- ~~2005 – 2083~~ ***2007-2083*** Monitor Performance of ***Prototype Markers***~~. Test Markers and Test Berm~~. During this period, the DOE will monitor the performance of the test structures to develop information for use in the final design.

- 2018 – 2023 Test Message Comprehension. The DOE will gain operational experience for any information that may affect the composition of the intended messages, both narrative and pictogram, and then conduct testing for comprehension by populations indigenous to the countries represented by the languages used in the messages.

- 2083 – 2090 Final Design. During this period, the DOE will complete the final design of the permanent marker system.

- 2090 – 2093 Construct Permanent Marker System. During the period, the permanent marker system will be constructed including installation of messages.

- 1999 – 2093 Implement Information Collection and Establish Archival and Record Center Agreements. During this period the actions required to implement record keeping and record storage aspects of PICs are conducted. Individual actions and associated timelines are:

• ~~2003~~ ***2004*** Establish Filing System. The DOE will establish the filing system under which the record center and archival information will be assembled. Completion of the system by ~~2003~~ ***2004*** will support the information collection program.

- 2003 – 2033 Collect Operational Information. Collect the information relative to WIPP operation, including decommissioning, which will be included in the promulgated documentation.

- 2033 – 2090 Collect Active Control Period Information and Marker Configuration. Collect the information relative to WIPP active controls and the results of testing of the permanent marker system components and communication concepts.

- 2023 – 2034 Establish Agreements with Recipients. During this period the DOE will communicate with the planned document recipients to develop general agreements with respect to language translation, scope of translated material, format in which the material will be provided, and any financial support required to achieve acceptance by each recipient. Beginning about 2023 when most of the documentation should have been developed, this effort should start. The DOE expects two to three years to establish the agreements and another five to eight years for translation, with completion about the time that decommissioning and decontamination are finished. This provides for the incorporation of information related to decommissioning and decontamination.

- 2033 – 2034 Develop Summary Document. The DOE will develop the WIPP summary document to be provided for ease of public access and understanding of the WIPP.

- 2035 Promulgate Information Accumulated Through WIPP Closure and Decommissioning. The DOE will make a distribution of documents accumulated through the final closure, decontamination, and decommissioning of the WIPP.

- 2023 – 2033 Establish Agreements and Submit Information to Publishers. During this period, the DOE will establish agreements with map makers and text publishers including financial support and provide hazard, history, and location information to be included on maps and various text materials.

- 2083 – 2093 Finalize Archival Information. During this period, the DOE will develop the final additions to the planned submittal, which include information describing the WIPP history during the first 50 to 60 years following closure and the final configuration of the permanent marker system.

- 2093 Promulgate Archival & Records Center Information. The DOE will make the distribution of the final portion of the archived information nationally and internationally.

In a letter dated May 16, 2002 from Dr. Ines Triay to Mr. Frank Marcinowski, the DOE proposed to the EPA changes regarding the submittal of detailed plans and drawings depicting the permanent marker prototypes. The request includes a proposed revised schedule, as detailed in Table 7-9.

The EPA responded to the DOE request in a letter dated November 7, 2002, from Mr. Marcinowski to Dr. Triay (EPA Docket A-98-49, Category IIB-3, Item 41). The EPA response states that the schedule changes proposed by the DOE are insignificant with respect to the Certification Decision (63 FR 27396, May 18, 1998). The EPA also concluded that the DOE plans for testing provide significant details to support the need for additional testing time. As such, the EPA determined that the DOE may proceed with the proposed changes. In addition, the EPA provided the following comments related to the implementation of the passive institutional controls program. These comments serve as guidance to the DOE.

1. ***The Permanent Markers Testing Program Plan is a welcome development. The EPA appreciates the thoroughness of DOE's approach to this topic, especially the inclusion of references to the Quality Assurance Program Document. The use of reference standards and established quality processes, as well as a methodical approach to testing, will be important factors in demonstrating to the EPA that any future changes to the conceptual design have an adequate technical basis.***

2. ***The DOE is obligated to execute site markers as described in the CCA and subsequent DOE correspondence (February 7, 1997, letter from G. Dials to R. Trovato; Air Docket A-93-02, Item II-I-07). If the DOE determines that the original marker design (including location, number, materials, and configuration) should be altered or***

Table 7-9. Activities Related to the Implementation of the Permanent Markers Program

Activity	Reference Event	Original Timeframe	Current Status	Proposed Timeframe
Stone Monument Survey	First five years of operations	1999-2904	Completed	N/A
Identification of suitable source material	First five years of operations	1999-2004	Pending decisions on changes to design and material selection	2997
Submit plans for the test marker system	1st CRA submittal	2003	Proposed change to submit prior to second CRA	2007
Construct and test herm and test markers	Second five years of operations	2004-2999	Pending proposed change and testing program	2998
Monitor performance of test berm and test markers	After construction	2997-2083	Pending proposed change and testing program	2009 - until closure
Testing comprehension of marker messages submittal of testing plans to EPA	Fourth CRA submittal	2018	No change	N/A
Develop final design of markers	Upon termination of testing program	2083-2090	Final design to be submitted with the final CRA	2933 (anticipated)
Finalized Translated Messages	Prior to building of final permanent markers	N/A	Finalized messages will be submitted with the final CRA	2933 (anticipated)

improved, the Department must notify the EPA and receive the Agency's approval before proceeding.

Certain changes (such as different component materials or dimensions) may be possible without modifying the certification, as long as the design itself remains essentially the same. However, the introductory section of the proposal (page 2) states, "DOE plans to re-examine whether…all of the components of the permanent marker system proposed in the CCA are needed." Elimination of one or more components may require modification.

3. ***Condition 4 of the Certification Decision requires the DOE to show that PICs will be implemented "as soon as possible following closure of the WIPP." DOE's change notice states that all measures in their final form will be presented in the last recertification application before site closure (approximately 2033). Throughout the operational phase of the WIPP, the DOE should present information in each recertification application showing progress with regard to testing and implementation of all PICs (markers, archived records, etc.).***

4. Based on conclusions reached by John Hart and Associates, the DOE suggests that "portions of the permanent marker system originally conceptualized…are impractical" (page 1 of the introductory section). Concerns about the specific design of the surface granite monoliths led us to require further information about the monoliths in Section(a)(2) of Condition 4 of the WIPP Certification. Nevertheless, the EPA explicitly concluded in the Certification Decision that the proposed marker system – including the salt-core based berm – was practicable. To justify a departure from the markers that were proposed, the DOE would be expected to provide an adequate technical basis showing that an alternative is likely to be more durable and effective as a marker. EPA believes that further testing and analysis of materials (e.g., basalt), processes (e.g., granite exfoliation), and configurations (e.g., salt core of the berm) should be done before DOE concludes that certain features of the marker system are impractical.

7.3.4 Effectiveness of Passive Controls in Reducing the Rate of Human Intrusion

The EPA raises the issue of the expected ability of the passive institutional controls to convey information to future societies in two areas. In the context of the assurance requirement in which no assumptions can be made to limit the uncertainty of the future states of societies, the EPA states

> Any compliance application shall include the period of time passive institutional controls are expected to endure and be understood. (40 CFR § 194.43[b])

In the context of credit for passive institutional controls in deterring inadvertent human intrusion for use in performance assessments, the EPA goes on to state that

> The Administrator may allow the Department to assume passive institutional controls 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 (40 CFR § 194.43[c]).

To limit the speculation about the state of future society, the EPA has provided additional guidance by stating that "EPA expects that the DOE will establish a framework of assumptions for passive institutional controls that is a prudent extrapolation of the future state assumptions established in 194.25" (EPA 1996b, ***p.*** 61) and by providing for the existence of certain societal "common denominators" based on "patterns of human behavior that may be detected throughout history and around the world" (EPA 1996b, ***p.*** 61).

Section 7.3.4.1 addresses the issue of how long the passive institutional controls are expected to endure and be understood in the context of the Assurance Requirement (40 CFR § 194.43[b]) and Section 7.3.4.2 addresses the issues of how long these controls are expected to endure and be understood and the resulting credit in deterring inadvertent human intrusion in performance assessment calculations (40 CFR § 194.43[c]).

7.3.4.1 Expected Effectiveness

The passive institutional controls in the Conceptual Design Report (DOE 1994) were developed from the recommendations of the Markers Panel convened in 1991, modifying them for reasons such as constructability or resource requirements. The Markers Panel developed fundamental principles of long-term communication making only the most minimal assumptions about what future societies would be like (for example, they will be human beings similar to what we are today). No assumptions were made about what languages they might be speaking or how technologically sophisticated they might be. Because no assumptions were made about language or technology, the Markers Panel developed strategies that attempt strategies to communicate with individuals in a variety of means and in a systems approach whereby the various components reinforce and supplement the other messages.

Without assumptions about technological sophistication, messages will be provided in various levels of complexity, ranging from the most basic marker of human construction rather than a natural phenomenon, to the entire written record of information about the repository and its certification. Because it is not known what languages will be spoken in the future, the markers will include non-linguistic means of communication, such as pictures of humans, star charts, and the periodic table of the elements. In this way, the design of the markers responds to the EPA's requirement for the "most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location" (40 CFR § 191.14[c]). While the Markers Panel focused its efforts on the repository footprint, based on the 40 CFR 191 definition of human intrusion, the entire withdrawal area will be identified by on-site passive institutional controls to satisfy criteria in 40 CFR § 194.43. Because of the requirement for records and archives, plans have been made to place materials within the existing governmental and scientific systems of recordkeeping.

In addressing the issue of credit for passive institutional controls in performance assessment calculations, the DOE examined historical analogues for the controls components (see ***CCA*** Appendix EPIC, Chapter 5). Certain design characteristics of these historical analogues have survived destruction from both societal turmoil and natural processes. By designing the PICs to mimic and enhance these design characteristics, the DOE believes that the passive institutional controls for the WIPP will be capable of surviving at least as long as the historical analogues. Based on the characteristics of the markers, these components have the capability of lasting in excess of several thousand years. This conclusion is consistent with the conclusions of both teams of the Markers Panel whose estimates were based on basically the same design characteristics for the markers and on a wide variety of future states of society. The multiple copies of the records in the records centers and archives, the selection of highly durable materials (that is, archival paper and carbon-black ink), and the fact that the records will have value in the economic and health areas suggest that at least some copies of the records have a high probability of surviving for many hundreds to thousands of years.

The Markers Panel concluded that the messages proposed have a high probability (greater than 0.70) of being understood by all potential levels of technology for at least 2,000 years (Team A estimated at least 5,000 years). Although the Markers Panel considered only the messages on the markers, the same information, both text and pictographs, will be included in the records in records centers and archives. As a result, the DOE concludes that these records will be interpretable for as long as the documents survive.

7.3.4.2 Credit Taken in Performance Assessment Calculations

In addition to their use for compliance with the assurance requirements, ~~the passive institutional controls have a separate function in deterring human intrusion into the disposal system for performance assessment calculations. While only minimal assumptions were made about future society for the purposes of designing the passive institutional controls, more detailed assumptions need to be made to provide actual numbers for performance assessment calculations.~~ ***credit for passive institutional controls may be used in PA calculations. In 40 CFR § 194.43(c), EPA allows credit in the form of reduced likelihood of human intrusion.*** The Preamble to 40 CFR 194 limits any credit for passive institutional controls in deterring inadvertent human intrusion to 700 years after disposal***. During the certification process, the DOE sought passive institutional controls credit in the CCA based on the conclusions of a designated task force. CCA Appendix EPIC documents the basis for this credit. For the performance assessment calculations in the CCA, the passive institutional controls were considered to be 0.99 effective in deterring inadvertent human intrusion over the entire withdrawal area for 700 years.***

However, the EPA performance assessment verification test (PAVT) calculations did not include credit for passive institutional controls (63 FR 27396). ~~This shorter time period is an important factor in the development of numbers to evaluate the effectiveness of passive institutional controls for performance assessment. The effectiveness of passive institutional controls is further described in Appendix EPIC.~~ ***In the certification decision (EPA 1998), the EPA concluded its discussion on this matter as follows:***

> ***However, EPA's final decision today applies only to the credit proposal in the CCA and should not be interpreted as a judgement on the use of PICs credit in PAs generally. In the future, DOE may present to EPA additional information derived from an expert elicitation of PICs credit. Any future PICs credit proposals will be considered in the context of a modification rulemaking, and will be subject to public examination (63 FR 27396).***

In this recertification application, the DOE claims no credit for the effectiveness of passive institutional controls. As indicated by the EPA, the DOE may claim such credit in future recertification applications.

~~Active institutional controls will be implemented at the WIPP after closure to control access to the site and will ensure that only those activities allowed by the LWA take place at the site. The existence of active institutional controls will preclude human intrusion in the withdrawal area, although there is a regulatory prohibition against taking credit for the effectiveness of active institutional controls in performance assessment calculations beyond 100 years after disposal. Because of the nature of the system of active institutional controls, the effectiveness of the active institutional controls would be the controlling factor for performance assessment calculations up to 100 years. Thus, the effectiveness of passive institutional controls for use in performance assessment is focused on the time period from year 100 to year 700 after disposal. See Appendix EPIC for discussion and analysis.~~

~~The Markers Panel developed its recommendations for the longevity of marker materials and configuration based, in part, on historical analogues. When the passive institutional controls task force (PTF) assessed the effectiveness of the passive institutional controls, as described in Appendix PIC, additional historical analogues were considered, and a one-to-one comparison was developed between individual passive institutional controls components and individual historical analogues. This one-to-one comparison allowed the PTF to identify general periods of time for endurance of each passive institutional control. At the same time, the PTF identified potential failure mechanisms of the markers components, the records and archives system, and governmental control components. Because the passive institutional controls were designed to address failure mechanisms based on historical analogues that endured and those for which there is a record of failure, the PTF believes that physical failure of the passive institutional controls components over the entire withdrawal area will not occur in the time frame of interest for performance assessment. This belief is supported by the fact that no failure mode applies to all passive institutional controls and failure of the marker system requires failure of all components of the marker system.~~

~~After physical durability was evaluated, the PTF studied the ability of messages to be understood. Building upon assumptions listed by the EPA in the Compliance Application Guidance as common denominators of human behavior, the PTF developed a list of assumptions about how future societies would operate, focusing on potential intrusions to explore for and exploit natural resources. One of the PTF's assumptions is that English will be understandable to the resource exploration and exploitation community for at least 1,000 years. This assumption is made based on (1) 1,000-year-old English literature can be understood by scholars today, (2) English is a world language with a concomitant inertia against radical and rapid change, and (3) the valuable nature of the resources in the area means that resource-seeking individuals and corporations will make the effort to decipher past records dealing with resource availability. The PTF believes that, for the time frame of interest for performance assessment, the ability of potential drillers to interpret past records is virtually certain.~~

~~Other assumptions made by the PTF are discussed in Appendix EPIC. The PTF provides the basis for assumptions relating to basic human attributes, government, language, natural resources, and estimating passive institutional controls effectiveness. The PTF established this framework of assumptions through a "prudent extrapolation" of the future state (that is, present-day) assumptions established in 40 CFR § 194.25.~~

~~The failure mode that remained after these PTF evaluations were performed was human error, either in obtaining and documenting a lease or a permit to drill, or in actually setting up a drill rig and drilling a borehole in the wrong location. When a search of the New Mexico portion of the Delaware Basin resource records did not yield any documentation of wells drilled in the wrong location, the PTF queried individuals who had many years of experience with drilling in both the Delaware Basin and the encompassing Permian Basin. These individuals were able to provide five instances of wells drilled in the wrong location, although none was in the Delaware Basin. Based on 429,000 wells drilled in the area in question, these five instances resulted in a failure rate of 0.00001 for the Permian Basin and 0.00 for the Delaware Basin. There may be other wells drilled in the wrong location that were not identified in the recent search. In addition, there may be additional failure modes that were not identified in the passive institutional controls effectiveness report. Because of these possibilities, the PTF increased the calculated failure rate~~

~~by three orders of magnitude to 0.01 to provide a bounding value for performance assessment calculations.~~

~~A one percent failure rate would mean that out of every 100 permit requests, one involved an unlawful permit, or one involved a location error on the permit itself, or the drillers set up in the wrong location (that is, in the wrong lease). Such a high failure rate, however, would be widely known within the drilling community and the failure rate would have caused the implementation of stronger controls over drilling.~~

~~Thus, for performance assessment calculations, the passive institutional controls are considered to be 0.99 (that is, 1 to 0.01) effective in deterring inadvertent human intrusion over the entire withdrawal area.~~

7.4 Multiple Barriers

The WIPP facility has incorporated multiple natural and engineered barriers, including plugs, seals, and backfill into its design. As a part of the DOE's program to evaluate multiple barriers, an Engineered Alternatives Task Force (EATF) evaluated optional additional engineering measures for the WIPP facility. The findings of the task force are summarized in the *Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives* (DOE 1991). A more recent study, the Engineered Alternatives Cost/Benefit Study, updated the 1991 EATF activity and augmented it with more in-depth and comprehensive analyses of the relative benefits and detriments of the alternatives. Benefits and detriments at the waste generation and storage sites were evaluated in this study as well as those at the WIPP. (This study is included in ***CCA*** Appendix EBS.)

Beyond the requirements contained in 40 CFR § 191.14(d) relating to multiple barriers, 40 CFR § 194.44 has imposed certification criteria upon the DOE with regard to engineered barriers. The following sections provide a discussion of the manner in which the DOE has complied with the multiple barrier requirement of 40 CFR § 191.14(d) and an overview of the manner in which the engineered barrier criteria of 40 CFR § 194.44 have been met. A detailed discussion of the cost and benefit analysis dictated in 40 CFR § 194.44 is provided in ***CCA*** Appendix EBS.

7.4.1 Requirements for Multiple Barriers

By requiring the use of both natural and engineered barrier types as the assurance requirement, the EPA intends to ensure that the impacts of the failure of any single barrier type will be minimized.

In the LWA, Congress mandated that the Secretary will use both natural and engineered barriers. Waste form modifications may be used at the WIPP to isolate waste after disposal to the extent necessary to comply with the final disposal regulations. Therefore, the disposal system design involving the Salado as a natural barrier and the shaft seals as engineered barriers complies with this assurance requirement as indicated by the compliant complementary cumulative distribution functions (CCDFs) shown in Section 6.5.

7.4.2 Objectives for Multiple Barriers

The primary objective for the implementation and the use of multiple barriers at the WIPP facility is to help guard against unexpectedly poor performance from one type of barrier. This is accomplished by a design that includes multiple types of barriers.

7.4.3 Implementation of Multiple Barriers

The baseline design for the WIPP facility includes the concept of multiple barriers for isolation and containment of waste. Barriers that are part of the design include natural barriers (for example, hydrological, geological, and geochemical conditions) and engineered barriers (for example, borehole plugs, shaft seals, panel closures, and backfill). The effectiveness of these barriers is modeled in the performance assessment to demonstrate the ability of the disposal system to meet EPA standards.

Although the DOE plans to apply multiple engineered systems to aid in waste isolation, the EPA specified in the WIPP certification that only MgO backfill meets the regulatory definition of an engineered barrier.

Section 194.44(a) provides a criterion for certification for the analysis of the cost and benefits of various engineered barrier options. The text in the following subsections describes the DOE program that meets the engineered barrier requirements.

7.4.3.1 Engineered Alternatives Cost and Benefit Study

To fulfill the benefit and detriment evaluation criterion contained in 40 CFR § 194.44(b), the DOE published *Engineered Alternatives Cost/Benefit Study; Final Report* (DOE 1995) (see ***CCA*** Appendix EBS). The EPA's criterion for this cost and benefit study is as follows:

> In selecting any engineered barrier(s) for the disposal system, the Department shall evaluate the benefit and detriment of engineered barrier alternatives, including but not limited to: cementation, shredding, supercompaction, incineration, vitrification, improved waste canisters, grout and bentonite backfill, melting of metals, alternative configurations of waste placements in the disposal system, and alternative disposal system dimensions. The results of this evaluation shall be included in any compliance application and shall be used to justify the selection and rejection of each engineered barrier evaluated. (40 CFR § 194.44[b])

The primary purpose of this cost and benefit study was to provide the DOE with information for use in selection or rejection of additional engineered barriers that provide assurance in the performance calculations. The current facility baseline, as represented in performance assessment, provides sufficient multiple barriers to obtain compliance with the requirements of 40 CFR § 191.14(d) as described in Sections 6.4.4 (Shaft Seal Engineered Barriers), 6.4.5 (The Salado Formation Natural Barrier), and 6.5 (Performance Assessment Results).

The approach used in the study was to screen potential engineered alternatives compiled from previous studies, the ten technologies specified in 40 CFR § 194.44(b), and input elicited from stakeholders. The screening process used a working group composed of technical professionals from various related fields to compare the proposed engineered alternatives to the established definition of an engineered alternative and then to determine if those alternatives that meet the definition also meet regulatory and technological feasibility criteria. The outputs of the screening process were

- a list of engineered alternatives that did not meet the definition or screening criteria, along with the justification for their rejection, and
- a list of engineered alternatives retained for further consideration.

The screening process evaluated 111 proposed engineered alternatives and screened out all but 54 (see ***CCA*** Appendix EBS, Section 2.2.2). The 54 alternatives retained were then subjected to a DOE management-level assessment to determine the set of alternatives that would be retained for full analysis through the study. The basis for this assessment was to:

- develop a set of alternatives that address important WIPP performance issues, such as reducing the solubility of actinides in brine and improving the strength of the waste,
- analyze those alternatives that have high technical feasibility (that is, those alternatives that have been subjected to bench-scale testing at the least), and
- assess those alternatives that have a high likelihood of being permitted in a reasonable amount of time.

This assessment resulted in the selection of 18 alternatives for full analysis through the study. The screening process, including this DOE management-level assessment, was included in the scope of an independent peer review done on the study to address the requirements of 40 CFR § 194.27(a)(3). The peer review panel concluded that the entire screening process was reasonable and acceptable. Details of the peer review are found in ***CCA*** Appendix PEER (Section 3.2).

The 18 alternatives finally selected for further study consisted of nine basic alternatives and nine variations. The 18 alternatives were compared to the criteria in 40 CFR § 194.44(c):

> (i) The ability of the engineered barrier to prevent or substantially delay the movement of water or waste toward the accessible environment;
>
> (ii) The impact on worker exposure to radiation both during and after incorporation of engineered barriers;
>
> (iii) The increased ease or difficulty of removing the waste from the disposal system;
>
> (iv) The increased or reduced risk of transporting the waste to the disposal system;
>
> (v) The increased or reduced uncertainty in compliance assessment;
>
> (vi) Public comments requesting specific engineered barriers;
>
> (vii) The increased or reduced total system costs;

(viii) The impact, if any, on other waste disposal programs from the incorporation of engineered barriers (for example, the extent to which the incorporation of engineered barriers affects the volume of waste);

(ix) The effects on mitigating the consequences of human intrusion. (40 CFR § 194.44[c][1])

In addition to the criteria listed above, ***CCA*** Appendix EBS includes analyses that evaluated

- existing waste that is already packaged,
- existing waste that is not yet packaged,
- existing waste that is in need of repackaging, and
- to-be-generated waste.

All 18 alternatives met the intent of these criteria. This process is further described in Section 2 and Appendix O of ***CCA*** Appendix EBS. The variations originated in the screening process, details of which can be found in Sections 2.2 and 2.3.1 of ***CCA*** Appendix EBS.

For comparison, the baseline was considered to be the WIPP facility with no additional engineered barriers beyond shaft seals and panel closures. The 18 final engineered alternatives, along with a brief description of each, are listed below.

- **Supercompact Organics and Inorganics.** Solid organic and inorganic wastes are sorted to remove items that cannot be compacted. Sorted waste is precompacted in 35-gallon (132.6-liter) drums and then supercompacted. Usually, the contents of four supercompacted drums are placed in a 55-gallon (208-liter) drum. Sludges are not processed.
- **Shred and Compact Organics and Inorganics.** Solid organics and inorganics are shredded and compacted in 55-gallon (208-liter) drums using a mechanical shredder and a low-pressure compactor. Sludges are not processed.
- **Plasma Processing of All Wastes.** All wastes are processed through a mechanical shredder and the input waste stream is controlled to ensure a suitable metal to nonmetal ratio. The waste is processed through a plasma arc centrifugal treatment system and placed into 55-gallon (208-liter) drums.
- **Sand Plus Clay Backfill.** A mixture of medium-grained sand and granulated clay is used as backfill. The mixture is placed around the waste stack and between the drums, filling the void space between drums and unmined host salt in waste emplacement panels. A fifty percent void space is assumed.
- **Salt-Aggregate (Grout) Backfill.** A salt-aggregate grout mixture is used as backfill to fill the void spaces between drums and unmined host salt in waste emplacement panels. This backfill consists of a cementitious-based, salt-aggregate grout with crushed salt

aggregate and is pumped around the waste stack and between the drums filling the void spaces. A twenty percent void space is assumed.

- **Cementitious Grout Backfill.** A cementitious grout backfill consisting of ordinary Portland cement, sand, and fresh water is pumped around the waste stack and between the drums filling the void space. A twenty percent void space is assumed.

- **Supercompact Organics and Inorganics, Salt-Aggregate and Grout Backfill.** Monolayer of 2,000 drums in a room that is 6 feet (1.83 meters) high, 33 feet (10.1 meters) wide, and 300 feet (91.4 meters) long.

- **Supercompact Organics and Inorganics, Clay-Based Backfill.** Monolayer of 2,000 drums in a room that is 6 feet (1.83 meter) high, 33 feet (10.1 meter) wide, and 300 feet (91.4 meter) long.

- **Supercompact Organics and Inorganics, Sand and Clay Backfill.** Monolayer of 2,000 drums in a room that is 6 feet (1.83 meter) high, 33 feet (10.1 meter) wide, and 300 feet (91.4 meter) long.

- **Supercompact Organics and Inorganics, CaO Backfill.** Monolayer of 2,000 drums in a room that is 6 feet (1.83 meter) high, 33 feet (10.1 meter) wide, and 300 feet (91.4 meter) long.

- **Salt Backfill with CaO.** A backfill of commercially available granulated lime and crushed salt is placed around the waste stacks and between the drums filling the void space. A fifty percent void space is assumed.

- **Enhanced Cement Sludges, Shred and Add Clay-Based Materials to Organics and Inorganics, No Backfill.** This alternative includes two processes to treat the waste. The first is an enhanced cementation process of previously solidified and as-generated sludge. Existing sludges are fed into a mechanical crusher and shredder. The crushed waste is mixed with an enhanced cement and the product is poured into 55-gallon (208-liter) drums. Newly-generated sludges are solidified with the enhanced cement. The second process shreds solid organic and inorganic wastes and adds clay to the shredded waste. This waste product is packaged in 55-gallon (208-liter) drums.

- **Enhanced Cement Sludges, Shred, and Add Clay-Based Materials to Organics and Inorganics, Sand and Clay Backfill.** This alternative includes two processes to treat the waste. The first is an enhanced cementation process of previously solidified and as-generated sludge. Existing sludges are fed into a mechanical crusher and shredder. The crushed waste is mixed with an enhanced cement and the product is poured into 55-gallon (208-liter) drums. Newly-generated sludges are solidified with the enhanced cement. The second process shreds solid organic and inorganic wastes and adds clay to the shredded waste. This waste product is packaged in 55-gallon (208-liter) drums. A mixture of medium-grained sand and granulated clay is used as backfill. The mixture is placed around the waste stack and between the drums filling the void space between drums and unmined host salt in waste emplacement panels. A fifty percent void space is assumed.

- **Enhanced Cement Sludges, Shred, and Add Clay-Based Materials to Organics and Inorganics, Cementitious Grout Backfill.** This alternative includes two processes to treat the waste. The first is an enhanced cementation process of previously solidified and as-generated sludge. Existing sludges are fed into a mechanical crusher and shredder. The crushed waste is mixed with an enhanced cement and the product is poured into 55-gallon (208-liter) drums. Newly-generated sludges are solidified with the enhanced cement. The second process shreds solid organic and inorganic wastes and adds clay to the shredded waste. This waste product is packaged in 55-gallon (208-liter) drums. A cementitious grout backfill consisting of ordinary Portland cement, sand, and fresh water is pumped around the waste stack and between the drums filling the void space. A twenty percent void space is assumed.

- **Enhanced Cement Sludges, Shred, and Add Clay-Based Materials to Organics and Inorganics, Salt Aggregate Grout Backfill.** This alternative includes two processes to treat the waste. The first is an enhanced cementation process of previously solidified and as-generated sludge. Existing sludges are fed into a mechanical crusher and shredder. The crushed waste is mixed with an enhanced cement and the product is poured into 55-gallon (208-liter) drums. Newly-generated sludges are solidified with the enhanced cement. The second process shreds solid organic and inorganic wastes and adds clay to the shredded waste. This waste product is packaged in 55-gallon (208-liter) drums. A salt-aggregate grout mixture is used as backfill to fill the void spaces between drums and unmined host salt in waste emplacement panels. This backfill consists of a cementitious-based, salt-aggregate grout with crushed salt aggregate and is pumped around the waste stack and between the drums filling the void spaces. A twenty percent void space is assumed.

- **Enhanced Cement Sludges, Shred, and Add Clay-Based Materials to Organics and Inorganics, Clay-Based Backfill.** This alternative includes two processes to treat the waste. The first is an enhanced cementation process of previously solidified and as-generated sludge. Existing sludges are fed into a mechanical crusher and shredder. The crushed waste is mixed with an enhanced cement and the product is poured into 55-gallon (208-liter) drums. Newly-generated sludges are solidified with the enhanced cement. The second process shreds solid organic and inorganic wastes and adds clay to the shredded waste. This waste product is packaged in 55-gallon (208-liter) drums. A backfill consisting of commercially available pelletized clay is placed around the waste stack and between the drums, filling the void space. A fifty percent void space is assumed.

- **Enhanced Cement Sludges, Shred, and Add Clay-Based Materials to Organics and Inorganics, CaO and Salt Backfill.** This alternative includes two processes to treat the waste. The first is an enhanced cementation process of previously solidified and as-generated sludge. Existing sludges are fed into a mechanical crusher and shredder. The crushed waste is mixed with an enhanced cement and the product is poured into 55-gallon (208-liter) drums. Newly generated sludges are solidified with the enhanced cement.

The second process shreds solid organic and inorganic wastes and adds clay to the shredded waste. This waste product is packaged in 55-gallon (208-liter) drums. A backfill of commercially available granulated lime and crushed salt is placed around the waste stacks and between the drums filling the void space. A fifty percent void space is assumed.

- **Clay-Based Backfill.** A backfill consisting of commercially available pelletized clay is placed around the waste stack and between the drums, filling the void space. A fifty percent void space is assumed.

The product from the evaluation of each factor evaluated was integrated into a quantifiable result called a performance vector. This vector expresses the performance of each engineered alternative relative to the baseline. The results of the factor analyses are presented in detail in ***CCA*** Appendix EBS (Section 5.4).

The Engineered Alternatives Cost/Benefit Study (***CCA*** Appendix EBS) was useful to the DOE, as it identified engineered barriers that could be used to improve long-term repository performance. Specifically, the advantages of a backfill that chemically altered the pH of brine in the disposal room were identified in ***CCA*** Appendix EBS (Section 3.1) as providing significant benefit in reducing the quantity of mobile actinides. Alkaline earth oxides (such as calcium oxide [CaO]) are known to readily react with water to form hydroxides. These hydroxides are free to react with carbonic acid that may form in the disposal room. The reaction buffers the brines to a pH that reduces the amount of actinide in solution. After further analysis, which is documented in ***CCA*** Appendix BACK and discussed in ***CCA*** Appendix SOTERM, the DOE selected magnesium oxide (MgO) as the backfill material that provided the desired long-term benefit while minimizing the operational impacts associated with the more caustic CaO. The beneficial effects of MgO backfill are now included in the WIPP performance assessment calculation. Relevant discussions can be found in Sections 3.3.3 and 6.4.3.4. ***Additional related information developed since the preparation of the CCA is provided in Appendix BARRIERS.***

7.4.3.2 Incorporation into Repository Design

In its guidance to implementation of the certification criteria in 40 CFR § 194.44(d), the EPA requested that the DOE describe how engineered barriers are incorporated into the repository. The purpose of this section is to identify the location of these descriptions and the location of the analysis that evaluates the performance of the engineered barriers.

Shaft seals delay the movements of radionuclides toward the accessible environment through the shafts. These shaft seals are described in detail in ***CCA*** Appendix SEAL and are summarized in Section 3.3.~~1~~**2**. Analysis of the effectiveness of shaft seals is included in ***CCA*** Appendix SEAL (Section 8) and Section 6.4.4. Panel closures prevent the movement of radionuclides toward the accessible environment by limiting the magnitude of releases that can occur during certain human intrusion events. The design of panel closures is described in ***CCA*** Appendix PCS, summarized in Section 3.3.2, and their role in the repository model is discussed in Section 6.4.3. ***More recent related information is provided in Appendix BARRIERS.*** Backfill substantially delays the movement of radionuclides toward the accessible environment by limiting, through chemical means, the amount of actinides that can be dissolved in brines that enter the repository.

The placement of backfill is described in Section 3.3.~~3~~***1***, and its design and functions are described in ***CCA*** Appendix SOTERM ***and Appendix PA, Attachment SOTERM*** ~~of this application~~. Actinide mobility is discussed in Section 6.4.3. Borehole plugs are used to limit the volume of water that could be introduced to the repository from overlying water-bearing zones and to limit the volume of contaminated brine that could be released to the accessible environment. Borehole plug design is addressed in Section 3.3.4. In addition, parameter values selected to implement the various engineered components into the PA model are described in Appendix ***PA, Attachment*** PAR. Borehole plugs, as described in Section 3.3.4, are also included to mitigate the potential for contaminant migration.

The EPA concluded in its certification that the use of MgO backfill meets the regulatory intent of the engineered barriers portion of the regulation. The certification decision (EPA 1998) includes the following regarding engineered barriers:

> ***The EPA finds that DOE complies with Section 194.44. The EPA found that DOE conducted the requisite analysis of engineered barriers and selected an engineered barrier designed to prevent or substantially delay the movement of water or radionuclides toward the accessible environment. The DOE provided sufficient documentation to show that MgO can effectively reduce actinide solubility in the disposal system. The DOE proposed to emplace a large amount of MgO around waste drums in order to provide an additional factor of safety and thus account for uncertainties in the geochemical conditions that would affect CO_2 generation and MgO reactions (63 FR 27397).***

Since the certification, the DOE has performed additional MgO-related analyses. These analyses are reported in Appendix BARRIERS.

7.5 Resource ~~Characteristics Evaluations~~ *Considerations*

The EPA discourages the location of repositories in areas in which valuable natural resources are present, through the assurance requirements in 40 CFR § 191.14(e). This assurance requirement states that

> Places where there has been mining for resources, or where there is a reasonable expectation of exploration for scarce or easily accessible resources, or where there is a significant concentration of any material that is not widely available from other sources, should be avoided in selecting disposal sites. Resources to be considered shall include minerals, petroleum or natural gas, valuable geologic formations, and ground waters that are either irreplaceable because there is no reasonable alternative source of drinking water available for substantial populations or that are vital to the preservation of unique and sensitive ecosystems. Such places shall not be used for disposal of the wastes covered by this part unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future (40 CFR § 191.14[e]).

The purpose of the requirement is to provide assurance that site selection actions further reduce the likelihood of future intrusion into the repository by giving preference to those sites without currently recognized resources.

In promulgating 40 CFR 194, the EPA provided for a clear manner in which to assess compliance with this requirement, stating that

> If performance assessments predict that the disposal system meets the containment requirements of § 191.13 of this chapter, then the Agency will assume that the requirements of this section and § 191.14(e) of this chapter have been fulfilled (40 CFR § 194.45).

Section 6.5 demonstrates compliance with 40 CFR § 191.13, including resource considerations, and hence compliance with 40 CFR § 194.14(e). The EPA further provides, in its guidance to 40 CFR Part 194, that the DOE

- document that the effects of mining and drilling over the regulatory time frame have been incorporated into performance assessments according to the requirements of § 194.32, § 194.33, and § 194.43;
- document that performance assessments incorporate the effects on the disposal system of any activities that occur in the vicinity of the disposal system or are expected to occur in the vicinity of the disposal system soon after disposal, according to the requirements of § 194.32; and
- document whether the results of performance assessments demonstrate compliance with the containment requirements of § 191.13.

~~The DOE has satisfied the EPA guidance concerning resource evaluation. This information is documented in Chapter 6.0.~~ The DOE has satisfied the EPA criteria concerning resource evaluation. This information is documented in Section 6.5.2. The mean CCDFs in Figure 6-***36***~~38~~ incorporate~~s~~ both the effects of mining inside the controlled area (see Section 6.4.6.2.3 for a description of the mining conceptual model) and the effects of intermittent and inadvertent drilling (see Section 6.4.7 for a discussion of the drilling conceptual model). In addition, the impacts of resource development outside the controlled area were considered in the development of disposal system conceptual models.

7.5.1 Resource Considerations Prior to 40 CFR Parts 191 and 194

The WIPP site selection occurred prior to promulgation of 40 CFR Parts 191 and 194. Resource considerations were included in the site selection process for the WIPP and are documented in the WIPP FEIS (DOE 1980) and ***CCA*** Appendices GCR and IRD. The objective of the program for demonstrating compliance with the resource considerations requirement is to document the rationale used in the decision-making process.

7.5.2 Implementation of Resource Considerations

Resource considerations were included in the site selection process for the WIPP and are documented in the WIPP FEIS (DOE 1980, Section 7.3.7). The FEIS describes a four-step decision-making process that was applied to siting the repository. This process is summarized below:

- Step 1 – Bedded salt was selected as the most promising geologic medium, and geographic regions that contain extensive bedded salt formations were identified. This was accomplished by gathering and evaluating existing information concerning rock types and their geographic distribution. Desirable criteria were identified and the most favorable regions were identified.

- Step 2 – A literature review was performed to narrow the number of regions identified in Step 1. Once a region was selected, candidate sites within the region were chosen. Selection criteria were used to compare the sites. Those sites that satisfied the most criteria were selected for further evaluation. Resource-conflict considerations were applied on a broad scale at this stage of the process.

- Step 3 – The candidate sites identified in Step 2 were subjected to further investigations covering geology, hydrology, archaeology, demography, and biological resources. The results of all the site evaluations were compared, and the site that best met the selection criteria was selected for additional site characterization. At this stage, the types and quantities of natural resources present at the site were considered in detail.

- Step 4 – In this final step, a detailed system analysis was performed. This analysis addressed the specific geologic environment, the waste forms, the disposal facility design, and the potential failure modes with respect to radiation safety and environmental impact.

Based upon the above process, the DOE concluded that the favorable characteristics of the WIPP site (good hydrological characteristics, salt medium, moderate depth, salt thickness, low population density, lack of significant economic conflicts, and others) uniquely qualified it for a repository for defense waste. These characteristics also compensate for any increased likelihood of future disturbance. ***CCA*** Appendix IRD provides further analysis of compliance with the resource disincentive requirement. Section 2.3.1 provides a summary of known and inferred resources in the vicinity of the WIPP. ***CCA*** Appendix DEL contains resource-development-related information used in the conceptual model of disposal system performance.

7.6 Waste Removal

Removal of the waste any time after emplacement is possible. Because the repository was initially mined to provide access to the repository rooms, access to the waste can be accomplished using similar mining technologies. Location and removal are also possible using similar equipment modified to operate remotely. A remote retrieval demonstration was conducted at the WIPP in April 1992.

7.6.1 Requirements for Waste Removal

With the promulgation of 40 CFR Part 194, and in particular 40 CFR § 194.46, the EPA specifies the criteria for demonstrating compliance with this requirement. Specifically, the EPA mandates that "any compliance application shall include documentation which demonstrates that removal of waste is feasible for a reasonable period of time after disposal." The EPA states that this documentation should "include an analysis of the technological feasibility of mining the sealed disposal system, given technology levels at the time a compliance application is prepared."

In promulgating its disposal regulations, the EPA stated that "any current concept for a mined geologic repository meets this requirement without any additional procedures or design features" (EPA 1985, 50 FR 38082).

Because the WIPP facility is a mined repository, no additional actions other than documentation to meet this assurance requirement are necessary. The rationale for this assurance requirement is to preclude use of some disposal technologies that would not allow future generations to recover the wastes, should they decide to do so. According to the EPA, recovery need not be easy or inexpensive but only possible (EPA 1985). ***CCA*** Appendix WRAC describes a feasible system for waste removal using available mining technologies.

7.6.2 Implementation of Waste Removal

After determining the existing repository condition, the mining and waste removal operations will be designed to minimize the amount of contamination and exposure to allow limited human access for assessments, equipment retrieval, and repairs. Any radiological work will be performed using standard industry practices and approved procedures.

Radiological sampling activities will be planned and implemented so that recovered wastes can be handled. Packaging the removed waste and any decontamination of containers can be accomplished with standard automation techniques. Plans and procedures will ensure that the amount of additional contaminated material produced during the actual waste removal is minimized.

The removal concept is composed of the following five phases.

Phase 1 – Planning and permitting.

Phase 2 – Initial above ground setup and shaft sinking.

Phase 3 – Underground excavation and facility setup of underground ventilation, radiation control, packaging areas, decontamination areas, maintenance, remote control center, and personnel support rooms.

Phase 4 – Waste location and removal operations, including mining waste removal, packaging, package surveying and decontamination, transportation to surface, staging for off-site transportation, and off-site transportation.

Phase 5 – Closure and D&D of the facility.

Each of the five phases is summarized below and described in detail in ***CCA*** Appendix WRAC (Section 5).

7.6.2.1 Planning and Permitting

A decision to remove waste will initiate the planning and permitting phase. Permitting requirements will be based on governing regulations at the time removal is authorized. The planning and permitting program will identify all permits and research the available technologies at that time to determine available removal techniques and the condition of the repository. After initial research is completed, a plan will be drafted to itemize and schedule all removal activities.

7.6.2.2 Initial Above Ground Setup and Shaft Sinking

Above ground support buildings will house the exhaust fans and filters, administration, operations and maintenance facilities, control center waste staging and decontamination areas, the warehouse (containers), and others, as deemed necessary.

7.6.2.3 Underground Excavation and Facility Setup

After the shafts are completed, drifts will be run and ventilation paths will be established using air control regulators. Support rooms will be excavated for maintenance, control rooms, and packaging areas. Air locks will be constructed to provide the necessary level of control and separation. All equipment required for removal, packaging, and related support equipment will be installed.

Excavation will be in two stages. Initial excavation will not contact waste, but will mine support rooms and haulage drifts that provide ventilation and access to the waste. The second stage will remove the waste.

7.6.2.4 Waste Location and Removal Operations

The waste removal will be performed in separate operations. The waste will be removed by mining the area where the waste was emplaced. The mined waste will be transported to the packaging areas. The waste can be removed many ways using standard equipment. ***CCA*** Appendix WRAC (Sections 6 and 7) contains a brief description and feasibility of using various mining techniques for waste removal. An appropriate level of radiological controls will be used, depending upon the radioactivity of the mined waste.

7.6.2.5 Closure and D&D of the Facility

After waste is removed from the repository, the facility will be decommissioned according to the current regulations at that time.

REFERENCES

40 CFR Part 191 Disposal Regulations; Final Rule." *Federal Register,* Vol. 61, No. 28, pp. 5224 – 5245, February 9, 1996. Office of Radiation and Indoor Air, Washington, D.C.

~~Bellus, P.A., and Eckerman, J. 1994. *Airborne or Spaceborne Surveillance Radar Detection of WIPP Site*. Westinghouse Electric Corporation, 10950, Minnetonka, MN.~~

Hora, S.C., von Winterfeldt, D., and Trauth, K.M. 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant*. SAND90-3063. Sandia National Laboratories, Albuquerque, NM.

International Atomic Energy Agency (IAEA). 1999. Maintenance of Records for Radioactive Waste Disposal. IAEA-TECDOC-1097, Vienna, Austria.

John Hart and Associates, P.A. 2000a. Contractor Report, Permanent Markers Monument Survey, Waste Isolation Pilot Plant, Carlsbad, NM.

John Hart and Associates, P.A. 2000b. Contractor Report, Permanent Markers Materials Analysis, Waste Isolation Pilot Plant, Carlsbad, NM.

John Hart and Associates, P.A. 2000c. Contractor Report, Ancient Cementitious Materials, Waste Isolation Pilot Plant, Carlsbad, NM.

Murphy, John N., and Parkinson, H.F. 1978. *Underground Mine Communications*, Proceedings of the IEEE, Vol. 66, No. 1, pp. 26 – 50, January 1978.

New Mexico Bureau of Mines and Mineral Resources ***(NMBMMR***). 1995. *Final Report Evaluation of Mineral Resources at the Waste Isolation Pilot Plant (WIPP) Site*. Vol. I, Ch. I-III, December 22, 1994.

Powell, J.A. 1976. *An Electromagnetic System for Detecting and Locating Trapped Miners*, U.S. Bureau of Mines Report of Investigations, RI 8159, U.S.B.M, Pittsburgh, PA.

Trauth, K.M., Hora, S.C., and Guzowski, R.V. 1993. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant*. SAND92-1382. Sandia National Laboratories, Albuquerque, NM. ~~WPO 23389.~~

~~EPA (~~U.S. Environmental Protection Agency~~)~~ ***(EPA)***. 1985. "40 CFR Part 191: Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule." *Federal Register*, Vol. 50, No. 182, pp. 38066 – 38089, September 19, 1985. Office of Radiation and Air, Washington, D.C.

U.S. Environmental Protection Agency ***(EPA***). 1988. Test Methods for Evaluating Solid Waste. Volume 1A through 1C and Volume 2. Field Manual Physical Chemical Methods (3rd Edition). Report EPA/SW-846, September 1988, National Technical Information Service, Springfield, VA.

U.S. Department of Energy (***DOE***). 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant*. DOE/EIS-0026. Vols. 1 and 2. Assistant Secretary for Defense Programs. Washington, D.C. ~~WPO 38835, WPO 38838, WPO 38839.~~

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

U.S. Department of Energy (***DOE***). 1991. *Draft Report: Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force*. DOE/WIPP 91-007, Rev. 0. Westinghouse Electric Corporation, Carlsbad, NM.

U.S. Department of Energy (***DOE***). 1994. *Permanent Marker Conceptual Design Report* Draft. Rev. 2, November 1994. U.S. Department of Energy, Carlsbad, NM.

U.S. Department of Energy (***DOE***). 1995. *Engineered Alternatives Cost/Benefit Study; Final Report*. DOE/WIPP 95-2135. U.S. Department of Energy, Carlsbad, NM.

U.S. Department of Energy (DOE). 1999. 40 CFR Parts 191 and 194 Compliance Monitoring Implementation Plan (MIP), Waste Isolation Pilot Plant, Carlsbad, NM.

U.S. Department of Energy (DOE). 2000. Permanent Markers Testing Program Plan, Waste Isolation Pilot Plant, Carlsbad, New Mexico, DOE/WIPP 00-3175, Carlsbad Area Office, Carlsbad, NM.

U.S. Environmental Protection Agency (***EPA***). 1996a. "40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the EPA (U.S. Environmental Protection Agency). 1996b. *Compliance Application Guidance for 40 CFR Part 194*. EPA 402-R-95-014, March 29, 1996. Office of Radiation and Indoor Air, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1996c. Docket A-93-02, Item II-I-01, Enclosure 1).

U.S. Environmental Protection Agency (EPA). 1997. Docket A-93-02, Item II-I-07, Enclosure 1c).

U.S. Environmental Protection Agency (EPA). 1998. "40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance With the Disposal Regulations: Certification Decision; Final Rule." Federal Register, Vol. 63, No. 95, pp. 27396, May 18, 1998. Office of Radiation and Indoor Air, Washington, D.C.

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