CARD No. 44
Engineered Barriers

44.A.1 BACKGROUND

Assurance requirements were included in the disposal regulations to compensate in a qualitative manner for the inherent uncertainties in projecting the behavior of natural and engineered components of the repository for many thousands of years (50 FR 38072). Section 194.44 is one of the assurance requirements in the Compliance Criteria. Section 194.44 implements the assurance requirement at Section 191.14(d) to incorporate one or more engineered barriers at radioactive waste disposal facilities. The disposal regulations define a barrier as "any material or structure that prevents or substantially delays movement of water or radionuclides toward the accessible environment" (Section 191.12(d)). Section 194.44 requires that DOE conduct a study of available options for engineered barriers at the WIPP and submit this study and evidence of its use with the compliance application. Consistent with the containment requirement at Section 191.13, DOE must analyze the performance of the complete disposal system, and any engineered barrier(s) that DOE ultimately implements at the WIPP must be considered in this analysis and EPA's subsequent evaluation (see Response to Comments Document for 40 CFR Part 194, p. 16-11). This CARD combines the discussion of requirements Section 194.44(c) through (e) because they pertain to the same analysis by DOE.

44.A.2 REQUIREMENT

(a) "Disposal systems shall incorporate engineered barrier(s) designed to prevent or substantially delay the movement of water or radionuclides toward the accessible environment."

44.A.3 ABSTRACT

EPA expected DOE to describe the engineered barrier(s) selected for implementation at the WIPP. EPA also expected the CCA to document how those engineered barrier(s) prevent or substantially delay the movement of water or radionuclides to the accessible environment, as well as how they reduce uncertainties in modeling performance of the disposal system.

DOE selected magnesium oxide (MgO) backfill as an engineered barrier. DOE plans to emplace bags of MgO between and around waste containers in the repository. The CCA stated that MgO will substantially delay movement of radionuclides by controlling chemical conditions in the underground waste panels to reduce the solubility of radionuclides in water, and may delay movement of water by reacting with brine to reduce free water in the disposal system. In addition, DOE found that use of MgO would fix pH levels within a narrow range, bounding an important modeling parameter whose value might otherwise be highly uncertain.

EPA reviewed the information contained in the CCA and agreed that the emplacement of MgO in waste panels of the WIPP may be expected to substantially delay the movement of water or radionuclides. EPA determined that MgO is likely to perform as expected because laboratory experiments conducted by DOE show that the chemical reactions necessary to control pH can occur in the disposal system. Further, the large amount of MgO proposed for emplacement in the

WIPP ensures that adequate MgO will be available to react chemically as predicted. Finally, the plan for emplacing MgO appears feasible.

For compliance with this requirement, EPA did not evaluate panel seals, shaft seals or borehole plugs. EPA considered these items to be features of the disposal system design and evaluated them in that context. For further information on the disposal system design, see **CARD 14—Content of Compliance Certification Application**.

44.A.4 COMPLIANCE REVIEW CRITERIA

EPA required DOE to incorporate engineered barrier(s) that would prevent or delay the movement of radionuclides, thereby increasing confidence in the predictions of long-term repository performance. The desired reduction in uncertainty associated with these predictions could be accomplished by including a barrier (with predictable, tested, and demonstrated performance characteristics) that may be emplaced in a manner consistent with the desired performance. DOE could propose one or more engineered barriers for the purpose of meeting the assurance requirement at Section 194.44(a).

As stated in EPA's Compliance Application Guidance (CAG, p. 61), EPA expected the compliance application to:

- Specify the method for incorporating the engineered barrier(s).
- Provide a qualitative evaluation and justification of the barrier's ability to prevent or substantially delay the movement of water or radionuclides toward the accessible environment.
- Clearly explain how inclusion of the selected engineered barrier(s) contributes to system performance.
- Qualitatively discuss the reduction in uncertainty associated with engineered barrier performance in relation to total system performance.

EPA sought a description and analysis of the design and performance characteristics of each barrier to be used at the WIPP. EPA expected the performance of these barriers to be accurately modeled in the performance assessment (PA) (see **CARD 23—Models and Computer Codes**). EPA did not set specific performance standards for any single barrier because the regulatory standard is based on total system performance. Specifying the performance of a single barrier could create a second and potentially conflicting standard for acceptability of the WIPP (Response to Comments Document for 40 CFR Part 194 (EPA 1996) pp. 16-6 to 16-13).

44.A.5 DOE METHODOLOGY AND CONCLUSIONS

The information addressing DOE's compliance with Section 194.44 was presented in CCA Chapters 7.4 (pp. 7-89 to 7-96), 3.3.3, and 6.4.3.4, and in Appendices BACK, PCS, DEL, SEAL, EBS, SOTERM.2.2 and WCA.4.1.

Appendix EBS is the primary support document for the requirements at Section 194.44. It contains the Engineered Alternatives Cost/Benefit Study (EACBS) used by DOE to select engineered barriers for implementation at the WIPP. The study examined the benefit and detriment of potential engineered barriers at the WIPP, as compared to the baseline design of the facility. The baseline design of the WIPP includes natural barriers (e.g., hydrologic and geologic conditions) and other features (e.g., shaft seals and borehole plugs) to isolate and contain waste (p. 7-90). Information regarding the facility design and its incorporation in the PA is discussed in greater detail in **CARD 14—Content of Compliance Certification Application** and **CARD 23—Models and Computer Codes**, respectively.

Based on the results of the Engineered Alternatives Cost/Benefit Study, DOE identified MgO backfill as an engineered barrier to be emplaced within the disposal rooms at the WIPP. The primary purpose of the MgO is to control chemical conditions in the repository after closure. DOE determined that solubility (and thus mobility) of important radionuclides at the WIPP could be reduced by controlling pH levels of brine in the disposal system. DOE found that alkaline conditions (pH levels above 7.0) in the repository favor lower solubility of actinides (including plutonium, americium, and other radionuclides proposed for disposal at the WIPP). MgO could maintain pH levels within this beneficial range by initiating chemical reactions that would reduce levels of carbonic acid in disposal rooms (p. 7-95).

<u>Chemical Conditions in the Disposal System</u>

Based on experimental data reported in Appendices SOTERM.2.2.2, SOTERM.3.4 and SOTERM.3.6, DOE determined that solubility of actinides in the brine in the repository under baseline conditions (no MgO backfill) would be highly dependent on the pH and carbon dioxide (CO_2) fugacity (a coefficient related to the gas pressure) of the brine. The brine pH and the CO_2 fugacity are in turn both dependent on the amount of CO_2 present in the disposal system.

Appendices BACK.1 and SOTERM.2.2.2 indicate that within some postulated scenarios of the WIPP PA, there will be a significant quantity of CO_2 generated as a result of microbial degradation of carbon-containing waste material (i.e., cellulosics, plastics, and rubbers). The formation of CO_2 can increase the solubility of the actinides through the following means:

- CO_2 reacts with water to form carbonic acid, which increases pH levels.
- Previously formed carbonic acid disassociates to form carbonate species. The carbonate ions bind with actinides to form highly soluble species.
- CO_2 dissolves in water, causing higher CO_2 fugacity.

DOE provided discussions of these chemical processes in Appendices BACK and SOTERM.

Carbonic Acid

Upon contact with water, CO_2 reacts to form carbonic acid. Carbonic acid, although a relatively weak acid, is capable of driving the pH of the repository into the acidic range (i.e., below 7.0), where the solubility of the actinides is typically higher than at neutral or slightly basic pH. Another issue related to carbonic acid formation is that carbonate species (CO_3^{-2}) are generated as carbonic acid disassociates. The carbonate ion is known to bind very strongly to the actinides, forming stable, relatively highly soluble species (see Appendix BACK.1). Thus the presence of carbonic acid in any significant quantity increases the actinide solubility, both by lowering pH and by forming soluble actinide carbonate complexes.

Fugacity of Carbon Dioxide

Appendices SOTERM.2.2.2 and WCA.4.1.2 indicated that the pmH (the $-\log_{10}$ of the hydrogen ion molality) of the brine is a function of the amount of CO_2 dissolved in the brine. (Appendix SOTERM also indicated that for high ionic strength solutions, the pmH is a better indication of acidity than pH, $-\log_{10}$ of the hydrogen ion activity.) The generation of CO_2 increases the CO_2 fugacity and decreases the pmH of the brine. Depending on the level of microbial degradation of carbon, DOE estimated that the fugacity of CO_2 could vary between zero atmospheres and 60 atmospheres. As shown in Figures SOTERM-1 and SOTERM-2, as the fugacity of CO_2 exceeds 50 atmospheres, the pmH of both the Salado and Castile brines (the two brines considered most likely to be present in the repository) approaches 4.5 (original Salado and Castile brines exhibit pH values of about 6 or 7). At these pmH and CO_2 fugacity conditions, the solubilities of actinides are much higher than at neutral or slightly basic pmH and low CO_2 fugacities.

Selection of MgO as the Engineered Barrier

Based on the results of the benefit/detriment study documented in Appendix EBS, DOE concluded that a chemically buffering backfill was a high-benefit/low-cost engineered alternative. This information was presented in Appendices BACK and SOTERM. In a letter to EPA dated March 13, 1997, which responded to EPA's request for additional information regarding the efficacy of MgO as predicted in the CCA, DOE provided a paper entitled, "Implementation of Chemical Controls Through a Backfill System for the Waste Isolation Pilot Plant (WIPP)" (Docket A-93-02, Item II-I-15). This paper represented a summary of the preliminary results of DOE's experimental activities, which are discussed below.

DOE indicated that to mitigate the detrimental effects of possible CO_2 generation, a material was required that would maintain the pH of the brines in the alkaline region and remove CO_2 generated in the repository. DOE screened several materials for their ability to control the pH in the repository to values in the alkaline range. Some materials, in addition to controlling pH, were also capable of reducing carbonate concentration through the formation of relatively insoluble carbonates, including the alkaline earth oxides: calcium oxide (CaO), calcium hydroxide ($Ca(OH)_2$), MgO, and brucite ($Mg(OH)_2$). The alkaline earth oxides react readily with water to form corresponding hydroxides. Since the removal of free water from the disposal area by the reaction with the oxides would be viewed as an added benefit, DOE narrowed the list of candidate materials to CaO and MgO.

Both CaO and MgO have similar chemistries. However, CaO is more caustic and would create more operational difficulties during emplacement of the backfill due to additional worker health and safety requirements. In addition, the equilibrium brine pH yielded by the reaction of $Ca(OH)_2$ would be expected to be as high as 13 or greater, while MgO is expected to buffer the system at a more moderate pH of approximately 9-10. DOE indicated that while the solubility of actinides decreases as pH increases, there is a possibility that the solubility of actinides may decrease to some minimum solubility as pH rises, and then increase with further increase in pH. For these reasons, DOE chose to emplace MgO backfill in the repository.

The MgO backfill can react with water (brine) in the disposal room to form the hydroxide brucite. Brucite would then be available to react with any carbonic acid that is present to form solid magnesium carbonate minerals—such as magnesite ($MgCO_3$)—and water. The reaction will buffer the brines to a slightly alkaline pH that reduces the solubility of the actinides and effectively removes the carbonate from the system due to the low solubility of $MgCO_3$. DOE described experiments that were conducted to determine the actual mineralogy of the magnesium carbonate formed during this reaction. DOE's experimental results to date indicate that in addition to magnesite, two other mineral phases have been identified. They are dypingite ($Mg_3(CO_3)_4(OH)_2 \cdot 5H_2O$) and nesquehonite ($MgCO_3 \cdot 3H_2O$). DOE further stated that modeling has shown that these two mineral phases yield approximately the same chemical conditions as when the formation of magnesite occurs.

DOE determined that MgO was also capable of mitigating the effects of CO_2 generation in the disposal room (Chapter 6.4.3.3). As stated above, MgO will react with water (brine) in the disposal room to form the hydroxide brucite. Brucite will then be available to react with CO_2 to form solid magnesium carbonate minerals such as magnesite and water. Appendices SOTERM.2.2.2 and WCA.4.1.2 indicate that this reaction will buffer the pmH at approximately 9.4 in Salado brine and 9.9 in Castile brine and the CO_2 fugacity at 10^{-7} for both brines.

DOE calculated the quantity of MgO necessary in the repository to ensure removal of CO_2 from the gas phase by first estimating the maximum amount of CO_2 that could be generated by all processes that may contribute to CO_2 production. DOE assumed that every atom of carbon in the repository would form CO_2. In a letter to EPA, DOE indicated that the total number of moles of MgO required to react with the maximum possible amount of CO_2 that could be generated is 9.85×10^8 moles (Docket A-93-02, Item II-I-10, Enclosure 2g, p. 3). Based on appropriate conversion factors (40.3 grams/mole, 0.001 kg/gm, 2.202 kg/lb, and 0.0005 lb/ton), a total of 43,700 tons of MgO are required to react with the maximum estimated carbon dioxide production. In order to provide a factor of safety, DOE proposed to emplace 85,600 tons (almost 2×10^9 moles) of MgO in the repository. In determining this quantity, DOE calculated the volume of space in the repository available to receive backfill, considering the size of the backfill packages and the density of the backfill in the packages.

In "Implementation of Chemical Controls Through a Backfill System for the Waste Isolation Pilot Plant (WIPP)," DOE discussed the experiments conducted to demonstrate the ability of MgO to mitigate the impact of CO_2 production on the solubility of actinides in the repository (Docket A-93-02, Item II-I-15). This paper provided a brief description of the experiments that were conducted and concluded that:

- The reaction of industrial grade MgO is sufficient to function effectively as a pH buffer with the repository time scale.

- DOE has experimentally confirmed that the MgO backfill will have sufficient reactivity to function effectively as a pH buffer and will effectively remove CO_2 from the system through precipitation of relatively insoluble carbonate phases, and that the solid phases expected to be formed over a very short time-scale will yield approximately the same chemical conditions as those expected from the formation of magnesite.

- The formation of reaction products on the surfaces of the backfill material do not have a significant, detrimental impact on the ability of the MgO to maintain the predicted chemical conditions.

<u>Decrease in Uncertainty</u>

As noted in Appendices WCA.4.1.2, WCA.8.17, and SOTERM.2.2.2, there is considerable uncertainty regarding the amount of microbial degradation and associated CO_2 generation, that will actually occur in the repository. Depending on the level of microbial degradation of carbon, DOE estimated that without the use of MgO backfill, the fugacity of CO_2 could vary between zero atmospheres and 60 atmospheres. This wide range of CO_2 fugacity is accompanied by a correspondingly wide range of brine pH values (approximately 4-13) and carbonate concentrations. Since the solubility of actinides is related to the pH of the brine, the uncertainty in the amount of microbial degradation would result in a wide range of potential actinide solubilities for input to the PA. In previous PA calculations, actinide solubility has been shown to be important to disposal system performance (see Chapter 6.4.3.4, p. 6-105). DOE intends to emplace enough MgO backfill into the repository to ensure that CO_2 uptake via reactions with the hydrated MgO will exceed the highest estimated CO_2 generation rate. DOE concluded that the addition of MgO backfill in this quantity not only will maintain alkaline conditions (which favor lower actinide solubilities) in the repository, but also will minimize the uncertainty of the CO_2 fugacity (by ensuring a low level of CO_2 in brine regardless of generation rate) and thus reduce the uncertainty of actinide solubility values used in the PA.

<u>Method of Incorporating the Engineered Barrier</u>

In response to an EPA request to document the implementation of MgO so that its placement can be correlated with the assumptions used in the PA (Docket A-93-02, Item II-I-1, Enclosure 2, p. 11), DOE provided additional information by letter dated February 26, 1997 (Docket A-93-02, Item II-I-10, Enclosure 2g, pp. 2 to 3). The magnesium oxide backfill will be purchased in dry granular or pelletized form within prepackaged polyethylene bags. The use of bags provides ease of handling during emplacement, and protects MgO from premature exposure to atmospheric CO_2 during and soon after emplacement. DOE has specified granular or pelletized MgO for several reasons: to reduce dusting potential in the event of a premature bag rupture; to maintain sufficient permeability to make the backfill material accessible to any brine flow; and to reduce the probability that the backfill material will be flushed out of the repository system by entrainment in an established brine flow field (Appendix BACK.2). DOE proposed to place MgO between the waste containers in the repository, between the waste containers and the walls of the repository, and above the stacks of waste containers.

Appendix BACK.2 indicated that while many forms of MgO are available, the form resulting from low-temperature dehydration of magnesium hydroxide is required to ensure sufficient reactivity with CO_2. Chapter 3.3.3 (pp. 3-33 to 3-39) of the CCA indicated that MgO backfill will be purchased and received in two different containers: a super sack holding approximately 4000 pounds (1,814 kilograms) and a mini sack holding approximately 25 pounds (11.3 kilograms). The prepackaged containers will be shipped to the WIPP by road or rail and delivered underground using established shaft and material handling processes (p. 3-34).

The mini sacks will be 34 inches (86.4 centimeters) long and six inches (15 centimeters) in diameter and will weigh approximately 25 pounds (11.3 kilograms). This size results in a volume of approximately 0.555 cubic feet per mini sack and a density of approximately 45 pounds per cubic foot. The mini sacks will be fabricated from a single layer of polyethylene or other suitable material and will have an integral handle and hook attached into the sack closure. Six sacks will be manually placed in the external voids of each seven-pack unit of drums just before the pack is placed on the waste stack. The mini sack will be lifted up behind the shrink wrap that surrounds the seven-pack and slid into place. The mini sack will be supported by the slip sheet that is present beneath each seven-pack of drums. A similar process will be used for standard waste boxes except that the six mini sacks will be hung from the lift clips located on the two flat sides of the standard waste boxes.

Mini sacks will also be stacked manually on the floor of the repository in the space between the waste stack and the side of the disposal room. DOE anticipates placing three rows of mini sacks, stacked four high, on each side of the waste stack. DOE calculated that the placement of mini sacks in this manner will result in a loading of up to 200 pounds of MgO (100 pounds per side of waste stack) per linear foot of waste stack.

The super sacks will be 6 feet long, 5 feet wide, and 1.5 feet high and will weigh approximately 4,000 pounds. These dimensions result in a volume of approximately 45 cubic feet and a density of approximately 89 pounds per cubic foot for each super sack. The super sacks will be of multi-wall construction with a vapor and moisture barrier. The super sacks will have an integral slip sheet or base attachment so that they may be handled and emplaced in a manner is identical to the waste units. The super sacks will be placed on top of the waste stacks after each row of waste units is in place. From Figure 3-8, it appears that five super sacks will be placed across the top of the waste stacks in the 33-foot wide room (p. 3-37). It appears that the six-foot long sides of the super sacks will be oriented across the disposal rooms.

In a letter to EPA dated February 26, 1997, DOE indicated that a preliminary placement test—performed using mini sacks and super sacks in the repository setting—demonstrated that backfill can be emplaced as described above without significant impact to waste handling operations (Docket A-93-02, Item II-I-10, Enclosure 2g, p. 2). DOE also stated that the WIPP waste handling procedure WH-1011, Revision 2, dated October 1, 1996, describes the waste emplacement procedure for mini sacks of MgO in the void spaces between waste drums in the 7-pack configuration. DOE is in the process of modifying the waste handling procedures to incorporate placement of mini sacks on standard waste boxes and between the waste stacks and disposal room wall, and placement of super sacks on top of the waste stacks.

In Chapter 3.3.3, DOE provided the results of calculations to show that MgO emplaced as described above would result in approximately 85,600 tons of MgO emplaced in the repository (p. 3-34). The calculation is based on the measurement of approximately 3,700 linear feet of waste stack in each of the ten waste panels. The configuration of MgO in super sacks will result in approximately 4,000 pounds per linear foot of waste stack, or about 7,400 tons per panel. The mini sacks placed between the waste containers will result in approximately 800 tons per panel and the mini sacks placed along the repository walls will result in approximately 360 short tons per panel. The total is approximately 8,560 tons per panel or 85,600 tons for the repository.

As described above, DOE calculated that a total of 43,700 tons of MgO is required to react with the maximum estimated carbon dioxide production in the repository. Dividing the mass of backfill to be emplaced (85,600 tons) by the mass required to react with the maximum possible carbon dioxide production yields a safety factor of 1.95. DOE concluded that an adequate amount of MgO will be emplaced in the repository to mitigate the effects of CO_2 production and thus substantially delay movement of radionuclides (Docket A-93-02, Item II-I-10, Enclosure 2g, p. 3).

44.A.6 EPA Compliance Review

EPA evaluated the information regarding engineered barriers that was provided by DOE in the CCA, Chapters 3 (pp. 3-14 to 3-45), 6 (pp. 6-105 to 6-114), and 7 (pp. 7-89 to 7-96), as well as in Appendices BACK, EBS, SEAL, PCS, SOTERM.2.2, and WCA.4.1 of the CCA. The Agency also considered supplemental information provided in the report "Implementation of Chemical Controls Through a Backfill System for the Waste Isolation Pilot Plant (WIPP)" (Docket A-93-02, Item II-I-15) and in a letter to EPA dated February 26, 1997 (Docket A-93-02, Item II-I-10, Enclosure 2g).

DOE specified the proposed method of incorporating the engineered barrier (MgO backfill) into the disposal system in the CCA, Chapter 3.3.3 and Appendix BACK. DOE identified MgO as the backfill material of choice, and provided the rationale for choosing the physical form of MgO to be used, the approximate grain size of the MgO to be emplaced, and the type and size of packages to be used to transport and emplace the MgO. The CCA also described how the MgO mini sacks and super sacks would be arranged around waste containers in the disposal rooms and indicated that the MgO backfill could be emplaced in the same manner and with the same equipment as the waste containers.

EPA found that the CCA, as submitted in October 1996, provided insufficient documentation regarding emplacement of MgO in the repository. The Agency therefore requested additional information from DOE to ensure that "MgO will be distributed as assumed in the conceptual models" and that "the excess volume proposed to be emplaced can actually be accommodated and . . . covers the uncertainties in the actual geochemical processes" (Docket A-93-02, Item II-I-1, Enclosure 2, p. 11). In response to EPA's request, DOE submitted supplemental information that indicated that a preliminary placement test had been performed using mini sacks and super sacks in the repository setting and had demonstrated that backfill can be emplaced without significant impact to waste handling operations (Docket A-93-02, Item II-I-10, Enclosure 2g, p. 2, and Item II-I-15).

EPA found the rationale and methodology for emplacing the MgO backfill within the repository to be technically adequate. The use of two types of closed containers (mini and super sacks) will allow the backfill material to be handled using the same equipment proposed for waste emplacement. The modification of waste handling procedures to incorporate placement of MgO mini-sacks provides additional assurance that the process is feasible and will be implemented as described.

The supplemental information also clarified the amount of MgO that will be emplaced in the disposal system. DOE determined that the total number of moles of MgO required to react with the maximum possible amount of CO_2 that could be generated was 9.85×10^8 moles, which equates to 43,700 tons of MgO. In the CCA, Chapter 3.3.3, DOE stated that approximately 85,600 tons (almost 2×10^9 moles) of MgO could be emplaced in the repository. The CCA did not provide the calculations used to determine the amount of MgO that could be emplaced in the repository and did not provide the dimensions of the super sacks (needed to calculate the density of the MgO in the super sacks). In order to verify that the volume of MgO projected to be emplaced can actually be accommodated, EPA obtained the dimensions of the super sacks from the WIPP RCRA Part B Permit Application (DOE 1996) and conducted confirmatory calculations (see Attachment A of this CARD).

These calculations confirmed that, based on the arrangement of MgO and waste containers described in Chapter 3.3.3, DOE would be able to emplace at least 86,500 tons of MgO in the repository. This amount of MgO would provide a 1.95 factor of safety compared to the 43,700 tons of MgO needed to react fully with any CO_2 that might be generated in the repository. EPA further notes that the reaction of MgO to brucite would consume water, an added benefit for which DOE did not take credit in the PA. Additionally, the other mineral species that may form (dypingite ($Mg_3(CO_3)_4(OH)_2 \cdot 5H_2O$) and/or nesquehonite ($MgCO_3 \cdot 3H_2O$) consume five and three times as much water, respectively. These factors constitute a conservative approach that accounts sufficiently for uncertainties in geochemical processes that may occur in the disposal system.

DOE provided a justification of the proposed barrier's ability to prevent or substantially delay the movement of radionuclides toward the accessible environment in Chapter 6.4.3.4 and Appendices BACK, EBS, SOTERM.2.2, and WCA.4.1. These portions of the CCA also described how the inclusion of the MgO contributes to the disposal system's performance. Chapter 6.4.3.4 stated that actinide solubility has been shown to be important to disposal system performance (p. 6-105). The CCA also stated that, based on experimental data, alkaline conditions in the repository favor lower actinide solubility (p. 6-106). Without MgO backfill, significant quantities of CO_2 could be generated by microbial degradation of waste components and could significantly increase actinide solubility by forming carbonic acid and by raising CO_2 fugacity of brine in disposal rooms. These processes could lead to higher solubility—and thus mobility—of radionuclides.

Appendix BACK and the supplemental paper, "Implementation of Chemical Controls Through a Backfill System for the Waste Isolation Pilot Plant (WIPP)" (Docket A-93-02, Item II-I-15) indicated that to mitigate the detrimental effects of possible CO_2 generation, a material was required that would maintain the pH of the brines in the alkaline region and remove CO_2 generated in the repository. DOE identified the alkaline earth oxides (e.g., MgO and Calcium Oxide (CaO)) as materials that could mitigate the detrimental effect of carbon dioxide generation in the disposal room. The alkaline earth oxide MgO will react with water (brine) in the disposal room to form the hydroxide $Mg(OH_2)$ (brucite). The hydroxide $Mg(OH_2)$ will then be available to react with any carbon dioxide or carbonic acid that is available in the disposal room to form solid magnesium carbonate minerals such as magnesite ($MgCO_3$) and water. The reaction will buffer the brines to a pH that reduces the solubility of the actinides and effectively removes the carbonate from the system due to the low solubility of $MgCO_3$. Appendices SOTERM.2.2.2 and WCA.4.1.2 indicated that this reaction will buffer the pmH at approximately 9.4 in Salado brine and 9.9 in Castile brine and the CO_2 fugacity at 10^{-7} for both brines. EPA's consideration of the chemical effects of MgO backfill on disposal system conditions is also discussed under the discussion of Section 194.24(b) in **CARD 24—Waste Characterization** and under Section 194.24 in the Response to Comments Document for EPA's final certification decision.

DOE provided a qualitative evaluation of the reduction in uncertainty in disposal system performance in Appendices WCA.4.1.2, WCA.8.17, and SOTERM.2.2.2. The CCA indicated that there is considerable uncertainty regarding the amount of microbial degradation (and associated CO_2 generation) that will occur in the repository. DOE estimated that without the use of MgO backfill, depending on the level of microbial degradation of carbon, the fugacity of CO_2 could vary between zero atmospheres and 60 atmospheres. This wide range of CO_2 fugacity is accompanied by a correspondingly wide range of brine pH values (approximately 4-13) and carbonate concentrations. Since the solubility of actinides is related to the pH of the brine, the uncertainty in the amount of microbial degradation results in a side range of potential actinide solubilities for input to the PA. Chapter 6.4.3.4 indicated that in previous performance assessment calculations, actinide solubility was been shown to be important to disposal system performance. DOE intends to emplace enough MgO backfill into the repository to ensure that CO_2 uptake via reactions with the hydrated MgO will exceed the highest estimated CO_2 generation rate.

EPA agrees that actinide solubility is an important parameter and believes that DOE's experimental results adequately support the conclusion that actinide solubility is dependent on pH and CO_2 fugacity. The chemical reactions of MgO described in the CCA can occur in the conditions expected in the disposal system and would control pH levels within a limited range. In addition, an independent peer review panel concluded that MgO backfill will function as assumed in the CCA (Docket A-93-02, Item II-G-22). EPA therefore concludes that DOE's qualitative justification was sufficient to show that the emplacement of MgO backfill in the repository will help prevent or substantially delay the movement of radionuclides toward the accessible environment by helping to maintain alkaline conditions in the repository, which in turn favors lower actinide solubilities. Furthermore, DOE's bounding of pH levels to a narrow range greatly reduces the uncertainty associated with pH and actinide solubility in the PA.

44.B.1 Requirement

(b) "In selecting any engineered barrier(s) for the disposal system, DOE 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."

44.B.2 Abstract

EPA expected DOE to conduct an evaluation of engineered barrier alternatives in order to compare the benefits and detriments of various barriers and then use the results of such a comparison to justify selecting or rejecting a barrier(s). EPA required DOE to consider, at a minimum, the following barriers: 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.

DOE conducted a scoping study and screening process during March and April of 1995, which EPA observed. The scoping effort produced a list of 111 potential barriers. The list produced from the scoping process explicitly included the barriers specified in 40 CFR 194.44(b). DOE referred to engineered barriers as "engineered alternatives." The list of potential barriers was then screened based on DOE's definition of a barrier:

> "a process, technology, method, repository design, or waste form modification which makes a significant positive impact on the disposal system in terms of reducing uncertainty or improving long-term performance."

Once the barriers were screened for meeting the definition, DOE again screened the list against a "must pass" set of criteria. These criteria addressed the technical feasibility of a potential barrier by examining the potential for regulatory compliance and permitting, availability of technology, and schedule of implementation. DOE provided a justification for the rejection of any barrier based on the preceding criteria. Fifty-four alternatives passed the screening process. The 54 alternatives were then "optimized" into logical combinations to provide a list of 14 alternatives that would address the most critical aspects of WIPP performance. The list of 14 alternatives were reviewed and revised by DOE to generate a final list of 18 alternatives to be evaluated using the eight factors contained in Section 194.44(c)(1)(i) - (ix). DOE combined factors (i) and (ix) into one factor for the purposes of their analysis. (See ensuing discussion of Section 194.44(c)(1) for details of this portion of the analysis.) The list of 18 alternatives analyzed and their definitions can be found in DOE's Engineered Alternative Cost/Benefit Study (EACBS) (Appendix EBS of the CCA).

44.B.3 COMPLIANCE REVIEW CRITERIA

EPA expected DOE to perform a comparative evaluation of potentially effective engineered barriers, including the following: 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. EPA expected the evaluation to include a broad scope of alternatives that represent the current state of technology with respect to delaying or preventing the movement of water or radionuclides. Barriers should be evaluated consistently for purposes of comparison.

EPA expected the results of the evaluation to focus on barriers with the greatest potential to reduce the uncertainty in predicting long-term repository performance. The evaluation should contain the following elements:

- List of all barriers to be considered.
- Clearly defined screening criteria.
- Justification for "screening out" any barriers.
- List of all barriers to be evaluated.
- Evaluation against the factors listed at Section 194.44(c)(1).
- Justification for not completing the full evaluation of any barrier.
- Final, comparable benefit/detriment evaluation in matrix or tabular form.

EPA expected the peer review of the evaluation of engineered barriers, as required at Section 194.27(a), to address the following issues: (1) the adequacy of the scope of alternatives considered; (2) the adequacy and appropriate application of the screening criteria; (3) how the factors against which the barriers were evaluated met the regulatory requirements and were sufficient to allow evaluation of the barriers; and (4) that the barriers were adequately evaluated (CAG, pp. 62 to 63).

44.B.4 DOE METHODOLOGY AND CONCLUSIONS

The information supporting DOE's compliance with this requirement was found in the Chapters 7.4.3 and 9.3.3, and Appendices EBS and PEER 4. To fulfill the benefit and detriment evaluation criterion contained in Section 194.44(b), DOE performed an analysis called the "Engineered Alternatives Cost/Benefit Study (EACBS) Final Report" (WIPP/WID-95-2135, Rev. 0, September 1995). This analysis was included in the CCA as Appendix EBS (and is referred to below as Appendix EBS). All citations in the sections below are to this appendix unless otherwise stated.

The purpose of the cost/benefit study in Appendix EBS was to provide DOE with information on which to base the selection or rejection of additional engineered barriers as assurance measures. The study included a qualitative assessment of estimated cost, potential risks, benefits, and relative repository impacts from the implementation of engineered barriers. The impact on the entire waste management complex (as a system) was considered where appropriate. In Appendix EBS, DOE defined the term engineered alternatives (EAs) as engineered barriers that are technically feasible processes, technologies, methods, repository designs or waste form modifications and make a significant positive impact on the disposal system in terms of reducing uncertainty in performance calculations or improving long-term performance (p. 1-1).

DOE identified several important assumptions that were used during the evaluation of engineered barriers:

- ♦ The assumed baseline design of the disposal system did not include backfill or waste processing requirements beyond those required by the WIPP Waste Acceptance Criteria (WAC).
- ♦ The information presented in Appendix EBS was used to select or reject EAs for assurance purposes only, and not to demonstrate compliance with EPA's containment requirements.
- ♦ The results of the analysis in Appendix EBS were qualitative; however, both qualitative and quantitative methods were used to generate the output information.
- ♦ The output of the evaluations in Appendix EBS compared the results of the analysis of each EA with a baseline and not to each other. Numeric rankings of EAs were not provided.

The study provided a qualitative comparison of the potential benefit that a particular engineered barrier (or group of barriers) might have in reducing the uncertainty in the PA or improving the baseline design's long-term performance. The study did not provide specific designs for the engineered barriers.

Method Used to Evaluate Engineered Barriers

Appendix EBS, Chapter 2.1 (pp. 2-1 to 2-4) describes the method DOE followed to conduct the evaluation of the benefit and detriment of engineered barriers. The process was composed of five basic components:

- ♦ Identify potential engineered alternatives by compiling an initial list of potentially viable engineered barriers based on previous studies, proposed regulations, and input solicited from stakeholders.

- ♦ Screen the initial list of engineered barriers to determine which engineered barriers should be retained for further detailed analysis and which should be eliminated because they do not have a significant positive impact on system performance.

- ♦ Optimize the remaining engineered barriers based on technological feasibility and effectiveness to determine the set of engineered barriers to analyze in detail.

- ♦ Analyze the optimized engineered barriers against the eight factors prescribed in Section 194.44(c)(1).

- ♦ Summarize the results of the evaluation in a tabular or matrix form.

DOE provided a detailed description of how these components were carried out in Chapters 2, 3, and 5 of Appendix EBS, as discussed below.

<u>List of Engineered Barriers Considered</u>

Appendix EBS, Appendix A (Table A-1) of the CCA provides a complete listing of the 111 initial engineered barriers screening candidates. Chapters 1.2.2 (p. 1-6) and 2.2.1 (p. 2-3) describe how the initial list was compiled. Each engineered barrier was identified by the same number throughout the evaluation. During the screening process described below, selected engineered barriers were refined to allow a more detailed evaluation. The refined engineered barriers used the same number as the original, but a lower case letter was added to its designation.

After DOE's preliminary PA raised concerns that design enhancements to the disposal system or waste forms might be required to reduce or eliminate gas generation in the repository and the consequences of human intrusion, DOE established the Engineered Alternatives Task Force (EATF) in September 1989 to identify and screen potential engineered barriers to address these concerns specifically. In its final report (DOE 1991), the EATF identified an initial list of 64 engineered barriers, screened the list down to 36, and subsequently combined the 36 into 14 combinations (Nos. 65 to 79).

The next twenty engineered barriers (Nos. 80 to 99) were obtained from the Systems Prioritization Method, Iteration 2 (SPM-2) Baseline Position Paper on Actinide Source Term (SNL 1995). Finally, DOE included the ten engineered barriers specified in Section 194.44(b) in the list of barriers to be evaluated (Nos. 100-Cementation, 101-Shredding, 102-Supercompaction, 103-Incineration, 104-Vitrification, 105-Improved waste containers, 106-Grout and bentonite backfill, 107-Metal melting, 108-Alternative configuration of waste emplacement, and 109-Alternative disposal system dimensions).

<u>Clearly Defined Screening Criteria</u>

DOE developed a screening process that used a qualitative assessment of the potential benefits of engineered barriers on the WIPP disposal system. In advance of the full multi-factor analysis of the engineered barriers required under Section 194.44(c), DOE evaluated the validity of the engineered barriers on the initial list. The intent of the screening process was to identify those engineered barriers that were valid and viable, and which had some expectation of improving the disposal system performance and/or reducing uncertainty in the prediction of the disposal system performance. Appendix EBS (Chapter 2.2.2 and Appendix D, Attachment D7) described the screening criteria that DOE used in the initial evaluation of the list of 111 engineered barriers and stated that a two-tiered approach was used to screen the initial list. The first tier involved a qualitative comparison of conceptual technologies with DOE's definition of engineered barrier, and the second tier consisted of a qualitative comparison of those conceptual technologies that meet the definition with a "must satisfy" criterion. The must-satisfy criteria included regulatory feasibility (ease or difficulty of achieving regulatory compliance) and technological feasibility (maturity of the technology) (Appendix D, p. D2-1).

The Engineered Alternative Screening Working Group (EASWG), comprised of a professional facilitator and professionals from many technical fields (with direct knowledge of the WIPP project and/or other DOE waste programs), was convened in 1995 to conduct the screening and develop the definition of an engineered barrier used by DOE. (Note: An engineered barrier must meet the definition of barrier as defined in 40 CFR Part 191, and the final waste form must meet the WIPP WAC.) To ensure consistency with both EPA's regulations and the WAC, DOE defined an engineered barrier to be a barrier or waste form modification that meets at least one of the following conditions:

- Reduce the permeability of the waste stack.
- Increase the shear strength of the waste form.
- Reduce total gas produced from the waste form by reducing corrosion potential or rate, reducing microbial activity, or isolating and lowering available water/brine contact with the waste.
- Reduce the transport of radionuclides.
- Reduce the consequences of human initiated processes and events.
- Reduce the solubility of the radionuclides.

The "must satisfy" criteria used by the EASWG as the second tier of the screening evaluation involved regulatory and technological feasibility. Regulatory feasibility requires that the technology of the engineered barrier must be licensable in today's political climate and have a likelihood to demonstrate regulatory compliance. Technological feasibility requires that the engineered barrier must have been demonstrated at a minimum of laboratory bench scale and must have the potential for full-scale implementation in the future.

<u>Justification for "Screening Out" Barriers</u>

Appendix EBS (Chapter 2.2.2, Appendix D, Attachment D7) provided a description of how the screening process was conducted. Appendix EBS, Appendix D (Attachment D7,

Appendix E) provided the justification for the screening out of engineered barriers. For the actual screening exercise, the EASWG first compared each of the engineered barriers on the initial list to the definition of engineered barriers and then determined whether the engineered barrier is beneficial or detrimental to the disposal system. They then identified and deleted any duplicate engineered barriers on the initial list. The remaining engineered barriers were then compared to the "must satisfy" criterion.

Two lists, a "pass" list and a "reject" list, were developed based on the screening process. The pass list identified those engineered barriers that met the engineered barrier definition and the "must satisfy" criterion. The pass list is provided in Appendix EBS, Appendix B, and includes a brief description of the individual engineered barriers and a justification for their assignment to the pass list. Of the original 111 potential engineered barriers, 54 passed the screening process.

The reject list provided in Appendix EBS, Appendix C, identified those engineered barriers that did not meet the screening criteria and those engineered barriers on the initial list that were determined to be duplicates. Appendix C also documented the EASWG's rationale for why rejected engineered barriers did not meet the general engineered barrier definition or other screening criteria.

All ten of the engineered barriers specified in Section 194.44(b) (engineered barrier Nos. 100 to 109) were placed on the reject list. The justification for rejecting these engineered barriers was either that the individual barriers were duplicates of barriers already on the pass list, or that the barrier was inherently part of other barriers on the pass list. The EASWG determined the following:

- ♦ Cementation (No. 100) was inherently part of several engineered barriers already on the pass list (Nos. 2, 4a, 7, 66, 67, 68, 69, 70, 87, 88, 89, 90, 92, 93, 94 and 110) and did not require separate consideration.

- ♦ Shredding (No. 101) was not an engineered barrier, was inherently part of several engineered barriers already on the pass list (Nos. 3, 5, 6, 7, 8, 9, 15, 66, 67, 68, 69, 70, 71, 72, 73, 74, 78, 87, 88, 89, 90, 93, and 94), and did not require separate consideration.

- ♦ Supercompaction (No. 102) was a duplicate of No.1, Compact Waste, and was inherently part of several engineered barriers already on the pass list (Nos. 76, 77, and 79).

- ♦ Incineration (No. 103) was inherently part of No. 2, Incinerate and Cement, because incineration alone is not an engineered barrier. Incineration must be followed by a form of solidification to meet the particulate restriction in the waste acceptance criteria.

- ♦ Vitrification (No. 104) was a duplicate of No. 3, Shred and Vitrify Waste, and was also inherently part of several engineered barriers already on the pass list (Nos. 71, 72, 73, 74, and 78).

- Improved Waste Containers (No. 105) was a duplicate of No.63, Change Waste Container, and No. 64, Change Waste Container Material.

- Grout and Bentonite Backfill (No. 106) were inherently part of other engineered barriers already on the pass list (Nos. 33 and 35) and did not require separate consideration.

- Metal Melting (No. 107) was a duplicate of Nos. 11a and 11b, Melt Metals.

- Alternative Configuration of Waste Emplacement (No. 108) was inherently part of several engineered barriers already on the pass list (Nos. 38 and 39) and did not require separate consideration.

- Alternative Disposal System Dimensions (No. 109) was inherently part of several engineered barriers already on the pass list (Nos. 38 and 39) and did not require separate consideration.

The selected engineered barriers were then subjected to an optimization process to determine which of the 54 would be retained for full factor analysis. The intent of the optimization process was to:

- Develop a set of engineered barriers that address important disposal system performance issues such as reducing the solubility of actinides in brine and improving the strength of the waste.

- Ensure that the full factor analysis was conducted on those engineered barriers that had the highest technical feasibility (that is, those engineered barriers that have been subjected to bench-scale testing at a minimum).

- Ensure that the full factor analysis was conducted on those engineered barriers that had a high likelihood of being permitted in a reasonable time frame.

The optimization (prioritization) process (Chapter 2.2.3, p. 2-9, and Appendix D) was conducted in two steps. The first step in the process included the assignment of a relative feasibility score (0-5) to each of the 54 engineered barriers. The score was based on a qualitative assessment of both technological and regulatory feasibility and a preliminary qualitative assessment of the effectiveness of each of the 54 engineered barriers in four general categories of performance (gas generation, actinide solubility, waste permeability, and shear strength of waste). The results of the feasibility scoring and the effectiveness assessment were used to select those barriers with the optimum potential benefit to include in the full factor analysis. Initially, the optimization process identified fourteen engineered barriers (see listing at Appendix A, Table A-3).

The second step consisted of a DOE management-level assessment that selected a final set of engineered barriers to be retained for full analysis. This assessment eliminated several barriers primarily concerned with reduction in gas generation potential and added several barriers that would provide benefit related to actinide solubility, waste strength, and waste permeability. During the DOE-CAO review, modifications were made to the nine selected engineered barriers, considering other backfills in combination with the engineered barriers and modifying some of the original backfills. Appendix A, Table A-4, provided details regarding the nine EAs and nine variations, the changes that were made to the original list of 14 engineered barriers and describes the modifications.

List of Barriers to be Evaluated

Table 2-1 (p. 2-11) contains a listing and description of the 18 barriers that were evaluated in the full factor analysis in the engineered barrier study.

Evaluation Against the Factors Listed at Section 194.44(c)(1)

Chapters 3 and 5 contain information regarding how the 18 optimized engineered barriers were evaluated against the factors listed at Section 194.44(c)(1). A complete description of DOE methodology for this evaluation is provided in Section 194.44(c).

Justification for not Completing a Full Evaluation of Any Barrier

DOE completed a full evaluation of each barrier selected for evaluation.

Final, Comparable Benefit/Detriment Evaluation in Matrix or Tabular Form

The Executive Summary and Chapter 5 contain tables and matrices that summarize the results of the benefit/detriment analysis conducted by DOE.

Peer Review of the Evaluation of Engineered Barriers

Chapter 9.3.3 and Appendix PEER.4 of the CCA provided information regarding the independent peer review that was conducted for the Engineered Alternatives Cost/Benefit Study. See **CARD 27—Peer Review** for a discussion of the peer review process. An Engineered Alternatives Cost/Benefit Study Peer Review Plan was developed to describe the peer review process and the documentation requirements that DOE-CAO would use to ensure that the processes used in the Engineered Alternatives Cost/Benefit Study were appropriate for use in the demonstration of compliance. A copy of this plan was provided in Appendix PEER.4 of the CCA.

An independent peer review committee was assembled by the Waste-Management Education and Research Consortium to provide DOE with a review of the Engineered Alternatives Cost/Benefit Study Final Report. The peer review was conducted during May-July, 1996. The objective of the peer review was to assess the validity of the study's assumptions and conclusions and the adequacy of DOE's technical approach. A copy of the final peer review report, dated July 10, 1996, was provided in the CCA, Appendix PEER.4 of the CCA.

After orientation and training, the peer review panel was briefed by the Engineered Alternatives Cost/Benefit Study report authors and DOE staff. The entire peer review panel participated in an evaluation of the process DOE followed to develop the initial list of engineered barriers to be considered and the process used by DOE to identify the engineered barriers that would be retained for full factor analysis. The panel then divided into three subcommittees to review the engineered barrier factors identified in Section 194.44(c). Subcommittee membership depended on expertise that was most appropriate for each set of factors. Finally, subcommittee findings were evaluated by the entire peer panel.

The overall conclusions of the peer review panel were:

- ♦ The information presented in the Engineered Alternatives Cost/Benefit Study was of high quality.
- ♦ The approach taken was valid.
- ♦ Conclusions drawn were reasonable.
- ♦ The analysis was conducted in accordance with the requirements of Section 194.44.

The peer review panel final report identified several findings, concerns, and issues. DOE developed a response to each of these items and then asked the peer review panel members to review DOE's responses and indicate whether they agreed or disagreed. DOE's responses and the panel's reaction to these responses were included in Chapter 9.3.3 of the CCA.

44.B.5 EPA COMPLIANCE REVIEW

EPA reviewed information regarding the evaluation of engineered barriers in Chapter 7.4.3, Chapter 9.3.3, and Appendices EBS and PEER.4.

<u>List of Barriers Considered</u>

EPA examined the initial list of barriers subjected to screening and found that it encompassed a broad range of measures that might be considered engineered barriers. The methodology for compiling the list of all engineered barriers to be considered in the evaluation was sufficiently explained in the CCA. Also, DOE's approach was adequately broad in scope, as was the technical expertise represented by the panel who compiled the list.

<u>Clearly Defined Screening Criteria</u>

EPA reviewed the description of the screening criteria that were used in the evaluation of the initial list of engineered barriers (Appendix D, Attachment D7, Chapter 2.2.2). EPA also reviewed the screening process that used a qualitative assessment of the potential benefits of engineered barriers in order to evaluate the validity of those barriers prior to conducting a full multi-factor analysis. The screening process identified those initial list engineered barriers that were valid and viable, with some expectation that they could improve the disposal system performance and/or reduce uncertainty in the prediction of the disposal system performance. EPA also reviewed the two-tiered screening process.

The rationale and methodology for developing the screening criteria and screening process for the engineered barriers evaluation were technically adequate because the criteria were consistent with EPA's definition of an engineered barrier. In addition, the criteria addressed EPA's expectation that DOE consider the feasibility of developing technologies. EPA found that the criteria were consistently applied during the screening process.

Justification for Screening Out Barriers

EPA reviewed DOE's description of how the screening process was conducted (Appendix D, Attachment D7, Chapter 2.2.2). The justification for screening out engineered barriers was provided in Appendix D, Attachment D7, Appendices C and E. In addition to reviewing documentation in the CCA, EPA attended the scoping and screening process in Carlsbad during March-April 1996. Based on EPA's observance of the process and review of the results, DOE's screening of engineered barriers prior to full multi-factor analysis was acceptable because the screening criteria were conservatively applied and the barrier remained on the list if there was any question of its appropriateness.

List of Barriers to be Evaluated

EPA found that the CCA clearly identified the list of barriers subjected to each screening review and the list of barriers eventually included in the full analysis of engineered barriers.

Evaluation Against the Factors Listed at Section 194.44(c)(1)

Appendix EBS, Chapters 3 and 5, provide information regarding how the 18 optimized engineered barriers were evaluated against the factors listed at Section 194.44(c)(1). DOE's methodology for this evaluation and EPA's review are discussed below under Section 194.44(c).

Justification for not Completing the Full Evaluation of Any Barrier

DOE completed the full evaluation of each barrier selected to be evaluated.

Final, Comparable Benefit/Detriment Evaluation in Matrix or Tabular Form

The Executive Summary and Chapter 5 provide tables and matrices that summarize the results of the benefit/detriment analysis conducted by DOE, which EPA found to be complete.

The EACBS identified engineered barriers that could be used to improve long-term repository performance. DOE used the results of the study to select a chemical backfill based on its low cost and high benefit. A backfill that chemically alters the pH of brine in the disposal room was identified as providing significant benefit in reducing the quantity of mobile actinides. After further analysis, documented and discussed in Appendix BACK and SOTERM, DOE selected

MgO as the backfill material that provided the desired long-term benefit while minimizing the operational impacts associated with the more caustic CaO (Chapter 7, p. 7-95).

Peer Review of the Evaluation of Engineered Barriers

In addition to reviewing documentation of the peer review, EPA representatives observed the peer review meetings. The peer review panel consisted of independent professionals with relevant expertise in multiple technical fields. The methodology used to conduct the peer review was found to be adequate (see **CARD 27—Peer Review**).

The panel evaluated and reported on: adequacy of requirements and criteria, validity of assumptions, alternate interpretations, uncertainty of results and consequences if wrong, appropriateness and limitations of methodology and procedures, adequacy of application, accuracy of calculations, and validity of conclusions. The review was performed in three phases: (1) compile EAs, screen and optimize; (2) analyze optimized EAs through the eight factor analysis; and (3) report analysis results. Subcommittees were established by the panel for reviewing the eight different EA evaluation factors identified in Section 194.44 with reviewers divided by expertise that was most appropriate for each set of factors and all findings were subsequently reviewed by the entire peer panel. The conclusions of the panel were that DOE's approach was valid, the conclusions drawn were reasonable and the analysis was conducted in accordance with Section 194.44 requirements.

EPA concurred with the findings of the engineered alternatives peer review. EPA's evaluation of DOE's process for selecting engineered barriers indicated that: (1) the scope of alternatives considered was adequate; (2) the application of the screening criteria was appropriate; (3) the factors against which the barriers were evaluated met the regulatory requirements and were sufficient to allow evaluation of the barriers; and (4) that the barriers were adequately evaluated.

44.C.1 Requirement

(c) (1) "In conducting the evaluation of engineered barrier alternatives, the following shall be considered, to the extent practicable:

(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 (e.g., the extent to which the incorporation of engineered barriers affects the volume of waste);
(ix) The effects on mitigating the consequences of human intrusion.

(c)(2) If, after consideration of one or more of the factors in paragraph (c)(1) of this section, DOE concludes that an engineered barrier considered within the scope of the evaluation should be rejected without evaluating the remaining factors in paragraph (c)(1) of this section, then any compliance application shall provide a justification for this rejection explaining why the evaluation of the remaining factors would not alter the conclusion.

(d) In considering the ability of engineered barriers to prevent or substantially delay the movement of water or radionuclides toward the accessible environment, the benefit and detriment of engineered barriers for existing waste already packaged, existing waste not yet packaged, existing waste in need of repackaging, and to-be-generated waste shall be considered separately and described.

(e) The evaluation described in paragraphs (b), (c) and (d) of this section shall consider engineered barriers alone and in combination."

44.C.2 ABSTRACT

EPA expected DOE to evaluate potential engineered barrier alternatives based on the factors identified in Section 194.44(c)(1)(i-ix) to the extent practicable. Information supporting DOE's compliance with this requirement was found in Chapters 7.4.3 and 9.3.3 and Appendices EBS and PEER 4 of the CCA. The Engineered Alternatives Cost/Benefit Study (Appendix EBS of the CCA) contains the evaluation using all nine factors in Section 194.44(c)(1).

EPA found that all of the barriers evaluated had considered all nine factors and that the evaluation considered and described existing waste already packaged, existing waste not yet packaged, existing waste in need of repackaging, and to-be-generated waste. EPA found that the evaluation fully documented the consideration of engineered alternatives alone and in combination.

44.C.3 COMPLIANCE REVIEW CRITERIA

The Compliance Criteria required DOE to demonstrate that all engineered barriers required under Section 194.44(b) were considered based on the factors identified in Section 194.44(c)(1) (i-ix) to the extent practicable. DOE must justify why consideration of such factors was not practicable for any barrier or was rejected prior to completion of the consideration of all nine factors, or use a combination of these methods. EPA expected a qualitative and comparative evaluation for purposes of judging the relative performance of each barrier. EPA did not expect an evaluation of the absolute performance of each barrier in the PA.

DOE must distinguish between the beneficial or detrimental effects that each barrier could have relative to four types of waste—existing waste already packaged; existing waste not yet packaged; existing waste in need of repackaging; and to-be-generated waste—and must explain these effects when justifying the selection of barriers.

As stated in the CAG (p. 65), EPA expected DOE's evaluation to consider engineered barriers alone and in logical combination. EPA did not expect DOE to evaluate all possible combinations of engineered barriers, but expected DOE to carry out evaluations of combinations of engineered barriers that were the most beneficial regarding the factors listed at Section 194.44(c)(1).

44.C.4 DOE METHODOLOGY AND CONCLUSIONS

DOE provided information regarding the evaluation of engineered barriers in Chapter 7.4.3, Chapter 9.3.3, and Appendices EBS and PEER.4. (Unless otherwise noted, all references in this section are to Appendix EBS.) In Appendix EBS.3, DOE described how the 18 optimized engineered barriers were analyzed with respect to the nine factors described in Section 194.44. These barriers were composed of nine basic engineered barriers and nine variations on those barriers. DOE combined factors (i) and (ix) during the full factor analysis so that there were actually eight factors in the analysis. Appendix EBS.2.3, Table 2-1 (p. 2-11) provided a listing and description of all the barriers to be evaluated in the full factor analysis. DOE did not reject any of the 18 engineered barriers without evaluating each against all of the factors identified in Section 194.44(c)(1). In addition, Appendix EBS.2.1 (p. 2-3) stated that the engineered barrier cost/benefit study considered the benefit and detriment of engineered barriers for existing waste already packaged, existing waste that is not yet packaged, existing waste that is in need of repackaging, and to-be-generated waste. DOE evaluated the benefit and detriment of engineered barrier alternatives alone and in combination. DOE stated that all possible combinations of barriers were not considered because many combinations were not plausible (e.g., vitrification and plasma processing).

Appendix EBS.3 presented quantifiable performance measures and results for each of the eight factors. While some factors were characterized by a single performance measure, others required several different performance measures to describe the results. As shown in Appendix EBS.5, in order to facilitate integration of the results DOE condensed performance measures for each factor to define a multi-element "performance vector" describing the results for each engineered barrier. The performance vector expresses the performance of each engineered barrier relative to the baseline. A summary of the results of the evaluation of the engineered barriers was presented in both tabular and matrix form in Appendix EBS.5.4 (pp. 5-3 to 5-27).

Appendix EBS.2 and Appendix A, Table A-1, indicated that the list of initial engineered barrier screening candidates included both individual engineered barriers and combinations of engineered barriers. Sections 2, 3, and 5 of Appendix EBS indicated that the engineered barriers included in the multi factor analysis can be separated into three general categories: waste processing, backfill, and combination of engineered barriers.

Of the 18 engineered barriers evaluated in the multi-factor analysis, DOE evaluated three individual waste processing engineered barriers (Nos. 1, 6, and 10), five individual backfill engineered barriers (Nos. 33, 35a, 35b, 83, and 111), and 10 combination engineered barriers (Nos. 77a through 77d and 94a through 94f) that incorporated both multiple processing and multiple backfill barriers.

Waste processing engineered barriers (Nos. 1, 6, and 10) were analyzed for three processing scenarios—centralized, regionalized, and decentralized—each having inherent benefits and detriments affecting their efficacy as engineered barriers. In general, processing scenarios affect the entire waste disposal system (including generator/storage sites, waste transportation, other waste disposal systems, and the WIPP waste handling system) and were shown to have higher costs, risks, and schedule delays than the baseline and backfill-only engineered barriers. With the exception of plasma processing (No. 10), waste processing engineered barriers have a marginal performance impact on the repository. For the inadvertent human intrusion scenario, in which drilling passes through the repository and into a Castile brine pocket below the WIPP, plasma processing and cementitious backfills produced a notable improvement over the baseline case.

Backfill engineered barriers (Nos. 33, 35a, 35b, 83, and 111) were shown to have the least impact on the entire waste disposal system. The WIPP's waste handling system would be affected, but waste transportation, generator/storage sites, and other waste disposal systems would not. Cost, schedule, radiation and chemical exposure were all found to be similar to the baseline estimates. All of the backfill engineered barriers were found to improve long-term system performance.

Combination engineered barriers (Nos. 77a through 77d and 94a through 94f) include both multiple processing and multiple backfill barriers. The evaluation found that the combination engineered barriers had both benefits and detriments. The overall costs and schedule impacts of the combination engineered barriers and the transportation, worker and public risks (radiological, chemical accidental and incidental) are the highest of all the barriers. The overall impact on long-term disposal system performance for combination engineered barriers was found to be comparable to the performance associated with single backfill and processing engineered barriers.

DOE's methodology for considering each of the factors identified in Section 194.44(c)(1) is discussed below.

<u>Ability to Prevent or Substantially Delay the Movement of Water or Waste Toward the Accessible Environment and Effects on Mitigating the Consequences of Human Intrusion</u>

As noted above, DOE combined factors 194.44(c)(i) and (ix) into Factor 1 -- Effects of Engineered Barrier on Long-Term Performance of the Disposal System. The results of the analysis of engineered barriers relative to Factor 1 were provided in Appendix EBS.3.1. Factor 1 dealt with the impacts that an engineered barrier was predicted to have on the long-term performance of the disposal system. Impacts were predicted using the Design Analysis Model (DAM) (Appendix E), which considered the coupled processes of brine flow, creep closure, gas generation, radionuclide migration under undisturbed conditions, and the consequences of human intrusion scenarios.

The DAM was originally developed by the Engineered Alternatives Task Force (EATF) in 1991. The DAM simulates processes occurring in the repository (rooms, panels, access drifts, and shaft seals) for the 10,000-year regulatory period under both undisturbed and disturbed conditions. The DAM is a simplification of the PA and was intended to provide a relative comparison of the potential benefits of the different barriers on the performance of the repository. There was no attempt to determine the absolute effect of the barriers on the performance of the repository since the objective of the study was only to provide DOE with information for use in the selection or rejection of engineered barriers for added assurance in the performance calculations.

The 1992 PA, which was used as a reference for the study, indicated that there are three human intrusion scenarios that postulate the existence of future boreholes that penetrate the waste rooms and panels. The three human intrusion scenarios are fully described in Appendix EBS.3.1.3 (pp. 3-17 to 3-19) and Appendix E (pp. E-5 and E-6) as (1) E1 - a borehole through the repository, (2) E2 - a borehole penetrating into the repository, but not passing through the repository, and (3) E1E2 - a combination of both (1) and (2). These scenarios are addressed in greater detail under the discussion of Section 194.23(a)(1) in **CARD 23—Models and Computer Codes**.

Factor 1 was evaluated by considering the impacts of each engineered barrier on:

- ♦ Relative changes in the cumulative 10,000-year release of radionuclides, based solely on the quantity of cuttings released to the surface from each of the three human intrusion scenarios.

- ♦ Relative changes in the cumulative 10,000-year release of radionuclides into the overlying Rustler Formation from each of the three human intrusion scenarios.

The impact of each of the engineered barriers on the performance of the disposal system, relative to baseline conditions, was evaluated by varying input parameters in the DAM to reflect the characteristics of the engineered barrier. The parameters that were varied include: porosity and permeability of the waste/backfill composite material, brine inflow rates, shear strength of the waste/backfill composite, radionuclide solubility, and sorption of actinides on backfill material. Although both disturbed and undisturbed conditions were simulated, the study placed an emphasis on the effects of the engineered barriers on mitigating releases from the human intrusion scenarios, since the greatest consequences of releases were expected to occur as a result of human intrusion.

Factor 1 addressed the magnitude of reduction through a Measure of Relative Effectiveness (MRE) for cuttings removal to the surface and groundwater transport to the Culebra Dolomite via a borehole, assuming that the three human intrusion scenarios occur. An MRE is a unitless factor that expresses the change in magnitude of releases with respect to the baseline disposal system design.

<u>Impact on Worker Exposure</u>

DOE included the factor at Section 194.44(c)(ii) as Factor 3 - The Impact on Public and Worker Exposure to Radiation Both During and After the Incorporation of an Engineered Barrier. The results of the analysis of engineered barriers relative to Factor 3 were provided in Appendix EBS.3.3 (pp. 3-40 to 3-71).

Factor 3 characterized the human-health risks (due to incidental and accidental exposure) associated with the implementation of an engineered barrier, including those impacts realized at the WIPP site and generator or disposal facilities that handle TRU or TRU-mixed waste. Potential impacts included radiation effects (both occupational exposures and the release of material resulting from an off-normal accident scenario), effects from the release of hazardous material, and in the case of individuals within the facilities, ordinary industrial hazards. Impacts were considered for five groups of individuals at the WIPP and at the generator/disposal sites including:

- ♦ Workers directly involved with handling, processing, or storing TRU waste.

- ♦ Other workers in the facility who are not directly involved with the TRU waste (called "co-located workers").

- ♦ The co-located worker who receives the highest exposure to radiation or hazardous material from TRU waste activities.

- ♦ All members of the public who live within 50 miles of the facility where the TRU waste is being handled, processed, or stored.

- ♦ The member of the public located off-site who receives the highest exposure from activities associated with TRU waste handling, processing, or disposal (called the Maximum Off-Site Individual or MOI).

<u>Increased Ease or Difficulty of Removing Waste</u>

DOE included the factor at Section 194.44(c)(iii) as Factor 4 - The Increased Ease or Difficulty in Future Removal of the Waste from the WIPP Disposal System. The results of the analysis of engineered barriers relative to Factor 4 were provided in Appendix EBS.3.4 (pp. 3-72 to 3-87).

For the analysis of engineered barriers, waste removal was defined as the activity involving recovery of the waste after repository closure. The waste inventory and physical properties for each engineered barrier determined the underground panel geometry, which in turn determined the time required for underground removal. Underground waste removal considered the compressive strength and density of the waste form as well as the consolidation of the backfill expected to occur after a specified period of time. The occupational hazards for industrial accidents included the conventional hazards due to underground mining accidents, hazardous waste exposure, and radioactive waste exposure.

The main objective for the mine waste removal evaluation was to assess the degree of difficulty in extracting waste and backfill and how each of the engineered barriers influenced the associated risk and detriments for each barrier. If a waste/backfill was selected for its desirable characteristics for long-term isolation, it might be undesirable from the perspective of mine waste removal in that there might be an increase in hazard during removal. The components of Factor 4 included the waste volume and repository layout for each engineered barrier that would determine the number of panels for waste disposal and the unconfined compressive strength of the waste/backfill affecting mining advance rate.

The analysis of industrial hazards indicated that the number of accidents was related to the time required for underground waste removal, which in turn related to the underground continuous mining time. Each of the engineered barriers was ranked with regard to waste removal subjecting workers to risk. For waste forms exhibiting higher compressive strength, more time is required for mining and removal and a larger number of non-radiological and radiological accidents and doses were predicted. The results indicated that the engineered barriers identified as Nos. 77a through 77d—placement of waste in a single monolayer in a 6 foot by 33 foot room—would reduce mining excavation substantially, thereby reducing the number of underground mining accidents substantially. The results indicated little difference among the other engineered barriers.

<u>Increased or Reduced Risk of Transporting the Waste</u>

DOE included the factor at Section 194.44(c)(iv) as Factor 5 - The Increased or Reduced Risk of Transporting the Waste to the WIPP. The results of the analysis of engineered barriers relative to Factor 5 were provided in Appendix EBS.3.5 (pp. 3-88 to 3-124).

The transportation risk factor consisted of human health impacts due to radiation and hazardous material exposures that could result from transporting TRU waste from generator sites to the WIPP. The risk factor was defined in terms of the radiological, chemical, and non-radiological/non-chemical impacts of either normal, incident-free transportation or transportation accidents. It was determined that the "backfill only" engineered barriers would not impact transportation because they would not affect the waste form.

Transportation risks were evaluated based on the number of TRU waste shipments that would be required to dispose of the WIPP authorized waste volume of 6.2 million cubic feet. DOE estimated the total number of shipments from each storage/generator site and exposures to the public and workers. For radiological exposures, the comparison of the baseline with the radiological risk factors for the engineered barriers indicated that in general, there were no significant differences in the extent of radiological risks. For hazardous chemical exposures, the evaluation indicated that engineered barrier Nos. 1 and 77 have the highest chemical exposure hazard, followed by engineered barrier No. 6.

<u>Increased or Reduced Uncertainty in Compliance Assessment</u>

DOE included the factor at Section 194.44(c)(v) as Factor 2 - The Increased or Reduced Uncertainty in Compliance Assessment. The results of the analysis of engineered barriers relative to Factor 2 were provided in Appendix EBS.3.2 (pp. 3-20 to 3-39). Factor 2 estimated the barriers' ability to reduce uncertainty regarding the quantity of radioactive material that was expected to be transported to the accessible environment as a result of human intrusion scenarios. The factor estimated uncertainties by systematically manipulating the DAM input parameters from the Factor 1 analyses using a Monte Carlo simulation for each engineered barrier. The results of

Factor 2 were then used in conjunction with those of Factor 1 to characterize the potential for an engineered barrier to provide additional assurance in the performance of the disposal system.

The treatment of uncertainty in compliance assessment was realized by reducing both the magnitude of radioactive materials released to the accessible environment and characterizing the potential variability in that quantity. Factor 1 (Effects of Engineered Barriers on Long-Term Performance) addressed reductions in releases of radioactive material. Factor 2 addressed the ability of the engineered barriers to affect the uncertainty associated with predictions of quantities of radioactive material that might be released as a result of the intrusion scenarios. Reducing this uncertainty increases confidence in the performance of the disposal system.

A given engineered barrier might have an impact on one or more parameters that are important to repository performance. Because the physical processes expected to operate in the repository are nonlinear and interrelated, the impacts of uncertainty in the overall estimate of performance cannot be determined by examining changes in the uncertainty assigned to any one input parameter. Therefore, the Factor 2 evaluation of uncertainty generated a series of input parameter sets using Monte Carlo techniques that randomly sample the parameters's probability distributions. The DAM then used each set of input parameters to estimate the quantity of radioactive materials that would be transported across the immediate boundary of the WIPP repository, assuming that each of the intrusion scenarios occur. The uncertainty results were then correlated to those for the baseline design and comparisons were made of the proposed engineered barriers.

<u>Public Comments Requesting Specific Engineered Barriers</u>

DOE included the factor at Section 194.44(c)(vi) as Factor 6 - The Increased or Reduced Public Confidence in the Performance of the Disposal System. The results of the analysis of engineered barriers relative to Factor 6 were provided in Appendix EBS.3.6 (pp. 3-125 to 3-150).

The evaluation of Factor 6 was conducted in two phases to identify both past and current public concerns regarding the post-closure performance of the repository. Phase I consisted of an examination of public comments that DOE had already received to determine the frequency of concerns regarding the post-closure performance of the repository and the persistence of concerns over time. Sources of comments were the WIPP Final Safety and Analysis Report (1990), the responses to comments for Amendments to 40 CFR Part 191, and public hearings on EPA's Proposed Rule at 40 CFR Part 194. During Phase II, comments were collected during a series of focus group discussions and interviews in which participants were invited to share their concerns.

The combined findings from Phase I and Phase 2 were considered when selecting engineered barriers so that the public concerns could be addressed. Stakeholders suggested that DOE consider engineered barriers such as vitrification and alternate container material. No new engineered barriers were suggested that were not already being considered in the study.

Increased or Reduced Total System Costs

DOE included the factor at Section 194.44(c)(vii) as Factor 7 - The Increased or Reduced Total DOE Waste Management System Cost and Schedule Impacts. The results of the cost and scheduling analyses of engineered barriers relative to Factor 7 were provided in Appendix EBS.3.7 (pp. 3-151 to 3-192).

Factor 7 analyzed increased or decreased costs and schedule impacts on the total DOE waste management system due to the implementation of engineered barriers. The cost consisted of summarized waste processing, transportation, backfill, and emplacement handling for the engineered barriers. The analyzed costs included a comparative analysis of the incremental change in cost of the screened engineered barriers relative to the repository baseline. The analysis estimated the level of funding and labor that would have to be acquired and established a conceptual schedule of start and stop dates for each engineered barrier analyzed. Costs were analyzed by developing process flow diagrams that segmented the engineered barrier into conceptual elements. The costs for the engineered barriers were developed on the basis of waste quantities and required throughput rates to meet schedule restraints.

The schedule for each engineered barrier provided a measure of the barrier's desirability and the time required to implement the engineered barrier relative to the baseline. The schedule included the incremental change of implementing an engineered barrier on the baseline.

Impact On Other Waste Disposal Programs

DOE included the factor at Section 194.44(c)(viii) as Factor 8 - The Impact on Other Waste Disposal Programs. The results of the analysis of engineered barriers relative to Factor 8 were provided in Appendix EBS.3.8 (pp. 3-193 to 3-198).

Factor 8 included an assessment of the impacts that engineered barriers would have on other DOE waste processing and disposal programs, including programs for low-level waste and low-level mixed waste. The major impacts were assessed based on the additional volumes of waste that were projected to be generated by TRU waste processing with respect to each waste processing based engineered barrier. Engineered barriers that did not involve processing waste, such as "backfill only" barriers, were deemed to have minimal impact on other waste disposal programs.

DOE calculated estimated volume of secondary waste projected for each engineered barrier. Based on an analysis of various waste cementation processes, the secondary waste was assumed to be comprised of 50 percent low-level waste and 50 percent low-level mixed waste (p. 3-193). Engineered barrier No. 94 was projected to generate the most secondary waste (three times more than the baseline), and engineered barrier No. 10 was projected to generate the least (one-third less than the baseline). Engineered barrier Nos. 1 and 6 were projected to generate 2.6 times more secondary waste than the baseline.

44.C.5 EPA COMPLIANCE REVIEW

EPA reviewed the information found in Appendix EBS.3 regarding how factors (i) to (ix) at Section 194.44(c)(1) were considered during the evaluation of engineered barriers. All references in this section are to Appendix EBS.

DOE combined factors (i) and (ix) during the full factor analysis, so there were only eight separate factors in the DOE analysis. EPA found the combination of the two factors and the consideration of their effect on the long term performance of the repository to be an acceptable methodology. The Agency found that the Design Analysis Model (DAM) was sufficient to model both undisturbed scenarios and human intrusion, and thus effectively addressed both factors (i) and (ix). The range of parameters that were varied—e.g., porosity of the waste, brine inflow rates, radionuclide solubility—was adequate to reflect the relevant qualities of various engineered barriers and to enable EPA to evaluate the effects of the barriers. Although both disturbed and undisturbed conditions were simulated, the greatest consequences of releases are expected to occur as a result of human intrusion. The scope of human intrusion scenarios modeled in the DAM was appropriate for the engineered barrier evaluation.

For the other factors described in Section 194.44(c)(1), EPA agreed with the conclusions of the peer review panel that DOE considered an appropriate range of effects and developed a quantitative performance measure adequate to compare the effectiveness of engineered barriers. EPA agrees with DOE's conclusion that no performance measure was necessary for factor Section 194.44(c)(1)(vi), "public comments requesting specific engineered barriers," since it could be evaluated with a yes/no question and since public comments did not identify any barriers not already included in the evaluation. EPA confirmed that DOE did not reject any of the 18 optimized barriers without evaluating them against all of the factors identified in Section 194.44(c)(1).

DOE provided adequate information regarding how results for each factor were integrated into the performance vectors and presented a summary of the results in both tabular and matrix form in Appendix EBS.5.4. Table E-3 (pp. xiii-xv) summarizes selected output information from the analysis of each barrier and the baseline with respect to all eight factors. EPA found that DOE had established reasonable criteria for assigning values of "high," "low," or "medium" to performance measures for each criteria (pp. 5-17 to 5-22). These categorizations (and the tabular summaries) provided an appropriate method for weighting the study factors and comparing the performance of potential engineered barriers.

The analyses described in Appendix EBS.3 did not separately and specifically address each of the four waste types, i.e., existing waste already packaged, existing waste not yet packaged, existing waste in need of repackaging, and to-be-generated waste. However, EPA found that the study of engineered barriers addressed this issue substantively in several ways. First, DOE considered that the assumptions and methodology used in the evaluation of the benefits and detriments of the engineered barriers applied to all four waste categories and therefore did not require four separate analyses. Instead, DOE selected engineered barriers and evaluated their performance for three types of waste—sludges, solid organics, and solid inorganics—that DOE considered generally comparable for all waste sites (p. 1-6). DOE further accounted for the four waste types by separately considering decentralized, regional, and centralized waste processing schemes (pp. 5-25 to 5-27). Since the feasibility of such processing configurations is directly related to the waste packaging, EPA found that this methodology was technically adequate and satisfied the requirement for addressing each waste type.

EPA found that DOE provided sufficient information to demonstrate that the evaluation of engineered barriers considered the engineered barriers alone and in combination. EPA agreed that it was reasonable not to consider all possible combinations of barriers, since many combinations were not plausible. The methodology used by DOE to consider engineered barriers alone and in combination during the multi-factor benefit and detriment analysis was technically adequate on the basis of its broad scope and the large number of experts involved in the study.

44.D REFERENCES

DOE 1991. U.S. Department of Energy. Final Report of the Engineered Alternatives Task Force, Revision 0, DOE/WIPP 91-007. 1991. (CCA Reference #187)

DOE 1996. U.S. Department of Energy. Resource Conservation and Recovery Act Part B Permit Application, DOE/WIPP 91-005, Revision 6. April 1996.

SNL 1995. Sandia National Laboratories. Systems Prioritization Method - Iteration 2 (SPM-2) Baseline Position Paper: Actinide Source Term, SAND95-1017/1, WPO42382. 1995.

ATTACHMENT A
Verification That the WIPP Will Accommodate 85,600 Tons of MgO Backfill

1. Information provided by DOE in Section 3.3.3 of the CCA (see p. 3-34 and Figure 3-8).

    - There are about 3,700 linear feet of waste stack in a panel
    - Super sacks of MgO placed on top of the waste stacks will result in about 4,000 pounds per linear foot of waste stack, or 7,400 tons per panel
    - Mini sacks of MgO placed along the rib between the rib and the waste stacks will result in about 100 pounds per linear foot or 360 tons per panel
    - The total MgO to be placed in a panel is 8,560 short tons or approximately 85,600 short tons for the repository

2. Information provided by DOE in Chapter D of the RCRA Part B Permit:

    - Waste Disposal rooms are 33 feet wide and 300 feet long
    - There are seven disposal rooms per panel and they are separated by 100 foot thick pillars
    - The panel access drifts on either end of the disposal rooms are 33 feet wide
    - The mini sacks of MgO weigh 25 pounds and are 34 inches long and 6 inches in diameter
    - The super sacks of MgO weigh 4,000 pounds and are 6 feet x 5 feet x 1.5 feet

<u>Calculation of linear feet of waste stack per panel</u>

- Each Disposal Room is 33 feet wide and 300 feet long

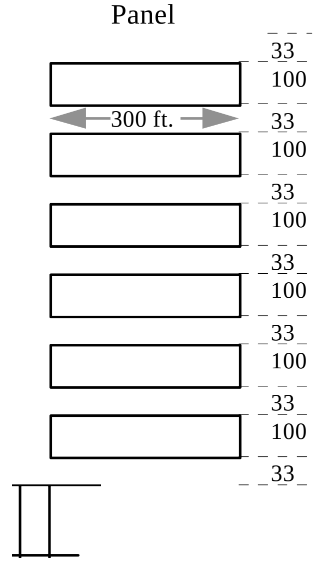
- Each pillar is 100 feet wide

- Linear feet of Disposal Rooms/panel
  $\frac{300 \text{ feet}}{\text{Room}} \times 7 \text{ rooms} = \frac{2{,}100 \text{ feet}}{\text{panel}}$

- Linear feet of Panel Access Drift
  $\left[\left(\frac{33 \text{ feet}}{\text{room}} \times 7 \text{ rooms}\right) + \left(\frac{100 \text{ feet}}{\text{pillar}} \times 6 \text{ pillars}\right) \right] \times 2 \text{ Drifts} =$

  $= [(231 \text{ feet}) + (600 \text{ feet})] \times 2 \text{ Drifts} = \frac{1{,}662 \text{ feet}}{\text{panel}}$

Panel



Total linear feet of waste stack/panel =

$2{,}100 \text{ feet} + 1{,}662 \text{ feet} = \frac{3{,}762 \text{ linear feet}}{\text{panel}}$

** DOE assumed 3,700 linear feet/panel in Chapter 3.

<u>Calculation of Total Weight of MgO to be Placed in Repository</u>

From Figure 3-8 of the CCA, it appears that DOE is planning to place 5 super sacks of MgO across the top of the waste stacks in the 33 foot wide room. Assume then that the super sacks will be oriented such that the long (6 foot) sides of the super sacks will be oriented across the disposal room.

From Figure 3-8 of the CCA, it appears that DOE is planning to place mini sacks 3 across and 4 high along each rib of a disposal room.

Amount of MgO in super sacks

Super sacks weigh 4,000 pounds with dimensions of 6 feet x 5 feet x 1.5 feet

*** Note: Dimensions of Super sack from Chapter D of the RCRA Permit Application, Revision 6**

4,000 lbs = 6 ft x 5 ft x 1.5 ft
4,000 lbs = 45 ft^3

Density of MgO in super sacks = **<u>89 lbs</u> = Density ft^3**

Cross sectional area of super sacks on top of waste stacks

$\left(\frac{6 \text{ feet}}{\text{sack}} \times 5 \text{ sacks}\right) \times (1.5 \text{ feet high}) = 45 \text{ ft}^2$

Cross Section of Room

$$\frac{\text{Volume of MgO}}{\text{Linear Foot of waste stack}} = 45 \text{ ft}^2 \times 1 \text{ foot} = \frac{45 \text{ ft}^3}{\text{Linear Foot}}$$

$$\frac{\text{Weight of MgO}}{\text{Linear Ft.}} = 45 \text{ ft}^3 \times \frac{89 \text{ lbs}}{\text{ft}^3} = \mathbf{\frac{4{,}005 \text{ lbs}}{\text{Linear Ft.}}}$$

** DOE assumed 4,000 lbs/linear ft. in Chapter 3

Weight of MgO in Repository due to super sacks

$$\frac{4{,}000 \text{ lbs}}{\text{Liner ft.}} \times \frac{3{,}700 \text{ linear ft.}}{\text{panel}} = \frac{14{,}800{,}000 \text{ lbs}}{\text{panel}}$$

$$\frac{14{,}800{,}000 \text{ lbs.}}{2{,}000 \text{ lbs/ton}} = 7{,}400 \text{ tons per panel} \times 10 \text{ panels} = 74{,}000 \text{ tons}$$

74,000 Tons of MgO can be placed in the repository in super sacks

** DOE assumed 7,400 tons/panel x 10 panels or 74,000 tons.

Amount of MgO in Mini Sacks

Along Ribs of Disposal Rooms, stacked 3 wide and 4 high on both sides of waste sacks.

Each sack is 6 inches in diameter = 0.5 ft.

$$\frac{\pi d^2}{4} = \text{Area of circle} = \frac{3.14\,(0.5)^2}{4} = \frac{0.196\ \text{ft}^2}{\text{per sack}}$$

In cross-section of the room - there are 24 sacks.

$$24\ \text{sacks} \times \frac{0.196\ \text{ft}^2}{\text{sack}} = 4.71\ \text{ft}^2 \text{ of MgO in a cross section slice of room.}$$

$$\frac{\text{Volume of room}}{\text{Linear ft.}} = 4.71\ \text{ft}^2 \times 1\ \text{ft} = \frac{\mathbf{4.71\ ft^3}}{\mathbf{Linear\ ft.}}$$

Density of MgO in Mini Sacks

mini sacks are $0.196\ \text{ft}^2 \times \frac{34\ \text{inches long}}{12\ \text{inches/ft.}}$ = **$0.196\ \text{ft}^2 \times 2.83\ \text{ft} = 0.555\ \text{ft}^3$**

mini sacks weigh 25 lbs. Density = $\frac{25\ \text{lbs.}}{0.555\ \text{ft}^3} = \frac{45\ \text{lbs.}}{\text{ft}^3}$

* $$\frac{\text{weight}}{\text{Linear ft.}} = \frac{45\ \text{lbs.}}{\text{ft}^3} \times \frac{4.71\ \text{ft}^3}{\text{Linear ft.}} = \frac{\mathbf{212\ lbs.}}{\mathbf{Linear\ ft.}}$$

This is approximately 2 times the amount estimated by DOE (100 lbs./Linear ft).

** It is likely that DOE’s calculations did not take into account the fact that mini sacks would be placed on both sides of the waste stacks.

$$\frac{\text{Weight of MgO}}{\text{Panel}} = \frac{212\ \text{lbs}}{\text{Linear ft.}} \times \frac{3{,}700\ \text{Liner ft.}}{\text{Panel}} = \frac{784{,}400\ \text{lbs.}}{\text{Panel}}$$

$\frac{784{,}400\ \text{lbs}}{2{,}000\ \text{lbs/ton}} = \frac{392\ \text{tons}}{\text{Panel}} \times 10\ \text{panels} =$ 3,922 tons in repository due to mini sacks along Ribs.

This closely matches DOE’s number.

<u>Amount of MgO in Mini sacks Between Waste Containers</u>

- Six mini sacks per 7 pack of containers or per SWB.

- From Part B Permit Application:

  There will be a maximum of 85,000 drum equivalents per panel.

$$\frac{\text{85,000 drum equivalents}}{\text{7 drums / 7 pack}} = \textbf{12,142 7 packs per panel}$$

DOE in Chapter 3.3.3 of the CCA assumed <u>10,836</u> 7 packs per panel.

Weight of MgO in mini sacks = 25 lbs
There are 6 mini sacks per 7 pack of drums
There will be 12,000 7 packs per panel

$$25 \text{ lbs} \times 6 \times 12{,}000 = \frac{\text{1,800,000 lbs of MgO}}{\text{Panel}}$$

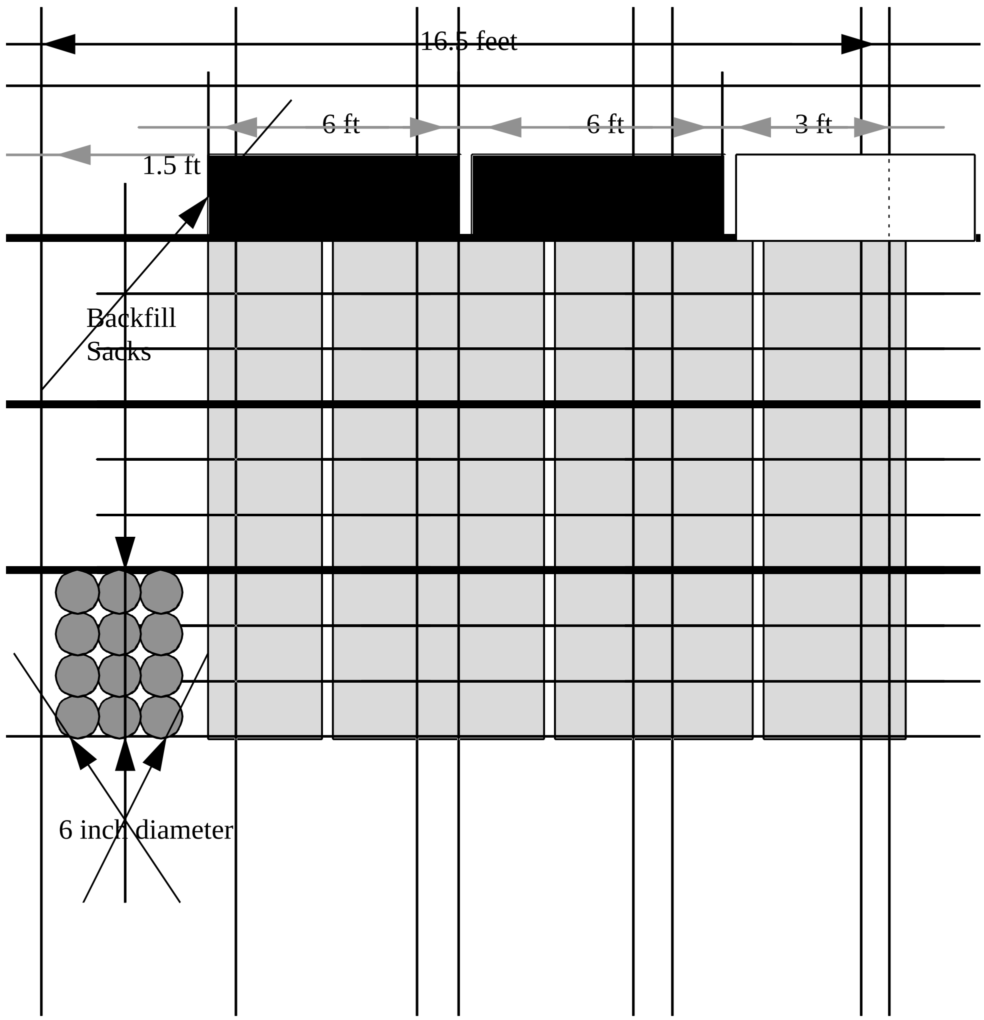
$$\frac{\textbf{1,800,000 lbs}}{\textbf{2,000 lbs/tons}} = \frac{\textbf{900 tons}}{\textbf{Panel}} \times \textbf{10} = \textbf{9,000 tons of MgO in Repository}$$

DOE assumed $\frac{\text{800 tons}}{\text{Panel}}$ or $\frac{\text{8,000 tons}}{\text{Repository}}$

<u>Total Calculated Weight of MgO that can be Accommodated in the Repository</u>

Super sacks	**=**	**74,000 Tons**
Mini sacks along Ribs	**=**	**3,920 Tons**
Mini sacks between waste containers	**=**	**9,000 Tons**
Total Approximately	**=**	**86,920 Tons of MgO can be placed in Repository**

This calculated value is higher than the 85,600 tons of MgO claimed by DOE on page 3-34 of the CCA.



Room Cross Section Showing the Position of Backfill Sacks