal monuments, most of which seem to have been recycled. This knowledge of what does not endure, because of natural processes and/or human actions, is applicable to the WIPP PICs in suggesting that messages presented on metal not be used as they may be recycled.

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 and structures of the Acropolis having survived for more than 2,400 years, survival of the granitic WIPP monuments and Information Center 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 buildings of the Acropolis. The DOE asserts that the WIPP Information Center is virtually certain to 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 that has not experienced weathering will be used. (2) Surface preparation — surfaces will be polished to remove all loose material and indentations where water could collect. (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 that has not experienced weathering will be used. (2) Surface preparation — surfaces will be polished to remove all loose material and indentations where water could collect. (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 area enclosed by the berm. Lower wind speeds, especially for the Information Center (height of 3 meters [10 feet]) that is well protected by the berm (height of 10 meters [33 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) Size and weight — message panels are large and difficult to transport. (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) Size and weight — message panels are large and the granite is difficult to break up. (2) Government ownership and regulation — recycling efforts 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 that has not experienced weathering will be used. (2) Messages located on interior walls of the Information Center — perpetrator would be harmed from ricocheting gunfire within the Information Center. (3) Engraved messages — messages will still be readable under paint. (4) Design — the walls are designed to be large flat surfaces that will be difficult to deface.

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 halfway between the berm and the Hot Cell. Within the buried storage room, tables, figures, diagrams, and maps will be engraved in the interior sides of the exterior structural walls. Seven granite slabs 3.7 meters wide by 3.0 meters high (12 feet wide by 10 feet high) will be emplaced within the buried storage room to create interior message walls for text information. Each interior message wall has engraved text on both sides, with one wall for each of the seven languages (the six official languages of the United Nations plus Navajo). Both sides of the interior message walls and the interior sides of the structural walls will have a granite veneer with duplicate engraved information of the material underneath. The existence of the storage rooms will be documented in the records located in the archives, the records centers, and the Information Center. The information contained in the buried storage rooms is the same as in the Information Center.

5.2.4.2 Historical Analogue: Newgrange

Durability. 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)

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

Communication. Newgrange was no doubt useful to the society(ies) that built and used this structure in antiquity. Construction by humans is obvious (Level I message). Evidence from excavations within and beyond the passage grave conveys a Level III message (i.e., who built the passage grave, when, what for, and why) [in part, for astronomical observations]) (O'Kelly, 1982). No evidence exists of an attempt by the creators of Newgrange to communicate the structure's usage across the centuries to future generations living in societies different than the creators' society. The PTF examined the physical endurance of Newgrange as a historical analogue for a buried storage room. Newgrange as a communications analogue (other than Level I) was not examined.

5.2.4.3 WIPP Relevance: Newgrange

The existence of Newgrange indicates that buried stone structures can last for thousands of years, providing protection for openings within the structures and the engraved messages on interior walls. Use of corbel construction, while stable in the case of Newgrange, can fail, causing the roof to collapse, as in the case of one passage 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.

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.

Communication. This historical analogue was not examined for communication.

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., expected 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 are potential failure mechanisms for an unexcavated buried room (including consideration of a shaft dug to the room entrance).

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

Removal intact (museum). (1) Interior walls of the buried rooms contain two layers of messages — one entire layer can be removed and the remaining message 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 remaining message 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 — recycling efforts 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 that has not experienced weathering will be used. (2) Messages located on interior walls of the buried rooms — perpetrator would be harmed from ricocheting 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 remaining message can still communicate effectively. (4) Engraved messages — messages will still be readable under paint. (5) Design — walls are designed to have large, flat surfaces that will be difficult to deface.*

The following are potential failure mechanisms if a buried room is excavated but left in place.

<u>Weathering (chemical alteration of rock structure)</u>. *(1) Material selection — granite is the most durable of rocks routinely used for construction. Fresh granite that has not experienced weathering will be used. (2) Surface preparation — surfaces will be polished to remove all loose material and indentations where water could collect. (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 with a roof to protect the message panels from rain*

<u>Infill</u>. *Material selection — Pristine granite is so durable that if the buried room becomes covered over by dunes, then it is available to later generations.*

<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 remaining message 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 information center contain two layers of messages — one entire layer can be removed and the remaining message 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 — recycling efforts 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 that has not experienced weathering will be used. (2) Messages located on interior walls of the buried rooms — perpetrator would be harmed from ricocheting 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 remaining message can still communicate effectively. (4) Engraved messages — messages will still be readable under paint. (5) Design — walls are design to have large flat surfaces that will be difficult to deface.

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

Weathering (chemical alteration of rock structure). (1) Material selection — granite is the most durable of rocks routinely used for construction. Fresh granite that has not experienced weathering will be used. (2) Surface preparation — surfaces will be polished to remove all loose material and indentations where water could collect. (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.

Erosion (physical removal of material). (1) Material selection — granite is the most durable of rocks routinely used for construction. Fresh granite that has not experienced weathering will be used. (2) Surface preparation — surfaces will be polished to remove all loose material and indentations where water could collect. (3) Message location — messages located on the walls inside the buried rooms to reduce the impact of blowing sand.

Buried by migrating dunes or the impact of vegetation. Durability of materials — if the reconstructed buried room becomes covered over, then it is available to later generations.

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 remaining message 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 — recycling efforts 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 ricocheting gunfire within the buried room. (3) Interior walls of the buried rooms contain two layers of messages — one entire layer can be defaced and removed and the remaining message can still communicate effectively. (4) Engraved messages — messages still readable under paint. (5) Design — walls are designed to have large flat surfaces that will be difficult to deface.*

5.2.5 Small Buried Markers

5.2.5.1 Conceptual Design

Several thousand small warning markers will be buried at randomly selected depths ranging from 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. Some individual warning markers will be made of granite, while others will be made of 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

Durability. 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. This state of the engraved text has survived both exposure on the surface and burial for over 3,600 years.

Communication. The text was written in cuneiform and in the Akkadian (Semitic) language. This is another example of communications enduring for more than 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

Similar to Hammurabi's diorite stele, the markers will be made of granite and other materials specifically selected for their durability. 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 are expected to 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

Durability. 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.

Communication. Inscribed clay tablets have been recovered in the same region dating from as early as 3200 B.C. (Kinder and Hilgemann,1974). These inscriptions can be translated.

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 are virtually certain to 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, fired clay, and aluminum oxide will be used because of their durability. Fresh granite that has not experienced weathering will be used. (2) Surface preparation — surfaces will be polished to remove all loose material and indentations where water could collect. (3) Dry climate at the WIPP (limited water available for chemical weathering). (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. (4) Random distribution and depths of markers preclude a cost-effective process for recovering the markers.

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 and recycling 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 printed with carbon-black ink.

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. Waste Isolation Pilot Plant Land Withdrawal Act

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

6. The Certification of Demonstration of Compliance with 40 CFR Part 191.

7. 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.

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

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

10. 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.

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

12. 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

Durability. The Vatican Archives (Pasztor and Hora, 1991) were established by Pope Paul V in 1612, almost 400 years ago. The oldest documents contained in the Secret Vatican Archives are from the ninth century, while the oldest series of documents are the 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.

Communication. With the focus on current English for communication over the 700 years over which credit for PICs may be applied to PA calculations (see PTF Assumptions (4) through (6)), the PTF did not emphasize languages other than current English. In fact, no credit is claimed for the communication in the other languages that will be a part of the WIPP PICs. However, it is clear that the Vatican Archives are an example of a body of documents whose intent can be understood centuries after their creation. This is all the more important because the Latin used in the documents in the Vatican Archives is now only a scholarly language, and is no longer even a widespread liturgical language.

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 Vatican 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 historical importance can be expected to have greater prospects 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 WIPP archives will contain data and information of economic importance to industries 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 is expected to endure and maintain records for at least 1,100 years, and has a high probability of enduring for thousands of years. WIPP information is expected to endure at least as long as the original paper can survive (i.e., thousands of years).

5.3.4 Historical Analogue: Ancient Documents

Durability. 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. Thousands 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 the ruins of the Great Wall of China dated from about A.D. 150 are discussed in Hunter (1978).

Communication. As was stated for the Vatican Archives, the focus of the PTF is on current English for communication over the 700 years over which credit for PICs may be applied to PA calculations (see PTF Assumptions (4) through (6)), and no credit is claimed for the communication in the other languages that will be a part of the WIPP PICs. However, it is clear that many ancient documents exist and their messages can be understood. This comprehension of ancient documents is, in many cases, possible even though the language may no longer be in common usage.

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 1,500 to 2,000 years, from the time when paper was invented, and can still be read and interpreted by scholars lends credence to our society's ability to preserve information and the media upon which that information is recorded. Based on the historical analogues of ancient documents, the DOE asserts that paper is expected to last for at least 2,000 years and has a high probability of lasting 4,400 years (the duration of papyrus, another organic material used for ancient 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) Cover of the Concise Summary contains language about long-term importance of the information contained in the record (safety). (2) Concise Summary — discourages the entire collection from being discarded because the summary points out the importance of the other documents.*

Archivist deciding that records are no longer important. *(1) Cover of the Concise Summary contains language about long-term importance of the information contained in the record (safety). (2) Concise Summary — discourages the entire collection from being discarded because the summary points out the importance of the other documents.*

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 (PTF Assumptions 4-6). (2) Communication through means other than language (e.g., pictures, graphs, figures, and maps) (Common Denominator 4 and PTF Conclusion 1).

5.4 Records Centers

5.4.1 Conceptual Design

Records centers, for the purpose of making a distinction from archives, are facilities created to facilitate certain activities (public and private) and that generally permit freer access by members of the public. These facilities do not normally exercise the degree of environmental control and information-medium selection as 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 and 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 offices of the Bureau of Land Management
- The local offices of the Bureau of Reclamation
- The Albuquerque office of the Bureau of Indian Affairs
- The Federal Records Center in Denver, Colorado
- 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 state libraries of the 50 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 to health-related records centers. 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

Durability. The German archives discussed here (Brachmann et al., 1991) consisted of separate 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. B, p. 17-18)

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):

> "Numerous archives suffered varying degrees of damages during World War 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. A, p. v)

Communication. Communication was not an issue for this historical analogue.

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 strategic 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 with 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

<u>Decay of paper</u>. (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 a records center.

<u>Theft</u>. (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.

<u>Misfiling</u>. (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.

<u>Catastrophes (including fire, flood, tornadoes, earthquakes)</u>. Multiple copies — records can be re-created.

<u>Recycling</u>. (1) Cover of the Concise Summary contains language about long-term importance of the information contained in the record (safety) (2) Concise Summary — discourages the entire collection from being discarded, because the summary points out the importance of the other documents.

<u>Archivist deciding that records are no longer important</u>. (1) Cover of the Concise Summary contains language about long-term importance of the information contained in the record (safety). (2) Concise Summary — discourages the entire collection from being discarded because the summary points out the importance of the other documents.

<u>Lost (including while consolidating collections, moving)</u>. Multiple copies — records can be re-created.

<u>Deliberate destruction (other than governmental actions)</u>. Multiple copies — records can be re-created.

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

<u>Warning not understood</u>. (1) Endurance of English (see PTF Assumptions 4-6).
(2) Communication through means other than language (e.g., pictures, graphs, figures, and maps) (Common Denominator 4 and PTF Conclusion 1).

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 potential for natural-resource exploitation 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).

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 a direct contradiction to the EPA's requirement that the PA assume that drilling will take place at historic rates for the 10,000 years of regulatory concern throughout the Delaware Basin including the Withdrawal.

5.5.2 Historical Analogue

Durability. The search for historical analogues for land restrictions at the WIPP suggests examples such as the Boston Commons in Boston, Massachusetts, and the plaza in Santa Fe, New Mexico. 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 in New York state, the Mall in Washington D.C., and Balboa Park in San Diego, California.

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 communications or transportation. Yellowstone was established to benefit the nation as a whole by preservation of our natural assets.

Communication. Communications is not relevant to the PTF's examination of this historical analogue.

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 to receive 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. The importance of a remote location is that it is easier to conduct prohibited activities without being detected.

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 Section 6.2 and that were introduced in Section 4.4, 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."

While the DOE cannot require future societies to reproduce documents or information as part of the PICs, evidence exists of information being reproduced/translated and passed down through history. Information about the Egyptian pyramids and the Acropolis are two examples.

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 demonstrate the ability of written records to endure across cultures and centuries.

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.

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 time frames 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. Berry (1983) also provides data supporting much better corrosion resistance for titanium and hastelloy. 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 hastelloy 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 a PICs system 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.

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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 framework on assessing the effectiveness of PICs in deterring inadvertent human intrusions, the premises used by the PTF in estimating this effectiveness, the conceptual design of the PICs components, the historical analogues that provide insight into how long certain design characteristics and materials can last and information can be understood, and possible failure mechanisms for each component and how the conceptual design for each component counteracts these mechanisms. This chapter integrates the information in these earlier chapters and provides the PTF's estimate of the effectiveness of PICs in deterring inadvertent human intrusion into the repository footprint and into the Withdrawal for the 700 years after closure. These inadvertent human intrusions, as guided by 40 CFR Part 194 (EPA, 1996c), are drilling for and the mining of natural resources. This chapter also includes arguments supporting this estimate.

6.1 Deterrent Components

Deterrent Components are those components that provide sufficient information to deter a potential intruder. These Deterrent Components were designed based on lessons learned from historical analogues as discussed in Chapter 5. The PTF believes that while some historical (ancient) structures have failed, those failures are not controlling in the discussion of the effectiveness of PICs for the WIPP, because all ancient structures are not analogues for the WIPP PICs. The WIPP PICs have been designed to exceed the performance of the historical analogues of which there is evidence and because of the regulatory constraints established for the WIPP.

Information located in records centers and archives may fail to correctly communicate because of natural or human initiated disasters/events. Fire, floods and rain damage, earthquakes, and tornadoes are examples of natural disasters. Additional natural events are the decay of paper and the deterioration of ink. Archival paper and carbon black ink will improve the performance of the information against natural forces. Even if a records center or an archive were subjected to fire, flood, etc., the WIPP information is located with other important information and people will attempt to save all of the records. In addition, multiple copies of the information will exist if the contents of an entire records center or archive are lost. The loss of one set of the information does not indicate failure for the entire component because within the regulatory framework established by the EPA, resource companies will still need to establish ownership and will go to another records location to find the necessary information (loss of records does not mean loss of ownership of resource rights).

Other aspects of the information located in the records centers and archives counteract the human initiated failure events of theft, misfiling, recycling. Control of who accesses documents, an established filing system, and attempts to establish the long-term importance of the information will increase their endurance. Once again, the existence of multiple copies means that the information will still be available for site investigators.

Natural or human-initiated disasters/events, such as fire, floods and rain, earthquakes, and tornadoes initially seem to pose threats to the survival of the markers components. To counter these threats, the markers have been designed to counteract these processes through the use of durable materials and designs. The use of granite for the markers will result in fire, rain, and tornadoes having superficial effects on the surfaces of the markers, and the structural considerations incorporated in the construction of the markers will eliminate any effects from the magnitude earthquakes to which southeastern New Mexico are subjected. The lack of drainage features at the WIPP indicates that this area is not subject to extensive flooding.

Human-initiated events, such as war, vandalism, and recycling pose threats to the markers' components. To counter the threat of vandalism, the markers will be made of large blocks of granite whose durability, size, and shape (e.g., large flat surfaces) limit the effects of casual vandalism. Recycling efforts for the granite markers are countered by the size and hardness of the markers, and the inability of these activities to occur in secret (i.e., the level of effort required to perform these activities would also attract attention from resource workers and the ranchers whose stock are being frightened and forage that is being destroyed by these activities). As stated previously, collateral war damage and systematic vandalism (e.g., the monuments and markers at the WIPP being caught in the middle of a tank fight, the target of a scorched earth policy of a retreating army, the target of rampaging renegade troops, the target of deliberate destruction by cults, or the development of new highly destructive technologies that can be owned by the general public) will be low probability events at the WIPP for 700 years after closure. In addition, vandalism of this type is beyond the realm of a prudent extrapolation of today's societal conditions.

Historical analogues are used for design purposes and to indicate how long records can last. The PTF believes that the design solutions implemented for the records centers and archives for retaining WIPP material apply lessons learned from known failures and make retention of sufficient material to correctly communicate the necessary information a highly likely event. The design solutions implemented range from having both records centers (easier access to potential intruders) and archives (greater preservation potential) retain the information to having multiple locations for storing the information under multiple jurisdictions to having a truthful representation of the risks of intruding upon the disposal system transmitted to future generations. Past failure rates are not applicable here because the archives and records systems envisioned to be a part of the PICs are more elaborate and scientifically based than past systems and incorporate design solutions to address past failure modes.

The following discussion examines each of the Deterrent Components from the view point of effectiveness over 700 years. Rather than present quantitative effectiveness estimates that suggest a level of precision that cannot be supported by available information (Budescu and Wallsten, 1987), the PTF provides qualitative estimates. The expression "virtually certain" is used to indicate a high level of confidence while recognizing a possibility, no matter how remote, that an alternative conclusion may occur.

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).

6.1.1.1 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 Section 5.2.2.4) and barring unforeseen failure mechanisms, 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 text on the monuments are virtually certain to be legible for at least 2,500 years, which is the minimum lifetime of the engraved text on the Rock of Behistun. Because these ages are minimums, a life expectancy for the inscriptions on the monuments substantially longer than 2,500 years after disposal is realistic and highly probable, because the Stonehenge engravings of figures, which are at least 4,000 years old, are still distinguishable.

Estimates of the ability of future generations 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 (PTF Assumption 6 and Regulatory Assumption 4) and that pictures will be able to convey meaning independent of or as a supplement to written warnings (Common Denominator 4) (e.g., facial expressions representing emotions and pictographs representing potentially harmful activities). Based on these assumptions and common denominator, the warnings inscribed on the monuments are virtually certain to 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 if one or several of the monuments are deliberately destroyed or removed.

6.1.1.2 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 build a rock structure that will endure for at least as long as the structures at the Acropolis (PTF Assumption 10), the PTF concluded that the Information Center is virtually certain to 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 and are not structurally analogous to the Information Center, whereas buildings at the Acropolis were designed for human use and are 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 survived 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 (PTF Assumption 10) (including walls knocked over in a face-down position or buried by drifting sand). Even if the structure of the Information Center fails, the protected inscriptions 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 (Common Denominator 2); (2) future generations will continue to be curious about the meaning behind unfamiliar structures and writings (Common Denominator 1); (3) current English will continue to be understood by individuals within the natural resource exploration and exploitation industries or governmental agencies (PTF Assumptions 4-6) (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) (Common Denominator 4 and PTF Conclusion 1). Based on these premises, 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.

6.1.1.3 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 a buried room will reveal another source of detailed information explaining 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 (PTF Assumption 10), 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 have the design characteristics to endure for at least 5,000 years. If a buried room is excavated and left exposed, its durability will be similar to that of the Information Center.

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 (Common Denominator 2); (2) future generations will continue to be curious about the meaning of unfamiliar structures and writings (Common Denominator 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) (PTF Assumptions 4-6); and (4) pictures will be able to convey meanings (Common Denominator 4 and PTF Conclusion 1) independent of or as a supplement to written warnings, 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 common denominators and the PTF assumption, the PTF concluded that the inscribed warnings on the walls of the buried rooms are virtually certain to be understood by individuals within the natural-resource industries or governmental agencies for thousands of years after disposal.

6.1.1.4 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 ensure 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. Granite, fired clay, and aluminum oxide currently are the candidate materials being considered for these markers.

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 (PTF Assumption 10), the PTF concluded that the buried markers are virtually certain to survive for at least 3,700 years, which is the approximately the time since the stele was created, with a high probability of surviving longer than 4,500 years, which is the minimum age of some of the older Mesopotamian artifacts. The precise duration that the stele and the artifacts were buried is not known, but any time that these objects were at the surface was time exposed to harsher conditions than when the objects were buried.

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 (Common Denominator 2); (2) future generations will continue to be curious about the meaning of unfamiliar objects and writings (Common Denominator 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) (PTF Assumptions 4-6); and (4) pictures will be able to convey meanings (Common Denominator 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 is virtually certain to be understood by individuals associated with natural resources for thousands of years after disposal. If the symbols cannot be understood, the inherent curiosity of future generations will make the symbols Awareness Triggers, although the text will remain a deterrent.

6.1.1.5 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 the copies of all the components has been identified. Based on the materials to be used to construct the various types of copies of all 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]) is virtually certain to 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 less emphatic than the one on the inner markers. A warning not to 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 cause 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. General records centers consist 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. Resource records centers are maintained by agencies that deal with land use, especially in the areas of natural-resource exploration and exploitation (e.g., the Bureau of Land Management and the 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 that is 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 be expected to 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. If a natural resources records center were destroyed through fire or natural disaster, a site investigator would be required to seek the information in another records center. The loss of a particular records center or piece of paper does not remove the requirements to identify current lease owners and to obtain permission to develop the resources.

The German archives during WWII serve as the historical analogue for the distribution of the WIPP documents in numerous records centers. The fact that a 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 contains 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 (Common Denominator 2); (2) future generations will continue to be curious about unfamiliar writings and structures (Common Denominator 1); and (3) current English will continue to be understood by individuals within the natural-resource exploration and exploitation industries and government agencies (PTF Assumption 6) along with those individuals in other fields of endeavors in which historical documents are important (PTF Assumptions 4 and 5). Because of the prominence of the WIPP records, the PTF concluded that the warnings contained in the WIPP records of the general records centers are expected to 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 that 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 widespread 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 additional assumptions that resource exploration and exploitation will continue for the entire regulatory period (Regulatory Assumptions 3 and 4) and government in any form will require record keeping and consultation of records (Common Denominator 7 and PTF Assumptions 2 and 3), the PTF concluded that resource records centers will remain active throughout the regulatory period (PTF Assumption 2 and Regulatory Assumption 4). 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 (PTF Assumption 7) and will be highly effective deterrents to inadvertent intrusion (Common Denominator 7 and PTF Assumptions 1 and 3) 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 ensures that at least some copies of these records will survive for an extended time and that lost records in some records centers can be reproduced from records in other records centers.

6.1.4 Archives

Archives are designed to preserve historically significant documents. In this capacity, the role of archives is preservation rather than 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 6.1.3).

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 are capable of surviving in at least some of the archives for more than 4,000 years based on the fact that papyrus with hieroglyphics approximately 4,500 years old and uninscribed papyrus approximately 5,000 years old have been found. 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 (Common Denominator 2); (2) future generations will continue to be curious about unfamiliar structures and writings (Common Denominator 1); and (3) current English will continue to be understood by individuals within the natural resources exploration and exploitation industries and government agencies (PTF Assumption 6) along with those individuals in others fields where historical documents are important (PTF Assumptions 4 and 5). For the potential intruder or the site investigator who visits an archive, the warnings within the WIPP records are almost certain to 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. Readily available translation will most likely 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.

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 (Common Denominator 6) will continue some form of land-use control (Common Denominator 7), especially in those areas having natural-resource potential (PTF Assumption 3). These offices are the resource records centers discussed in Section 6.1.3.

Drilling on the incorrect lease will subject the company to lawsuits for resource/mineral trespass. Exploiting resources on someone else's leases without being caught is highly unlikely because of state/agency inspections and the likelihood of being reported by economic competitors.

The PTF concluded that land-use restrictions are virtually certain to be completely effective deterrents against inadvertent human intrusion for as long as the paper recording these restrictions lasts. Even if an error is made in issuing a permit, a resource company has a vested interest in drilling on the correct lease instead of the incorrect lease. Because of the specialized and limited vocabulary associated with land-use restrictions, these restrictions are virtually certain to be interpretable by individuals in the natural-resource industries and/or government agencies (PTF Assumptions 4-6) 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 5 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

- 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
- WIPP homepage on the Internet

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.

- berm

The berm surrounding the repository footprint is intended to convey a Level I message indicating 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 from the surrounding area and more information is needed prior to the initiation of intrusion activities and by protecting the exposed markers enclosed within the aerial extent of the berm.

The historical analogues used to estimate the durability of the berm are the earthen banks surrounding the monoliths at Stonehenge (see Section 5.2.2.2). These banks were constructed as piles of earth with no reinforcement or other features designed to extend their lifetime. No credible occurrence in the prudent extrapolation of today's conditions was identified by the PTF that could disassemble the berm and completely remove the volume of material from the site. Based on the assumption that current science and technology have the capability to construct an earthen structure at least as durable as the banks at Stonehenge (PTF Assumption 10) and the belief that this capability is represented in the conceptual design of the berm (PTF Assumption 9), the PTF concluded that the berm is virtually certain to 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 and the physical setting 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 (e.g., mining the salt) will result in large volumes of the other materials being left behind (e.g., the riprap and caliche), which will continue to convey the Level I message.

- government ownership of the Withdrawal

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.

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 6.4.

6.3 Effectiveness of PICs System in Deterring Inadvertent Human Intrusions

The PTF did not attempt to estimate the contribution of the Gestaltic nature of the PICs system (see Section 4.4) when estimating the effectiveness of the PICs for PA. Given the short time frame for which credit may be given for the PICs in PA and the high levels of effectiveness of each component when considered independently in this time frame, the PTF decided not to include the concept of Gestalt and the likely accompanying controversies into the PTF estimates. For longer time frames in which substantially greater changes to society, technology, and language are likely to occur, the contribution of the Gestaltic nature of the PICs system is likely to be a larger contributor to estimates of PICs effectiveness in deterring inadvertent intrusions.

Based on the PICs systems approach (Chapter 4) and the PICs designs (Chapter 5), each of the individual Deterrent Components in the PICs system will offer virtually complete effectiveness in deterring inadvertent human intrusions within the repository footprint for thousands of years. 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 the repository, 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.

The PTF believes that the design solutions implemented for the records centers and archives for retaining WIPP material apply lessons learned from known failures and make retention of sufficient material to correctly communicate the necessary information a highly likely event. The design solutions implemented range from having both records centers (easier access to potential intruders) and archives (greater preservation potential) retain the information to having multiple locations for storage of the information under multiple jurisdictions to having a truthful representation of the risks of intruding upon the disposal system transmitted to future generations.

To ensure that these design solutions are implemented as specified, the DOE is developing QA procedures addressing the three implementation steps (encode in language, capture in media, and transmit) from the general communications model (see Section 4.1) The PTF believes that these QA procedures will ensure that the correct information will get into the records centers and archives. This documentation will support the PTF conclusions as to the effectiveness of records centers and archives.

6.4 Conclusions for Use in PA

As noted in Section 2.5 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 the 100 years for which AICs are assumed to be effective in PA and cannot deter for more than several hundred years after closure. 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 PTF assumptions developed in Chapter 3 lead the PTF to assert that current English will be decipherable by the resource community for the entire period of interest to PA. Thus, the only failure mechanisms of the PICs for communicating with a potential intruder (i.e., a decision maker in the natural-resources industry) 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.

No failure mechanisms compatible with a prudent extrapolation of today's societal conditions have been identified by the PTF or any reviewer that could destroy all of the Deterrent Components associated with the WIPP. Because these PICs components are expected to perform so well for the 700 years of regulatory interest, the PTF decided to examine an existing PICs component (control of land use) for which failures are known to exist.

6.4.1 Types of Failure Data Appropriate for Consideration

Because the intent of the PICs will be to deter inadvertent human intrusion by the natural-resources industry, the PTF believes that it was appropriate to use information on recent failure rates within this industry as a surrogate for future activities (e.g., drilling activity). This approach is consistent with the EPA's approach on drilling rates. The evidence that is appropriate to look at in estimating failure rates is the evidence that is consistent with the type of activity that the PICs are designed to deter.

Drilling operations are not casual activities that can be done in secret. These operations include:

- site modification to accommodate access to the site and setting up the drilling rig and support facilities
- using large and noisy equipment
- a period of time that may extend to weeks or months for the drilling of a borehole.

In addition, drilling activities are in an industry where companies keep track of competitors' activities that could provide economically beneficial information. For example, one company setting up a drill rig on one lease is likely to attract other companies that will try to obtain adjacent leases in case the drilling locates economically important resources that may extend into the adjacent leases. Estimates of the effectiveness of controls for activities that can be conducted quickly, quietly, privately, and with no outward signs of activity are not relevant. Also illegal activities conducted deliberately are outside of the regulatory guidance for "inadvertent" activities.

6.4.2 Failure Data for Land-Use Controls

During the deliberations of the PTF, members of WID's Long-Term Regulatory Compliance Section reviewed drilling records for the New Mexico portion of the Delaware Basin dating back to 1914. These records are 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. The WID personnel 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 recalled 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 in the region (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). Occurrences of resource trespass are so rare that none of the agencies contacted have kept records. As a result, the PTF relied on anecdotal information from knowledgeable individuals. For the 11,500 oil and gas wells drilled in the Delaware Basin, no instances of drilling on the wrong leases were recalled. As a result, the failure rate (i.e., the rate of drilling in the "wrong" leases) was 0.0. For the Permian Basin in New Mexico and Texas, but outside the Delaware Basin, no instances of drilling on the wrong leases were recalled, but perhaps five instances of drilling in the correct leases but outside the designated drilling area of those leases have occurred out of 429,000 wells drilled. In the initial analysis, the PTF considered these five instances to be "failures" in order to introduce an element of conservatism. Even with this conservatism, the failure rate was 0.00001.

Subsequent investigations were conducted to determine the reliability of these failure rates for other geologic settings and other governmental administrations. Agencies in three states and three Canadian provinces were contacted, although one of the provincial agencies did not provide any data. To address the issue of what effect a prudent extrapolation of today's regulatory environment in the Delaware Basin would have on the rate of drilling in the "wrong" location (i.e., trespassing), the PTF considered contacting government agencies in countries with distinctly different regulatory environments from those in the U.S.A. and Canada. One of the problems in expanding the data base to other countries is that in most other countries, the central governments exclusively own the natural resources and either exclusively exploit the resources or strictly control which companies do. "Failures" in these countries by drilling on the wrong *claim* or *lease* do not occur and have not occurred, because claims and leases similar to those claims and leases in the U.S.A. and Canada do not exist and have not existed. Mexico can serve as an example of natural-resource development in a developing country in which the central government owns the natural resources. Exploration and exploitation of oil and natural gas in Mexico prior to 1938 was conducted by foreign petroleum companies that were invited in to develop large areas (i.e., hundreds of thousands of acres) when compared to the sizes of claims or leases that are available in the USA and Canada. Under the conditions at the time, any borehole drilled within the area being developed by a company was in the "correct" location (i.e., inside the property). After the Mexican government nationalized the petroleum industry in 1938, the federal government continued to own the resource rights and reserved exploration and exploitation for a government-owned company (National Petroleum Company). Exploration and exploitation continued to deal with large areas rather than small claims and leases. As a result, failures (drilling in the wrong claim or lease) do not occur.

For the reasons discussed above, the PTF limited the investigations to states in the U.S.A. and provinces of Canada that were at least partially underlain by bedded salt. The results of the investigations (Guzowski, 1996) for the states and provinces are: (1) in Montana, more than 1,200 wells have been drilled during the past six years with no instances of drilling on or into the wrong leases; (2) in Michigan, more than 40,000 wells have been drilled since the current drilling regulations went into effect in 1927 with no instances of drilling on or into the wrong leases; (3) in Wyoming, more than 60,000 wells have been drilled with perhaps two or three instances of drilling on or into the wrong leases; (4) in Manitoba, a total of 4,500 wells have been drilled for oil and gas with no instances of drilling on or into the wrong leases; and (5) in Alberta, the number of wells drilled ranges from 30,000 to 50,000 with perhaps 10 or 12 instances of drilling on or into the wrong leases.

The results of these investigations support the results from the Permian Basin investigation in that the occurrence of drilling on the wrong lease is a rare event. The typical failure rate for the states and provinces is 0.0 with an anomalously high rate for one Canadian province of approximately one in 3,000 or 5,000. A conservative estimate for all of the areas investigated (i.e., taking the low end of any ranges in the possible number of boreholes and the high end in the range of the number of failures) has 20 failures for 564,700 wells, or a failure rate of 3.5×10^{-5}. This failure rate is based on the single PICs component of government control of land use through records centers. No other PICs components planned for the WIPP exist for any of the areas investigated. If the WIPP area becomes one where all natural resources belong to the central government and claims and leases do not exist, the government or company involved in natural-resource exploitation will have a vested interest in conserving financial resources. The same basic procedure to site evaluation will be followed as today by conducting both literature and field research on the geology and natural-resource potential of an area prior to drilling. This literature research initially would encounter, at the very least, the Awareness Triggers in the natural-resource maps and records centers, and possibly the archives, thereby stimulating additional research that would encounter the deterrent messages and warnings. Field research would encounter the markers component.

6.4.3 PTF Recommendation of the Bounding Value

The PTF recognized two approaches to estimating the effectiveness of the PICs in PA. One approach estimates a specific value intended to represent the "real" effectiveness of the PICs, and a second approach estimates a bounding value that deliberately underestimates the PICs effectiveness. The PTF recognized that estimating a "real" value of PICs effectiveness would create additional areas of controversy, such as whether the estimated value is the "correct" value and whether effectiveness should be represented as a probability distribution function. To limit the areas of controversy, the PTF chose to estimate a bounding value for PICs effectiveness that encompasses any uncertainties associated with PICs effectiveness in PA.

For the sake of addressing the needs of PA, to account for unidentified possible failure mechanisms and sources of human error that could result in reduced effectiveness of the PICs system, and to account for any uncertainty in the performance of the individual components, 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. For PA purposes, the AICs are assumed to be completely effective in deterring inadvertent intrusions for the first 100 years after disposal (see Section 2.2). This estimated value is approximately two orders of magnitude higher than the anomalously high failure rate for Alberta and approximately three orders of magnitude greater than the mean failure rate for the areas, states, and provinces for which the PTF was able to obtain failure rates for the single PICs component of government control of land use. The PTF believes that the existence of additional Deterrent Components would have reduced the obtained failure rates. Thus, the PICs are to be 0.99 effective in successfully communicating with future generations about the WIPP. A 1-percent failure rate would mean that out of every 100 permit requests that result in the drilling of a borehole, one is a location error on the permit itself or one results in the drillers setting up on a wrong location that was not detected by any of the several personnel involved in resource acquisition and site development, whose jobs include ensuring that the company is legally secure in exploiting a resource. As stated in PTF Assumption 8, any government action that deliberately ignores or changes the land-use restrictions will result in intentional intrusion (e.g., a government agency that deliberately allows drilling at the WIPP to occur), and intentional intrusions are not relevant to PA.

A failure rate this high is not possible within an industry constrained by current procedures and technology, because such a high error rate would be widely known within the natural resources community, and the natural resources community would demand the implementation of stronger controls over drilling to protect financial investments and natural-resource assets.

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 premises established in Chapter 3.

The EPA's guidance states that

> "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)

The PTF believes that the common denominators, regulatory assumptions, and PTF assumptions developed for drilling are equally applicable for mining. As a result, the PICs effectiveness in deterring future drilling also applies to future mining.

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APPENDIX A

SELECTED EPA CONCERNS ABOUT PICS

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APPENDIX A

SELECTED EPA CONCERNS ABOUT PICS

The following discussion is derived from: EPA, 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 for 40 CFR 191*, EPA 402-R-96-002.

1. Section 12.2.5.2, last paragraph of the section on page 12-33 "EPA did not review the Markers Panel Team's results in order to apply numerical values to credit for PICs or even develop a credit methodology. Instead, EPA noted the great variability and uncertainty in the efforts of the two teams."

Response: The designs proposed by the two marker teams contained many of the same elements. These similarities do not support the EPA's claim of great variability. The estimates by each team of the duration and effectiveness of the marker components were relatively close with the markers being most effective in early times and the effectiveness decreasing in later times as the uncertainty about future societies and technologies increases. In the future-state assumptions of 40 CFR Part 194, the EPA has eliminated the speculation about the uncertainties in how societies and technologies may evolve. If the EPA had established these future-state assumptions in 40 CFR Part 191, the marker teams would not have had to deal with "great uncertainty."

2. Section 12.2.5.3, last sentence of the section on page 12-37 "Status of site markings at the other NTS off-site locations is not well documented and is currently being investigated (DOE94b)." DOE94b is "Communication with R. Navarro, Nevada Operations Office, Las Vegas, NV, January 14, 1994."

Response: Mr. Navarro was contacted regarding this topic on March 11, 1996, by the PTF (Rodriguez, 1996c). He did not recall any conversation concerning the topic of investigating the marking of Plowshare Projects. Further conversation with Ms. Roxanne Danz, a supervisor in the Restoration Health Physics group at the DOE's Las Vegas office (Rodriguez, 1996d), confirmed that all Plowshare Projects are marked. However, there is no record of any criteria or design basis being established with respect to what these markings are intended to convey or accomplish. Ms. Danz stated that all of the project sites she has visited have different configurations of markers.

Considering the variation of current marking configurations at the various Plowshare sites and the lack of any criteria for their marking design, it is not reasonable to make a comparison between Plowshare markers (for example the marker indicating Project Gnome) and the criteria established for the WIPP markers in 40 CFR Part 191 and 40 CFR Part 194. Furthermore, the conceptual design for the WIPP permanent markers system and worldwide information distribution is virtually in a class of markers and knowledge distribution unprecedented in history. Although some of the historical analogues are substantial in volume and mass, none of history's enduring markers were associated with an intent to distribute information worldwide to ensure their lasting knowledge in the mind of the public. Neither the analogues nor the

Plowshare Projects took the additional step to ensure identification on maps and charts as a means of conveying information.

3. Section 12.3.1.1, page 12-45 "On November 24, 1992, BLM published a description of the WIPP in the *Federal Register* as required by the LWA (57 FR 55277) [BLM, 1992]. BLM also submitted the required documentation to various governmental organizations on November 16, 1992.... [Woodard, 1996] (While this information was supplied to the Archivist of the United States and presumably has been filed, the existence and location within the Archives have not been uncovered in spite of numerous inquiries.)."

Response: The archival specialist working with the PTF recommended that the DOE should establish a filing code that the national archives will use when archiving documents and records received from the DOE related to the WIPP Project and that all documents submitted to the archive will contain this filing code. The DOE has an official archivist, and this archivist will be consulted in the development of this filing code.

4. Section 12.3.2, page 12-46, last paragraph "Even so, Tannenbaum has observed that storage materials may not last for the required 10,000 years; therefore, records must be periodically reproduced and perhaps translated into contemporary language (TAN84)."

Response: The records are not required to last for the entire 10,000 years of regulatory concern. The assurance requirements mandate that the PICs are the most permanent practicable. The DOE has developed a PICs system that contains redundant components so that the failure of a single component does not compromise the effectiveness of the PICs system. The PTF believes that future generations will reproduce these documents provided that they are perceived to be important. No credit was taken for the reproduction of information in estimating the effectiveness of the PICs system for PA calculations.

5. Section 12.3.2, page 12-47, second paragraph "Gillis mentions a downside to record-keeping redundancy (GIL85). Dispersal of the information to ensure its survivability may reduce detectability by persons at the site for whom it is most relevant."

Response: This is not a logical conclusion. Dispersal of information does not impact the detectability by persons at or near the site when that same information is provided at a number of locales near the site. The response to this concern is to make a sufficient number of copies that copies can be stored both locally and regionally.

6. Section 12.3.4.1, page 12-57 cites failure of the DOE to document the presence of an oil and gas well under the southwestern corner of the land-withdrawal area.

Response: As mentioned in Chapter 7, the DOE refutes this unfounded claim.

7. Section 12.4.1, page 12-64, last paragraph provides a discussion ending with "Institutions frequently outlive the governments which inaugurate them."

Response: This statement further supports the EPA's future-state assumptions in § 194.25.

8. Section 12.5.1.1, page 12-66, the EPA makes the statement "It is highly unlikely that a drilling crew would detect the presence of the markers."

Response: Surface preparation for drilling crew setup using today's technology make extremely likely the discovery of buried markers positioned at intervals selected randomly between 4.6 and 12.2 meters (15 to 40 feet), and 0.6 to 1.8 meters (2 to 6 feet) below ground, while the drilling crew is preparing a mud pit, which typically is of the dimensions of 30.5 meters by 61 meters (100 feet by 200 feet). This assertion of detection was confirmed by discussions with members of the WIPP Inadvertent Intrusion Advisory Panel and New Mexico Junior College (1995) on May 26, 1995. Their report of September 5, 1995, stated that intervals of 12 meters (40 feet) and 0.3 to 1.8 meters (1 to 6 feet) deep would ensure some markers are seen during excavation.

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APPENDIX B

COMPLIANCE WITH THE PASSIVE INSTITUTIONAL CONTROLS ASSURANCE REQUIREMENT

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APPENDIX B

COMPLIANCE WITH THE PASSIVE INSTITUTIONAL CONTROLS ASSURANCE REQUIREMENT

In 40 CFR 194.43, the U.S. Environmental Protection Agency (EPA) requires that:

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

At the same time, the EPA has indicated in the Supplementary Information published with 40 CFR Part 194 their desire to reduce undue speculation as it relates to human actions in their specification of what they call the "future states assumption":

> "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 predictions of the future state of society, science, languages or other characteristics of future mankind .... Hence, the final rule requires that performance assessments and compliance assessments shall include dynamic analyses of geologic, hydrogeologic and climatic processes and events that will evolve of 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." (61 FR 5227c-5228a/EPA, 1996c)

In addition, the EPA has stated in their Response to Comments Document For 40 CFR Part 194 that

> "The design of passive institutional controls, both markers and records, must be designed so that they are as permanent as possible, taking into account, to the extent possible, potential collapses in institutional, societal, or linguistic structures. The final rule requires that DOE document the period of time passive controls are expected to endure and be understood [§194.44]. Compliance with the assurance requirement for passive controls will be evaluated based in part on the depth of the analysis and the scope of potential societal changes which are accounted for in the design of passive controls." (EPA, 1996b, p. 7-7)

Thus, the DOE must address the two objectives of longevity of marker structures and communications means, and the addressing potential variability in society. The combination of the requirement for analysis and the prohibition on undue speculation about the future state of society leads one to conclude that the analysis must be qualitative in nature and not require specific numbers that would involve assumptions about the future state of society and the undue speculation EPA attempted to eliminate.

Analysis of Most Permanent Practicable Passive Institutional Controls

A method for evaluating the requirement in §191.14 for "the most permanent markers, records, and other passive institutional controls practicable" is to examine analogues of human constructed buildings or sites as a key to what is most permanent and what was practicable to create. If markers incorporate lessons learned in long-term durability and communication effectiveness, and are consistent in design with the longest lasting structures, then markers and records are the most permanent designs practicable.

Reference to Chapters 5 and 8, and to the Markers Panel reports (Trauth et al., 1993) will indicate that the design elements reflect lessons learned. The DOE's commitment to the design elements as represented in the conceptual design show the PICs to be implemented are consistent with the longest lasting human structures.

Scope of Potential Societal Changes Represented in the Passive Institutional Controls Design

A method for evaluating the design of the PICs in response to consideration by the EPA of the "depth of the analysis and the scope of potential societal changes which are accounted for in the design of passive controls" is to examine the societal basis for the communications recommendations from the Markers Panel.

The Markers Panel deliberations did not assume that one could validate predictions about the future state of languages, level of technological sophistication, or governmental control. Their response to the uncertainty of future societies was to assume that communication means had to be available for individuals from any culture, speaking any language, or with any level of technological sophistication.

The overall recommendations for markers (which is applicable to archives and records) was to utilize a systems approach whereby different components are available to communicate with different individuals and to provide different pieces of information, with enough interconnections to reinforce the information and help fill in any gaps. Within the system, messages are to be provided in different levels of complexity (five different levels from the most basic information of a manmade structure to detailed scientific information on the waste inventory) to address possible variation in the future level of technological sophistication. The different media used for the communications (e.g., berms, stone monuments, buried ceramic disks, and paper) address durability and access issues. Information was to be communicated by linguistic (seven current languages of wide distribution and usage) and non-linguistic (e.g., pictographs, star charts, and the periodic table of the elements) means to address uncertainty about languages to be spoken in the future. While languages change over time, certain basic words are more stable, so the linguistic messages need to be created with simple sentences (no idioms or complex sentences) and with the most basic vocabulary available. Even the uncertainties of human actions with respect to vandalism or the desire to place things of value in museums, the marker design fundamentals suggest large constructions that are difficult to move or destroy. Even the uncertainty about future continuity of property rights is addressed by the requirement for truthful messages about the health implications of possible intrusions.

Technical consultations on archives and records suggest that for long-term maintenance of information in an archives or records system, the physical format should be rather small in size (communicate the salient information quickly and as a guard against curators destroying bulky information), have distinctive binding (reduce the probability of being misfiled and not rediscovered), be produced on durable archival paper, with the documents having little resale value (no original signatures in the records and multiple copies in different locations), and with distinct cover language convincing a curator of the importance of the information and the need to preserve it for long periods of time.

APPENDIX C

EFFECTS OF THE COLLAPSE OF CIVILIZATION ON THE PROBABILITY OF EXPLORATORY DRILLING AT THE WIPP

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Sandia National Laboratories

Albuquerque, New Mexico 87185

date: April 2, 1990

to: D. R. Anderson, 6342

Robert V. Guzowski

from: R. V. Guzowski, 6342

subject: Effects Of The Collapse Of Civilization On The Probability Of Exploratory Drilling At The WIPP

A preliminary scenario analysis for the WIPP (Guzowski, 1990) indicated that the integrity of the disposal system depends on whether or not future drilling occurs into the waste-filled rooms and drifts. In dealing with future human intrusion, the question arises as to how long into the future exploratory drilling for resources is likely to occur. At the WIPP, the only natural resource at depths greater than the disposal rooms and drifts with the potential to be present in economic quantities is natural gas (Powers and others, 1978). Based on estimates of the quantities of reserves and undiscovered resources for oil and natural gas (Mast and others, 1989; Kerr, 1989) and the current rate at which the reserves are being consumed (Kerr, 1989), the trend suggests that all of the oil and natural gas resources in the continental U.S. for practical purposes will be consumed within a relatively short period of time. The question arises as to how long exploratory drilling will continue. Depletion of a resource in an area generally will result in an end to exploratory drilling for that resource at that location. For some undefined time after depletion, the possibility exists that industry will go back to an area for "one more look." This rechecking of areas also will eventually stop if no new resources are discovered. Another question arises as to what conditions are required for exploratory drilling to begin again. In various discussions on the subject, a number of people have stated the opinion that exploratory drilling would begin again as society redeveloped after the collapse of civilization even if exploratory drilling had previously been abandoned. The purpose of this memo is to consider the factors that have allowed drilling technology to develop to its present level, and to consider whether these same factors would be available after the collapse of civilization.

DEGREE OF COLLAPSE

In this discussion on the reestablishment of drilling technology, collapse of civilization is considered to occur at a time after the period of active institutional controls of the WIPP and to include complete loss of knowledge of drilling technology, the geologic controls for hydrocarbon accumulation, and the exploitation of natural resources by a previous civilization.

FACTORS THAT CONTROLLED THE DEVELOPMENT OF DRILLING TECHNOLOGY

Several factors were required for the development and advancement of the petroleum industry. In the past, natural gas usually was burned at the well as a waste product. At some locations, this practice continues today. The following discussion is based on the factors in oil discovery that led to advancement in drilling technology. Advancements in drilling for oil also apply to drilling for natural gas. These factors are:

(1) In the early stages of oil discovery, shallow reservoirs supplied enough petroleum so that once uses were found for the material, supply was sufficient or could readily be located to maintain the demand for the product.

(2) Oil reservoirs were associated with certain geologic settings. The distribution of reservoirs was not random. A theory was developed as to the origin and accumulation of oil and gas. Through time, the number of geologic settings where hydrocarbons could be found increased, although the basic theory as to why hydrocarbons accumulated remained basically the same. A relatively consistent association was noted between production and geologic setting when moving from one region into new but geologically similar region. This association confirmed the theory of the origin and accumulation of oil and gas.

(3) Once the targets of hydrocarbon accumulation were identified, progressively deeper targets were investigated as demand increased and techniques were developed to locate deeper targets. Improved drilling techniques had to be developed before boreholes could reach greater depths.

REDEVELOPMENT OF DRILLING TECHNOLOGY AFTER CIVILIZATION COLLAPSE

In order to develop the capability to drill to depths greater than the waste-filled rooms and drifts, the same basic steps would have to be followed as listed above. For the following reasons, the steps cannot be followed. These reasons are:

(1) Except for possibly small occurrences, all of the shallow oil and gas reservoirs have been located and exploited. Any remaining reservoirs are not likely to supply sufficient material to create enough demand to encourage drilling for additional supplies.

(2) Because of the previous exploitation of reservoirs and the use of secondary and tertiary recovery techniques, little if any production is likely to occur from previously worked reservoirs. As a result, no association between the accumulation of productive amounts of oil and gas with particular geologic settings is likely to be recognized. If the location of hydrocarbon reservoirs is not observed or is not predictable, a theory of hydrocarbon accumulation cannot be developed or confirmed.

(3) With no consistent association between shallow geologic settings and productive hydrocarbon reservoirs, no reason would exist to suspect that deeper geologic settings would be more productive than the shallower

settings. With no incentive for deep drilling, drilling technology would not progress beyond the early stages, if any development occurs at all.

CONCLUSIONS

The technology that enables drilling to considerable depths evolved from a technology that was initially limited to drilling to shallower depths. As shallower resources were consumed and demand continued to increase, the economic incentive developed to encourage deeper drilling. Progressively deeper drilling required the development of progressively more sophisticated drilling techniques. A total collapse of civilization would result in the loss of drilling technology. Because of previous exploitation of hydrocarbon resources, all of the factors that led to the evolutionary development of drilling technology are not currently present and will not be present again in the future. As a result, a collapse of the current civilization or the projection of what the current civilization will develop into would mean that the next civilization, if one develops at all, will not redevelop to the level of a hydrocarbon-based industrialized economy.

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

WIPP/CAO-96-3168,

November 14, 1996, Revision 1

December 6, 1996

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

ADDENDUM

to

Effectiveness of Passive Institutional Controls in Reducing Inadvertent Human Intrusion into the Waste Isolation Pilot Plant for Use in Performance Assessments WIPP/CAO-96-3168, Revision 1, November 14, 1996

December 6, 1996

Robert V. Guzowski[1] and Kathleen M. Trauth[2]

INTRODUCTION

The following is a brief discussion that indicates the typical process that takes place prior to resource exploration and extraction by drilling or mining, and how the WIPP PICs fit into the process to deter inadvertent human intrusion. A few clarifications must be made. The first of these clarifications is that this process does not invoke §194.25 Future state assumptions. Instead, this process relies on the PA guidance found in §194.33 Consideration of drilling events in performance assessments. In this case, procedures do not have to be exactly as they are today, but must operate in a similar fashion to achieve the same goals.

The second clarification is to reiterate that failure to deter considers only inadvertent human intrusion. Any drilling or mining that takes place with the knowledge that the WIPP Withdrawal is an area where drilling or mining is prohibited is intentional and is not to be considered by the PTF or in the PA calculations.

The third clarification is that the failure of any one PICs component (or a portion of a PICs component) to correctly communicate does not constitute a failure to deter, as defined in Rev. 1. Because of the regulatory framework established by the EPA, the normal conduct of resource exploration and extraction would require a failure of each of the PICs deterrent components encountered in order to have an inadvertent drilling or mining activity. It is possible that information transfer in one of the portions of a PICs component could fail, e.g., incorrect information transfer at one of the steps shown below. The discussion below shows that the resource development system has so many internal and external checks that the likelihood of all

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of the steps failing in order to allow a failure to deter is extremely small. Because each of the deterrent components contains the message "DO NOT DRILL," any one of the PICs deterrent components could, by itself, deter an inadvertent human intrusion.

The source of error that potentially has the greatest impact is human error, and this error would be most associated with the information transfer associated with records and archives, and with the implementation of government control of land use.

Types of failures incorporated into the data obtained from discussions with regulatory resource personnel include: (a) having a correct lease, having a correct permit for the same location, but setting up in the wrong location (i.e., not setting up in the area for which the leases and the permit were obtained); (b) having a correct lease, having been provided with a permit for a location other than the area for which the lease was obtained, and drilling at the location on the permit even though the leases had not been obtained; and (c) having a correct lease, having been provided with a permit for that location when the permit should have been denied, and drilling at the location on the permit.

The specific New Mexico information is provided as an example of current procedures, and the general activities that, based on §194.33, will be a part of resource-development procedures.

ACTIVITIES MODEL

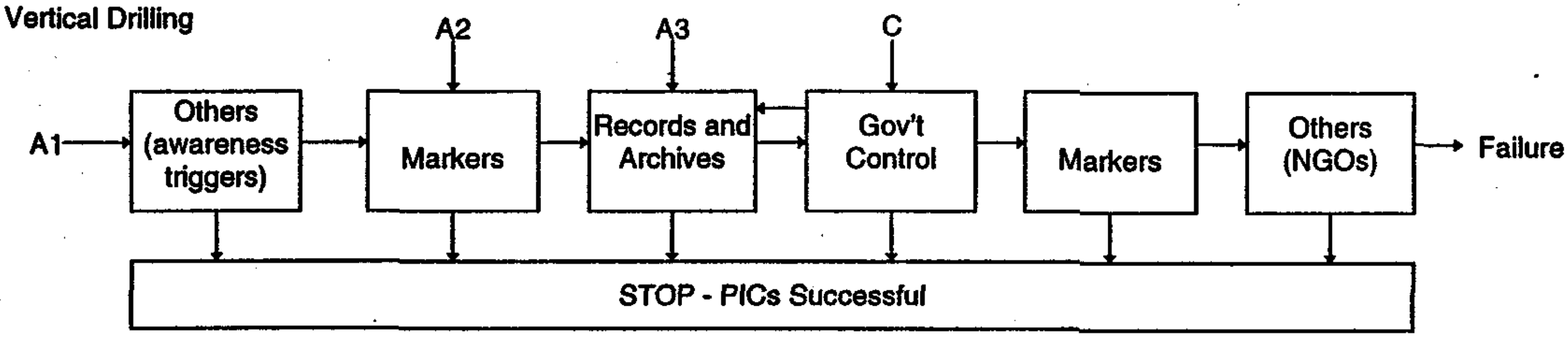
The following figure indicates the pathways through resource exploration and extraction activities where PICs could be encountered and where PICs could succeed or fail. The drawing accounts for both vertical (A) and horizontal (B) drilling, and accounts for potential intrusions that are new activities and those that would be extensions of existing activities (C). The 1, 2, or 3 designations attached to A and B indicate the locations that the potential intruder could enter into the PICs system. The text discusses the pathways for success or failure, realizing that a potential intruder could enter the system at different locations or be deterred at different locations.

Site investigation to identify candidate sites for drilling encounters awareness triggers

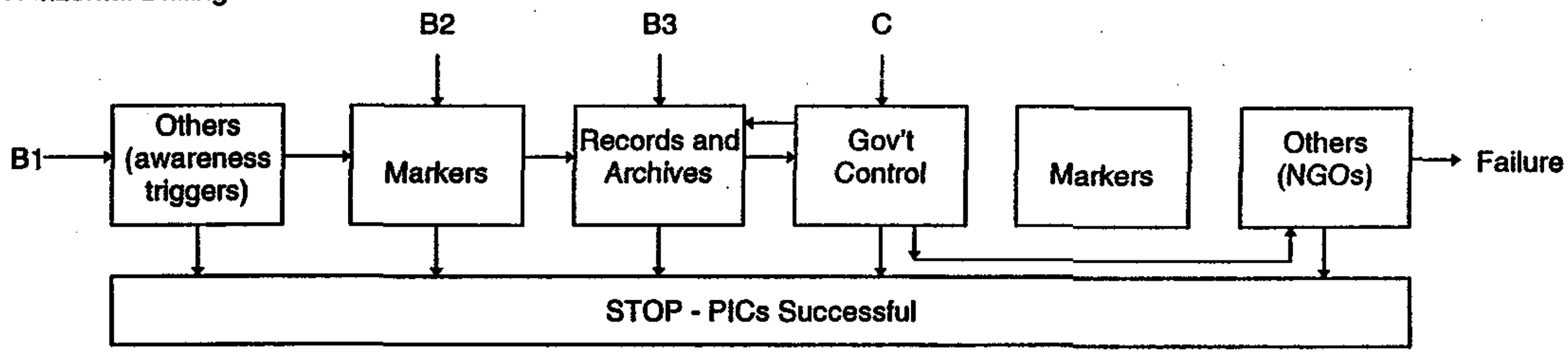
The "other" PICs category includes designation of the WIPP location on both general-use and professional-use maps. Anyone who has worked or owns leases in the northern Delaware Basin is virtually certain to have seen maps of one or more types with the WIPP designation. Anyone new to the northern Delaware Basin will be interested in obtaining information about where drilling and/or resource production has occurred in the past, whether the terrain is suitable for resource development, and where roads and power lines are located. In the process of searching for this information, maps and possibly other sources of information in which the WIPP is designated will be encountered. An exclusion zone consisting of 16 sections is virtually certain to be noticed by anyone engaged in resource exploration and/or production. The information conveyed by the awareness triggers (i.e., something called WIPP exists as a resource-exclusion or danger zone) may be sufficient to discourage a potential intruder from proceeding with the

ACTIVITIES MODEL INDICATING PICS A POTENTIAL INTRUDER COULD ENCOUNTER AND POSSIBLE PATHWAYS FOR PICS SUCCESS OR FAILURE (I.E., INADVERTENT HUMAN INTRUSION).

A. Vertical Drilling



B. Horizontal Drilling



A and B	lease and drilling permit must be acquired.
C	lease held and work done adjacent to Withdrawal, effort made to obtain lease and permit in the Withdrawal.

(NGO = non-governmental organization)

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process of obtaining resource rights. The PTF did not take credit for any deterrence offered by the awareness triggers that are likely to be encountered during the initial phase of site investigation.

A decision is made to obtain resource rights within the Withdrawal

At some point during the site investigation, a decision is made by the potential intruder to obtain resource rights within the Withdrawal. To qualify as a potential step leading to an inadvertent intrusion, the person trying to obtain resource rights would have to remain uninformed about the existence of the WIPP and the associated prohibitions. A potential intruder lacking this information is highly unlikely, and would be akin to individuals involved in the current resource industry in the northern Delaware Basin not knowing about the Potash Exclusion Area. If this decision is made with full knowledge about the existence of the WIPP and the prohibitions against human intrusion, any subsequent intrusion would be deliberate and therefore outside the scope of PA.

A records search is conducted to determine ownership of the resource rights of interest within the Withdrawal

Information about lease ownership can be obtained from some awareness triggers (e.g., land-status maps produced by the federal government, maps produced by companies supporting the resource industry) or through records centers dedicated to the resource industry, which would be the most current source of information. A search of a records center is virtually certain to encounter information that the resources within the Withdrawal are not available for exploitation. Information-transfer procedures for the Withdrawal will be similar to the procedures currently in place to notify resource personnel about the presence of the Potash Exclusion Area. Completion of this step in the procedure requires that the resource person remains uninformed about the WIPP, which is highly unlikely, because a 16-section no-intrusion zone in the area that the resource person is investigating would be difficult to miss.

Resource rights are applied for and obtained

The resource rights for the federal land within the Withdrawal, except for state leases in the southwestern corner of the Withdrawal, have been obtained by the Department of Energy, and these leases have been terminated. If someone is interested in acquiring the resource rights within the Withdrawal, the party would submit an application to the Santa Fe office of the Bureau of Land Management (BLM) for those rights. The Santa Fe office would then send the application to the district office of the BLM, where the district office checks the Resource Management Plan (RMP) to see if a lease for those particular resources is available. The RMP contains stipulations recorded by township and range on the availability of the land for leasing. In the case of the Withdrawal, no leases are available, because these leases have been terminated. For the drilling procedure to continue, new leases would have to be developed without knowledge of the prohibitions within the Withdrawal. Following normal procedures for issuing leases, the newly created lease would then go on a list of leases that will be available for competitive bidding. The availability of the list is published in a newspaper to inform the general public, and the list itself is sent to interested parties. At this point, non-governmental organizations (NGOs), some of whom are likely to have an interest in activities at the WIPP would be informed of a new lease in a previously designated exclusion area, and other companies/individuals in the resources industry would be aware that part of the Withdrawal has been opened for resource exploration and development and are highly likely to make inquiries to confirm the availability of the lease and to check whether the rest of the Withdrawal will also be opened. The likelihood that the status of the Withdrawal and the error in issuing the lease in the Withdrawal would not be noted by someone in the number of people and groups involved in this lease acquisition process is extremely low.

For drilling procedures to continue to the next step, the following individuals would have to remain unaware of the Withdrawal: the person/company interested in the resource rights within the Withdrawal, the personnel at the BLM who accepted the application and created a new lease, the personnel in NGOs with an interest in the WIPP, and the personnel in the resources industry on the notification list. The issuance of improper lease rights must remain a rare event. Because of the potential economic consequences associated with resource leases, the resources industry requires stability in the obtaining and holding of resource rights. If the issuing of improper resource rights were common, the resources industry would demand revisions to the procedures that would ensure that everyone played by the same rules.

The state leases in the southwestern corner of the Withdrawal are currently held by a company. Pending a final decision by the Environmental Protection Agency as to whether or not the Department of Energy has to acquire the leases, these leases can be transferred but not worked (i.e., no drilling). Application for transfer must be made to the Oil and Gas Division of the State Land Office, which must approve the transfer. Written procedures are available and must be followed, and a data base must be checked. Errors in the data base or in the application would be detected if the name and location on the application did not match the lease holder and lease location in the data base.

A drilling permit is applied for and improperly issued

If a person can progress to the point of obtaining the resource rights without knowledge of the WIPP, the next step of applying for a permit, which also would require this lack of knowledge, could occur. The fact that the issuance of a permit incurs financial commitments in the form of surety bonds ensures that certain regulatory obligations such as borehole sealing and site restoration are met. These financial commitments are likely to involve additional personnel within a company whose jobs include cost-benefit assessments in the commitment of financial resources. These additional personnel would also have to be unaware of the drilling exclusions for the Withdrawal.

Applications for drilling permits must include the location of the lease and the planned location of the borehole both at the surface and at depth. Additional information that must be supplied includes a description of the target unit(s) and plans for conducting the drilling (along with safety measures), closing the borehole, and remediating the site. The application is accompanied by surveying records locating the claim and the drilling site within the claim. The survey must be done by a registered surveyor. An engineer from the resource company may accompany the survey party. The probability that none of the additional company, surveying, and government personnel involved in this step would be aware of the prohibitions against drilling into the Withdrawal is extremely small. Being unaware of the Withdrawal is especially unlikely for the surveyor who is likely to have experience surveying in the region and who has traveled to the site while doing the survey, thereby encountering the marker system.

The legal and financial ramifications associated with drilling for natural resources ensures that operators keep track of each other in the areas of obtaining and developing leases. This is an internal check within the industry promoting accuracy in both the records centers and in the field activities (i.e., the correct drilling locations are developed).

Site preparation begins

Before drilling can begin, the site has to be prepared so that the drilling rig and supporting facilities can be set up. Site preparation consists of constructing access roads, leveling the drilling pad, constructing any structures, and the digging of necessary pits. The crew doing the work (or at least the foreman) will check maps and surveying flags to make certain than the required roads, facilities, and pits are in the correct locations. In the preliminary states of site preparation, someone in the crew is likely to notice the Withdrawal on the maps or to recall from previous experience that the Withdrawal is a no-drill area. The crew itself has no authority to stop work, although someone in the crew may check with someone with higher authority whether the location described in the work order is correct. If the crew goes to the drill site within the Withdrawal, at least some of the elements of the marker component are likely to be encountered. Because of the persistence of current English in the resources industry, someone on the crew may be able to understand the messages engraved on the monuments and Information Center. If the planned drilling is to occur within the area enclosed by the berm, the berm would provide a major obstacle to reaching the drill site, and inquiries are likely to ensure that the specified site is the correct site.

If none of these points of inquiry result in a stop-work order, site preparation can begin. For drilling sites within the berm enclosure, leveling the site and digging the pits is virtually certain to encounter one or more buried markers, whose depth and distribution were specified to ensure that they would be encountered during site preparation. These markers may or may not be noticed by the site-preparation crew. If none of these activities during site preparation alert a decision-maker in the company about the existence of the Withdrawal and the associated prohibitions, the next step in the drilling procedure can begin.

Site preparation for horizontal drilling could, at least theoretically, occur outside the Withdrawal without any of the markers being encountered.

Drilling operations begin at a site within the Withdrawal or a site that would penetrate the Withdrawal (horizontal drilling)

Upon the arrival of the drill rig, drill crew, mud engineer, and geologist, the markers would again be encountered. For inadvertent intrusion to occur, the personnel involved with setting up the drill rig, conducting the drilling operation, and the monitoring of the drilling fluid and geologic/resource data in the borehole would have to remain unaware that the drilling is occurring within the Withdrawal.

Non-governmental Organizations

Non-governmental organizations (NGOs) include conservation, environmental, and historical groups that have an interest in particular private or governmental activities, and who follow the progress of these activities. In the case of the WIPP, the NGOs would probably follow the activities of the natural-resources industry, as being the source of potential human intrusion. NGOs may act at any point in this process to question activities to ensure that laws and procedures are followed correctly.

CONCLUSION

From the figure and the accompanying discussion, one can see that the PICs of records centers and governmental control of land use would be encountered by all potential intrusions by the natural-resources industry. Some potential intrusions could encounter three or all four of the PICs (although it is possible to be deterred by the "others" category, explicit credit is not taken for them because they do not all provide sufficient information to indicate not to drill). Thus, examining only records centers and archives and governmental control of land use is the most conservative approach. If these two PICs can be successful, then the PICs system is successful.

The operation of the existing natural-resources industry is an analogue that can be useful in assessing the effectiveness of the PICs. The natural-resources industry operates with records centers and archives and with governmental control of land use, which are the PICs that would be encountered by all credible potential intrusion scenarios. These two PICs as encountered by the natural-resources industry have a historical rate of failure. Because the WIPP PICs are intended to deter inadvertent activity associated with the exploration for and exploitation of natural resources, the PTF believes that the historical rate of failure in the natural resources industry is an analogue for the future failure rate of the PICs. The historical rate of failure for selected U.S. states and Canadian provinces (as described in Rev. 1) is approximately 3.5×10^{-5}. The DOE intends to add additional deterrence (i.e., through markers) to a system that is highly effective. Because of the potential for error in the memory of failures and because of the potential for confusion as to the sources of errors (setting up on the wrong lease versus the issuance of incorrect permits), the PTF has recommended that the PA calculations use a failure rate that is approximately three orders of magnitude higher (i.e., 0.01) than the overall historical failure rate. Although the PTF has not distinguished between the various sources of historical errors, the PTF believes that errors of any source would have been recalled by the personnel contacted about the historical failure rates. The PTF also believes that any undetected/unremembered failures would be less than the bounding value recommended for PA calculations. A failure rate on the order of that recommended by the PTF would have resulted in enough litigation that regulatory personnel would have remembered many more incidents of failure than were reported.

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