CARD No. 33
Consideration of Drilling Events in Performance Assessments

33.A.1 BACKGROUND

The radioactive waste disposal regulations at 40 CFR Part 191 include requirements for the containment of radionuclides in a disposal system. The containment requirements at Section 191.13 specify that releases from a disposal system to the accessible environment must not exceed the release limits set forth in Appendix A, Table 1 of 40 CFR Part 191. Assessment of the likelihood that the WIPP will meet the Appendix A release limits is conducted through the use of a process known as "performance assessment" (PA). The WIPP PA essentially consists of a series of computer simulations that attempt to describe the physical attributes of the repository (site, geology, waste forms and quantities, engineered features) in a manner that captures the behaviors and interactions among its various components. The results of the simulations show the potential releases of radioactive materials from the disposal system to the accessible environment over the 10,000 year regulatory time frame. The PA must include both natural and man-made processes and events which have an effect on the disposal system (61 FR 5228). Section 194.33, "Consideration of drilling events in performance assessments," sets forth specific requirements for incorporation of human-initiated drilling events in the PA.

Drilling is incorporated in the PA as a single event or combinations of events based upon different scenarios. Drilling rates and activities are key to the calculation of releases, which are represented as complementary cumulative distribution functions (CCDFs). For more information on CCDFs and the results of the performance assessment, see the discussion of Section 194.34(a) in **CARD 34—Results of Performance Assessments**. Deep and shallow drilling rates and related activities directly affect the cumulative potential for contaminant releases to the surface or to subsurface geologic units. Drilling in the near future within the Delaware Basin will most likely be for oil and gas exploration/exploitation, which constitutes a deep drilling event. Shallow drilling may occur for other resources (e.g., water). For information on the natural and man-made events that were considered in the scope of the performance assessment, see the discussion of Section 194.32 (a) and (c) in **CARD 32—Scope of Performance Assessments**. For information on how selected features, events and processes were incorporated into models and computer codes, see the discussion of Section 194.23(a)(1) and (a)(3)(i) in **CARD 23—Models and Computer Codes**.

33.A.2 REQUIREMENT

(a) "Performance assessments shall examine deep drilling and shallow drilling that may potentially affect the disposal system during the regulatory time frame."

33.A.3 ABSTRACT

Section 194.33 requires DOE to evaluate and document the effects of deep and shallow drilling on the disposal system in the PA. In conducting its analysis, DOE must incorporate assumptions specified in the final compliance criteria regarding timing and duration of drilling, frequency of drilling, drilling practices and technology, and the effects of natural processes on boreholes.

Of the drilling-related activities present in the Delaware Basin and potentially near the WIPP, DOE determined that oil and gas exploration/exploitation, water, and potash exploration are the principal human-initiated activities that must be considered in the PA. Drilling was assumed to occur throughout the 10,000 year regulatory time period, although at lower drilling rates for the first 700 years (refer to Section 33.C.1 of this CARD). Activities other than deep and shallow drilling are not part of this requirement. See the discussion of Sections 194.32(b) and (c) in **CARD 32—Scope of Performance Assessments** for other features, events and processes considered in the performance assessment.

DOE considered three different combinations of deep drilling as part of the PA, referred to as E1, E2, and E1E2:

- The E1 Scenario—one or more boreholes penetrate a Castile brine reservoir and also intersect a repository panel.

- The E2 Scenario—one or more boreholes intersect a repository panel.

- The E1E2 Scenario—multiple penetrations of waste panels by boreholes of the E1 or E2 type, at many possible combinations of intrusions times, locations, and E1 or E2 drilling events.

No combinations of shallow drilling events were considered by DOE, because DOE screened shallow drilling effects from consideration in PA.

DOE also presented information on borehole sizes and depths (Appendix DEL.5), as well as the impacts of borehole installation on radionuclide migration and transport via cuttings, cavings, spallings, and direct brine release. DOE concluded that the CCA contained sufficient information on deep and shallow drilling methods and appropriately considered the effects of deep and shallow drilling on the WIPP disposal system.

EPA examined the CCA to determine if DOE sufficiently evaluated deep and shallow drilling practices in the Delaware Basin and identified representative drilling methodologies. EPA also examined the cavings, cuttings, spallings, and direct brine release mechanisms associated with drilling to determine if they were adequately addressed in the PA. Due to concerns regarding the spallings model raised by EPA and DOE's Conceptual Model Peer Review Panel, EPA performed an independent assessment of spallings releases to determine the factors that influence particle release by the spallings process, and the maximum particle size that could escape from the WIPP under different downhole pressure scenarios. EPA's analysis used off-the-shelf computer models that evaluated particle movement up a borehole annulus, and EPA found that the DOE's conclusions regarding maximum quantity of material that could be removed during a blowout event to be appropriate.

33.A.4 COMPLIANCE REVIEW CRITERIA

The final compliance criteria of 40 CFR Part 194 require that DOE consider in the PA both deep and shallow drilling events that could affect the WIPP during the regulatory time frame. As stated in the Compliance Application Guidance for 40 CFR Part 194 (CAG, p. 48), EPA also expected the compliance application to:

- Discuss how deep drilling is conducted for each resource.
- Discuss how shallow drilling is conducted for each resource.
- Demonstrate that boreholes drilled after closure of the disposal system were evaluated for their effect on the properties of the disposal system, and show the manner in which they were evaluated.

In addition, EPA expected the CCA to explain how drilling may affect the WIPP disposal system; specifically, the impact that drilling would have on pressurization of the WIPP, brine/fluid removal, and circulation of brine within the panels. Review of this second assessment is discussed in this CARD, but is also specifically examined in the context of conceptual models and representation of these models in computer codes. See the discussion of Section 194.23(a) in **CARD 23—Models and Computer Codes** for additional review criteria pertaining to the impact of drilling on the PA.

33.A.5 DOE METHODOLOGY AND CONCLUSIONS

DOE identified the following drilling-related activities as being present in the Delaware Basin and potentially near the WIPP (Appendix DEL.5, Tables DEL-3 through DEL-7):

- Oil/Gas exploration/exploitation and extraction, including enhanced oil recovery (shallow and deep drilling).
- Potash exploration/exploitation (shallow and deep drilling).
- Fluid injection related to oil/gas production (deep drilling).
- Sulfur coreholes (deep and shallow drilling).
- Hydrocarbon (gas) storage in geologic reservoirs, gas reinjection (deep drilling).
- Brine wells for solution mining (shallow drilling).
- Water supply wells (shallow drilling).
- Geothermal resources (deep drilling).

In Chapter 6.2.5 of the CCA, DOE identified oil and gas exploration/exploitation and water and potash exploration as the principal human activities that must be considered within the PA. The remaining human initiated activities—such as exploration for geothermal energy, water supplies, and sulfur and brine extraction (solution mining)—were eliminated based upon low probability, low consequence, or for regulatory reasons. See the discussion of Section 194.32(b) in **CARD 32—Scope of Performance Assessments** for additional information pertaining to resource determination, evaluation, and screening.

Deep drilling is defined by EPA as events that terminate 2,150 feet or more below ground surface, while shallow drilling events terminate no deeper than 2,150 feet below ground surface (Section 194.2). DOE provided information on the drilling methodologies for deep and shallow drilling related to exploration/exploitation of resources.

<u>Deep Drilling Methods</u>

DOE provided a description of well drilling, plugging, and abandonment practices typically followed in the Delaware Basin in Appendix DEL.5 (pp. DEL-26 to DEL-46). Chapter IX of NMBMMR 1995 (pp. IX-1 to IX-69) included a discussion of drilling targets and practices, with typical casing designs presented in Appendix DEL (Figure DEL-13). The typical operation sequence for well installation was presented as Appendix DEL, Attachment 1 (Delaware Basin). Oil and gas exploration, exploitation, and production comprise 99 percent of the deep boreholes in the Delaware Basin, with the remainder being sulfur, potash, and stratigraphic test boreholes (Appendix DEL, Table DEL-4).

DOE provided extensive information pertaining to the deep drilling process, from acquisition of leases to well completion and abandonment (Appendix DEL.6.1, pp. DEL- 47 to DEL.5.1). In the area near the WIPP site, deep drilling typically terminates between approximately 5,000 to 15,400 feet (2,134 to 4,695 meters) below ground surface. DOE stated that mud rotary drilling is the typical drilling method used in the Delaware Basin.

DOE provided the following summary of deep drilling activities in Appendix DEL.5.1. The drilling rig is positioned and leveled then drilling begins. The rig typically drills a series of boreholes, each decreasing in diameter with depth and lined with cement and steel (Appendix DEL, Section 5.1.8 and DEL Attachment 1, pp. 1-3). Figure DEL-13 shows a cross-section of cement and casing in a typical deep well. The typical well completion casing could include up to three different casings installed in the same location, including surface (which isolates the borehole from uppermost water-bearing units); intermediate (which cases the borehole through the salt-bearing units where the WIPP is located); and innermost, or longstring (which is installed down to the interval that the oil and/or gas occurs in, below the salt beds).

Deep wells are usually drilled so that the bottom of the borehole and top of the borehole are vertically aligned. However, drillers may also intentionally drill a deviated borehole when, for example, surface features precluded the installation of a vertical borehole. In this instance, the borehole deviates from vertical and the bottom hole survey coordinates can be significantly different from the surface coordinates (Appendix DEL5.1.5). However, while directional drilling can occur, it is not typical oil field practice, particularly in the Delaware Basin. DOE shows in

Plate DMP-7 that deviated drilling has occurred near the WIPP controlled area to access oil/gas reserves.

Shallow Drilling Methods

DOE discussed shallow drilling methodologies in Appendices DEL 5.2 (potash coreholes) and 5.3 (water wells). Although shallow drilling for hydrocarbons, sulfur, and brine extraction (solution mining) also occur, DOE did not explicitly discuss drilling methodologies for hydrocarbons and brine extraction (solution mining) because they are comparable to that for deep drilling, while drilling methodologies for sulfur are comparable to those for potash drilling. DOE indicated that potash coreholes are drilled to locate potash reserves, typically using conventional core drilling rigs (p. DEL-41). When a corehole has been drilled and the core extracted, it is usually abandoned after being filled with cement from the bottom to ground surface.

DOE indicated in Appendix 5.3 (pp. DEL-41 to DEL-42) that drilling for water wells is usually accomplished using rotary drilling rigs or a cable tool, and that wells are drilled using mud or air as the drilling fluid. When water is hit during drilling with either air or mud, the mud pit (which is now filled with water, in the case of air drilling) receives cuttings from the hole. PVC or steel casing is installed to the surface; water wells that are greater than 500 feet deep are completed with steel casing. When water wells are abandoned, the Office of the State Engineer supervises the plugging activities.

Evaluation of Borehole Properties

DOE presented information pertinent to typical borehole sizes and depths in Appendix DEL.5 (pp. DEL-26 to DEL-42). These borehole properties are discussed as having the potential to affect the disposal system through radionuclide migration and transport as detailed below. DOE concluded in Chapters 6.5.3 and 6.5.5 of the CCA that actinides expelled from the WIPP by these release mechanisms would not exceed EPA release limits. DOE's actinide release evaluation methodology is discussed more thoroughly in Section 194.23(c) in **CARD 23—Models and Computer Codes** and Section 194.34(a) in **CARD 34—Results of Performance Assessments**. In addition, DOE indicated that the properties and degradation history of borehole plugging material are very important to the containment capabilities of the WIPP (Chapter 6.4.7.2, pp. 6-156 to 6-161). Borehole degradation properties are discussed further in Section 194.33(c)(2) of this CARD.

Future Drilling Events Considered in the Performance Assessment

Future shallow drilling events were not considered in the performance assessment because DOE found them to be of low consequence to the PA calculations. For further discussion on the screening process and scope of the performance assessment, refer to Section 194.32(e) in **CARD 32—Scope of Performance Assessments**.

DOE considered three different combinations of drilling events, referred to as E1, E2, and E1E2:

- The E1 Scenario (Figure 6-11 of the CCA): one or more boreholes penetrate a Castile brine reservoir and also intersect a repository panel.

- The E2 Scenario (Figure 6-10 of the CCA): one or more boreholes intersect a repository panel.

- The E1E2 Scenario (Figure 6-12 of the CCA): multiple penetrations of the same waste panel by boreholes of the E1 or E2 type, at many possible combinations of intrusions times, locations, and E1 or E2 drilling events.

DOE identified four potential release mechanisms from the intrusion scenarios listed above. Intrusions on the disposal system could affect radionuclide migration and transport via:

- Cuttings—material intersected by a rotary drilling bit.

- Cavings—material eroded from a borehole wall during drilling.

- Spallings—solid material carried into the borehole during rapid depressurization of the waste disposal region.

- Direct Brine Releases—contaminated brine that may flow to the surface during drilling or through a borehole after it is abandoned.

- Long-Term Releases Following Drilling.

DOE modeled the occurrence of future drilling events through a random sampling methodology described in Appendix CCDF GF, Sections 2 and 3. Uncertainty relative to the time and location of drilling is stochastic (i.e., derived from random processes, without knowledge about the future). The random drilling rate as it pertains to drilling events is discussed under Section 33.C of this CARD. DOE incorporated drilling into the PA by repeatedly generating independent sequences of drilling-related events that could occur at the WIPP over the next 10,000 years. The defining parameters for the occurrence of future drilling events include not only the interval of time between drilling events and the location of drilling intrusions but also the following four parameters:

- Activity of waste penetrated by each drilling intrusion (not related to deep or shallow drilling, but included for completeness).

- Plug configuration in the borehole.

- Penetration of the Castile brine reservoir.

- Occurrence of mining (not related to deep or shallow drilling, but included for completeness).

DOE used random sampling from these distributions to calculate 10,000 different futures for the WIPP, expressed as CCDFs (Chapter 6.4.13.9). For additional information regarding DOE's selection and implementation of these parameters, see the discussion of Section 194.23(a)(1) and (2) in **CARD 23—Models and Computer Codes**. For additional information regarding construction of CCDFs, see the discussion of Section 194.34(a) in **CARD 34—Results of Performance Assessments**.

DOE concluded that the CCA contains sufficient information on deep and shallow drilling methods and their effects on the disposal system (Chapter 6.4.12).

33.A.6 EPA COMPLIANCE REVIEW

EPA reviewed the information presented by DOE in Chapter 6.2, Appendix DEL, and Chapter IX of NMBMMR 1995 to determine how extensively deep and shallow drilling was considered and whether the information provided was sufficiently comprehensive, accurate, and correctly calculated. EPA examined the list of references presented in the CCA relative to drilling (CCA References #230, #357, #664, and #667) and conducted a literature search for purposes of evaluating the fluid injection study (EPA 1998a). EPA determined that DOE's scrutiny of resources to assess deep and shallow drilling practices and frequencies was comprehensive. Refer to Section 194.32(a) and(c) in **CARD 32—Scope of Performance Assessments** for additional discussion of resource assessments. EPA also determined that DOE's conclusions regarding representative drilling methodologies in the Delaware Basin are consistent with available data. DOE's treatment of abandoned borehole properties and borehole plugging is discussed in Sections 194.33(c)(1) and (c)(2) of this CARD.

DOE did not identify air drilling as a current practice in the Delaware Basin and therefore did not include it in the PA. During the public comment period on EPA's proposed certification, commenters raised the issue that both air and mud drilling may occur in the Delaware Basin and that releases from air drilling could be greater than from mud drilling and potentially cause WIPP to fail the numerical containment requirements at 40 CFR 191.13. In response to issues raised by commenters, EPA examined the air drilling issue from several perspectives and documented its findings in the Technical Support Document *EPA's Analysis of Air Drilling at WIPP* (EPA 1998b) and in Response to Comments, Section 8 (Docket A-93-02, V-C-1). The results of EPA's analysis showed that air drilling is not common practice in the Delaware Basin. Also, even if air drilling were to occur, the volume of spalled material released is within the range presented in the CCA

EPA evaluated the drilling-related information in the CCA to determine how both deep and shallow drilling affect the WIPP disposal system, including but not limited to pressurization of the WIPP, brine/fluid removal, and circulation of brine within the panels. EPA concluded that DOE appropriately excluded shallow drilling from PA based upon low consequence (see Section 33.E.5 below for additional discussion of EPA's evaluation of shallow drilling exclusion). EPA also concluded that DOE appropriately simplified the intrusion scenarios to include the three types of drilling occurrences that, alone or in combination, are representative of potential future intrusion events into the WIPP. Detailed discussion of the intrusion scenarios and specific impacts that drilling has on the disposal system relative to degassing, assumed effects on panel seals, etc., are included under Section 194.32 (a) and (c) in **CARD 32—Scope of Performance Assessments** and Section 194.23(a)(1) in **CARD 23—Models and Computer Codes**.

Since EPA expected the CCA to explain how drilling may affect the WIPP disposal system, EPA also examined the impact that deep drilling would have on cavings, cuttings, spallings, and direct brine release mechanisms that are associated with drilling. Although EPA concluded that the cuttings, cavings, and direct brine release mechanisms are adequately assessed in the PA, EPA found that the spallings conceptual model was inadequate. This conclusion was also reached by DOE's Conceptual Model Peer Review Panel (Appendix PEER.1). In its Third Supplementary Peer Review Report, the Conceptual Models Peer Review Panel indicated that the results from spallings model are reasonable for use in PA and that they may overestimate releases (DOE 1997c, p. 17). EPA agrees that DOE's spallings model results are reasonable for use in PA. See the discussion of Section 194.23(a) in **CARD 23—Models and Computer Codes** for an explanation of why EPA deemed it appropriate to accept the spallings model results.

EPA examined the sampled parameters associated with the sequences of future events (i.e. E1, E2, and E1E2) that were calculated by DOE using the computer code CCDFGF, and concluded that the CCDF construction methodology was appropriate. However, EPA questioned DOE's Castile brine pocket parameterization and required modeling for the PA Verification Test (PAVT) to incorporate Castile brine pocket parameter changes. The PAVT confirmed that increasing Castile brine volume also increases potential releases. However, PAVT releases were still well below the EPA standard (DOE 1997a, 1997b). See also Section 194.23(a) in **CARD 23—Models and Computer Codes**, Section 194.14(a) in **CARD 14—Content of Compliance Certification Application**, and Section 194.34(a) in **CARD 34—Results of Performance Assessments**.

33.B.1 REQUIREMENT

(b) "The following assumptions and process shall be used in assessing the likelihood and consequences of drilling events, and the results of such process shall be documented in any compliance application:

(1) Inadvertent and intermittent intrusion by drilling for resources (other than those resources provided by the waste in the disposal system or engineered barriers designed to isolate such waste) is the most severe human intrusion scenario."

33.B.2 ABSTRACT

To comply with Section 194.33, DOE must evaluate all resources potentially involving drilling and must consider inadvertent and intermittent drilling to be the most severe human intrusion scenario. DOE identified three scenarios for human intrusion (E1, E2, E1E2) for which cumulative radionuclide releases are calculated, assuming different intrusion events and/or combinations of events. DOE determined that significant release of radionuclides from the disposal system can occur through only five drilling-related mechanisms: cuttings, cavings, spallings, direct brine releases, and long-term brine releases.

EPA evaluated resources identified by DOE to determine whether all resources were considered, and whether the DOE considered inadvertent and intermittent drilling the most severe human intrusion scenarios associated with drilling.

33.B.3 COMPLIANCE REVIEW CRITERIA

DOE must evaluate the full range of resources that involve drilling and must consider inadvertent and intermittent drilling as the most severe human intrusion scenarios. Specifically, DOE must identify drilling methodologies and possible effects that drilling could have on releases in order to fully address the intrusion scenarios in the PA. EPA expected any compliance application to demonstrate that exploratory and development wells were included in the analysis of inadvertent and intermittent intrusion by drilling for resources and the manner in which they were evaluated (CAG, p. 48). See Section 194.14(a) in **CARD 14-- Content of Compliance Application**, Section 194.32(a) in **CARD 32—Scope of Performance Assessments**, and Section 194.23(a) in **CARD 23—Models and Computer Codes** for criteria pertaining to the identification and evaluation of resources and the determination of intrusion scenarios as part of conceptual and computer model development.

33.B.4 DOE METHODOLOGY AND CONCLUSIONS

In regard to Section 194.33(b)(1), DOE concluded that inadvertent and intermittent drilling is the most severe human intrusion scenario and included it in the PA (e.g., Chapter 6.0.2.3, p. 6-5). All known wells, including hydrocarbon borehole exploratory and development wells were included in the DOE analyses. Appendices DEL (Section 7.3) and SCR.3 include DOE's analyses of drilling events in the WIPP area. Specifically, DOE identified scenarios for human intrusion and calculated cumulative radionuclide releases assuming different intrusion events and combinations of events (Chapter 6, Sections 6.2 and 6.3). See Section 194.23(c) in **CARD 23—Models and Computer Codes**, Sections 194.32(a) and (c) in **CARD 32—Scope of Performance Assessments,** and Section 194.34(a) in **CARD 34—Results of Performance Assessments** for additional information regarding DOE's methodologies and results related to inclusion of drilling intrusions into the PA.

In Table DEL-3 of Appendix DEL, DOE presents a listing of the types and number of boreholes encountered within the Delaware Basin. The hydrocarbon borehole category is broken down into seven individual types including oil, gas, oil/gas, dry, abandoned, injection, and service. Both exploratory wells (boreholes drilled to locate hydrocarbons) and developmental wells (boreholes drilled to exploit known reserves) are likely included within each of the categories listed in the table. For example, if a well was drilled to explore for natural gas or a well was drilled with the intention to extract more gas by secondary recovery method, in this classification both will be classified as gas wells.

By means of the evaluation of borehole types and standard well installation practices, DOE determined that significant release of radionuclides from the disposal system can occur through only five drilling-related mechanisms for both exploratory and development wells (Chapter 6.1.2.3, pp. 6-5 to 6-11, and Chapter 6.5.3, p. 6-216):

- ♦ Cuttings of material generated when waste is intersected by a drill bit.
- ♦ Cavings from a borehole wall displaced by drilling that causes stress failure of the waste material.
- ♦ Spallings carried into the borehole upon intersection and depressurization of the waste-disposal region.
- ♦ Direct brine releases, which include contaminated brine that may flow to the surface during drilling.
- ♦ Long-term brine releases, including contaminated brine that may flow through a borehole and into overlying geologic units after abandonment.

The result of each of the first three drilling-related mechanisms is the potential release of solid waste material to ground surface during well installation. Direct brine release has the potential for dissolved actinide transport to ground surface. DOE identified long-term brine release as a potential scenario for dissolved actinide transport to the Culebra and subsequent potential for release.

33.B.5 EPA COMPLIANCE REVIEW

EPA evaluated resources considered by DOE when developing human intrusion scenarios. EPA examined resources identified by the DOE (Chapter 2.3.1, pp. 2-146 to 2-156, Appendix GCR, and Appendix DEL.4) and compared them with potential resources available in the area. EPA reviewed DOE's data pertaining to wells associated with the exploration and development related to these resources (DEL.7) and concluded that DOE considered the full spectrum of inadvertent and intermittent human intrusion scenarios possible in the Delaware Basin and incorporated them into the PA.

EPA found that DOE adequately demonstrated that it had considered inadvertent and intermittent drilling into or through the repository as the most severe human intrusion scenario. EPA concluded that DOE appropriately evaluated drilling in the Delaware Basin for inclusion in PA and adequately considered the drilling locations, depths, completion intervals, practices, history, and occurrence of resources. Finally, EPA concluded that exploratory and development wells were appropriately included in DOE's analysis.

33.C.1 REQUIREMENT

(b) "The following assumptions and process shall be used in assessing the likelihood and consequences of drilling events, and the results of such process shall be documented in any compliance application:

(2) In performance assessments, drilling events shall be assumed to occur in the Delaware Basin at random intervals in time and space during the regulatory time frame."

33.C.2 ABSTRACT

EPA expected the application to provide documentation that drilling events were assumed to occur in the Delaware Basin at random intervals in time and space during the regulatory time frame, to discuss the methods and assumptions and their application to the drilling issue, and to discuss methods used to implement this assumption in PA.

EPA reviewed the CCA to assess how DOE evaluated random drilling in the PA during the regulatory time frame. In Chapter 6.4.12.2, DOE presented the number and timing of intrusions, which were developed using a Poisson process to calculate probabilistically the time period that elapses between intrusions, assuming a constant rate of 46.8 boreholes per square kilometer in 10,000 years (Appendix DEL, p. 81). DOE concluded that the most likely number of intrusions into a waste panel is 5 over 10,000 years, occurring with a probability of 0.1715 (the probability that zero intrusions will occur over 10,000 years is 0.0041) and that the largest number of intrusions that can occur is 14, occurring with a probability of 0.0011 (Chapter 6.4.12.2, p. 183).

DOE designated intrusion borehole locations based on a random assignment of a calculated intrusion among 144 discrete regions in the repository. DOE concluded that a borehole has a 20 percent probability of encountering excavated Salado (i.e., waste-filled repository or experimental regions), and an 80 percent chance of encountering unexcavated Salado.

33.C.3 COMPLIANCE REVIEW CRITERIA

To fulfill the requirements of Section 194.33(b)(2), DOE must identify deep and shallow drilling activities and justify how drilling rates and locations were implemented in the PA. As stated in the CAG (p. 48), EPA expected any compliance application to:

- Provide documentation that drilling events were assumed to occur in the Delaware Basin at random intervals in time and space during the regulatory time frame.
- Discuss the method and assumptions (e.g., Poison process) and their application to the drilling issue.

33.C.4 DOE METHODOLOGY AND CONCLUSIONS

DOE established the rate of future drilling as 46.8 boreholes per square kilometer per 10,000 years (Chapter 6.0.2.3, p. 6-5). In accordance with Section 194.33(c)(1), DOE assumed that current drilling practices will continue unchanged into the future.

DOE discussed the drilling rate assumptions in Chapter 6.0.2.3 (p. 6-5) and Appendix DEL.7 (pp. 80-84). DOE assumed random drilling events, with respect to both location and time, allocated among three time periods:

- An uncontrolled period (700 to 10,000 years).

- A period when passive institutional controls are effective (100 to 700 years), for which the drilling rate is two orders of magnitude lower than the rate experienced during the uncontrolled period.

- A period when institutional controls are active (0 to 100 years), during which no intrusions will occur.

In Chapter 6.4.12.2 (pp. 182-183), DOE outlined the process by which the random drilling rate assumptions were implemented. The number and time of intrusions were represented using a Poisson process to calculate the time period that elapsed between intrusions, based on historical drilling activity and assuming a rate of 46.8 boreholes per square kilometer (for the 700 to 10,000 year period), and 23.4 boreholes per square kilometer for the period when passive institutional controls are effective (100 to 700 years). Specifically, DOE stated in Chapter 6.4.12.2 (p. 182) that both the number and time of intrusions are determined sequentially by sampling from a cumulative distribution function that describes the time elapsed between a given intrusion and the next intrusion. The potential time between intrusions varied from 0 to 9,900 years. Using this process, DOE concluded that the most likely number of intrusions into a waste panel is 5, occurring with a probability of 0.1715. Zero intrusions occurred with a probability of 0.0041. DOE indicated that the largest number of intrusions that can occur is 14, with a probability of 0.0011 (Chapter 6.4.12.2, p. 183).

DOE assigned drilling rates based on basin-wide borehole information. The drilling rate calculated for the basin was then applied to the area of the repository by DOE randomly assigning intrusion borehole locations among 144 discrete regions in the repository. Each hypothetical intrusion was assumed to penetrate only one of the 144 blocks, and the probability of intersecting any given block was 1 in 144. Based on the ratio of excavated to undisturbed Salado in each grid block, DOE concluded that a borehole has a 20 percent probability of encountering excavated Salado (i.e., waste-filled repository or experimental regions) and an 80 percent chance of encountering unexcavated Salado (Chapter 6.4.12.3, p. 184).

DOE did not consider boreholes to be relevant to the potential for release outside the boundaries of the repository, and therefore only calculated locations that could potentially intrude the repository. Specific well locations in the remainder of the Delaware Basin were not calculated. Appendix CCDFGF presents details regarding how the probability of borehole intrusion scenarios was implemented in the construction of future realizations.

33.C.5 EPA Compliance Review

EPA reviewed DOE’s implementation of drilling rate and location assumptions and concluded that DOE used appropriate methodologies to derive drilling rates and locations. EPA determined that DOE adequately demonstrated that drilling events were assigned as occurring over random intervals of time and at random locations. EPA also reviewed DOE’s implementation of drilling assumptions and determined that the methodology employed by DOE in the calculations yields random drilling rate and location results. Use of Poisson distribution to project the time period that will elapse between intrusions is an acceptable approach. Division of the projected future into three distinct time periods was determined to be appropriately justified. EPA disallowed PA credit for passive institutional controls. Nonetheless, the PAVT calculations demonstrated that the effects of the proposed credits for active and passive institutional controls are insignificant and the PA results remain unaffected with or without the assigned credits (DOE 1997a, 1997b). See the discussion under Section 194.41(b) in **CARD 41—Active Institutional Controls** and Section 194.43(c) in **CARD 43—Passive Institutional Controls** for EPA's consideration of the basis of AICs and PICs credit. DOE's calculations of probability were implemented correctly. EPA's evaluation of the codes and DOE's utilization of 144 discrete regions in PA are discussed in Section 194.23(a) in **CARD 23—Models and Computer Codes**.

33.D.1 Requirement

(b) "The following assumptions and process shall be used in assessing the likelihood and consequences of drilling events, and the results of such process shall be documented in any compliance application:

(3) The frequency of deep drilling shall be calculated in the following manner:

(i) Identify deep drilling that has occurred for each resource in the Delaware Basin over the past 100 years prior to the time at which a compliance application is prepared.

(ii) The total rate of deep drilling shall be the sum of the rates of deep drilling for each resource."

33.D.2 Abstract

DOE must adequately characterize the frequency of deep drilling in the Delaware Basin by gathering standard industry practice information for all resource-related drilling in the Delaware Basin. The CCA must identify deep drilling resources, estimate the number of deep drilling events over the past 100 years, discuss deep drilling frequency, identify information sources, and specify the total rate of deep drilling.

DOE identified deep drilling that has occurred during the past 100 years for each resource in the Delaware Basin—including oil, gas, potash, and sulfur—and calculated the total rate of deep drilling to be the sum of the rates of for each resource. DOE calculated a deep drilling rate of 46.765 deep holes per square kilometer (0.39 square mile) over 10,000 years (Appendix DEL, p. 81).

EPA evaluated the CCA to determine the adequacy and accuracy of DOE's drilling rate calculations, supporting assumptions, and determinations.

33.D.3 Compliance Review Criteria

The CCA must adequately characterize the frequency of deep drilling in the Delaware Basin by gathering standard industry practice information for all resource-related drilling in the Delaware Basin. As stated in the CAG (p. 49), EPA expected the CCA to:

- Identify the resources for which deep drilling is used.
- Estimate the number of deep drilling events for each resource that have occurred over the past 100 years.
- Discuss the methodology used to calculate the frequency of the deep drilling rate.
- Identify the sources of information used to estimate the number of deep drilling events.
- Identify the total rate of deep drilling.

33.D.4 DOE Methodology and Conclusions

In Sections 7.3 and 7.4 of Appendix DEL, DOE identified deep drilling that has occurred during the past 100 years for each resource known to occur in the Delaware Basin (hydrocarbons, potash and sulfur) and calculated the total rate of deep drilling as the sum of the rates for each resource (Appendix DEL 4.2). DOE obtained information on deep drilling from two industry sources, Petroleum Information and the Midland Map Company, based on original records compiled by the New Mexico Oil Conservation Division (NMOCD) and the Railroad Commission of Texas Oil and Gas Division. Approximately 99 percent of the deep boreholes in the Delaware Basin were related to hydrocarbon exploration and exploitation. Industry database information regarding the number of deep drilling events/resource and information sources is presented in Tables DEL-3, DEL-4, DEL-6, and DEL-7.

DOE determined that field validation of original data is not feasible because of the extremely large area involved (approximately 23,077 square kilometers comprise the Delaware Basin) and the difficulties associated with comparing NMOCD and Bureau of Land Management (BLM) records against private company records. Nevertheless, DOE cited three reasons for confidence in its data (Appendix DEL, p. 80):

- The data are accepted by industry as standard.
- Independent verification of database reliability by two industry sources (Whitestar Corporation and Petroleum Information Corporation).
- Legal penalties, for which operators are liable for errors of omission or failure to comply with operations regulations (Appendix DEL.6), would provide operators with the incentive to file accurate information.

DOE stated that drilling for deep resources near the boundary of the WIPP site since 1974 has demonstrated that profitable quantities of oil and gas resources are present near, and likely beneath, the WIPP site. Figure DEL-6 shows oil and gas wells in the area surrounding the WIPP site.

DOE stated that three hydrocarbon exploration/exploitation deep wells have been drilled in the WIPP land withdrawal area (Appendix DEL 4.2.3, p. DEL-20). Of these, two were drilled prior to 1982, and were later plugged and abandoned. The third well, drilled in 1982, is currently producing natural gas from a sandstone reservoir of Pennsylvanian Atokan age. Condemnation actions 77-071-B and 77-776-B by the United States currently withdraws all of Section 31, which is approximately 2 miles to the southwest of the repository, from the surface to a depth of 6,000 feet (1,829 meters). Leaseholders have mineral rights below 6,000 feet (1,829 meters), which would be accessed by directional drilling from a surface location outside of Section 31.

Appendix DEL, Section 7.4 (p. DEL-81), presents DOE's calculated drilling rate in the Delaware Basin. The drilling rate was calculated using deep boreholes drilled for hydrocarbons, sulfur, and potash as well as for stratigraphic test holes as derived from industry standard data described earlier in this CARD (not including those test holes created during the WIPP investigation) (Appendix DEL, Table DEL-4). DOE calculated a rate of 46.765 deep holes per square kilometer (0.39 square mile) over 10,000 years.

The CCA contains tables that show the specific drilling rates for each type of well and for each type of resource (pp. DEL-83 to DEL-83). Table 6-5 of Chapter 6 includes deep drilling events, and DOE used the drilling rates calculated from all available historical data as a basis for assigning future rates. These values and related calculation methods are shown in Table 6-7 of Appendix DEL. Reductions were made to these rates for active institutional controls (AICS) and passive institutional controls (PICS) credit in the DOE analysis. As discussed on p. 6-181, AICS were credited for completely preventing inadvertent human intrusion for the first 100 years following repository closure. PICS were credited with reducing inadvertent intrusion to 1 percent of the calculated level for the period from 100 to 700 years post-closure. For a discussion of the basis of AICs credit, see Section 194.41(a) in **CARD 41—Active Institutional Controls**. For a discussion of DOE's claim of PICs credit, see Section 194.43(c) in **CARD 43—Passive Institutional Controls**.

33.D.5 EPA Compliance Review

EPA examined the CCA to determine the adequacy and accuracy of drilling rate calculations presented by the DOE, as well as supporting assumptions and determinations. EPA examined the comprehensiveness and adequacy of deep drilling information and compared DOE data to information on standard industry practice that had been collected for the Delaware Basin. EPA checked DOE's calculations regarding deep drilling frequency for accuracy and compared them with EPA's calculations based upon an independently derived database (EPA 1998a).

EPA's review determined that DOE appropriately identified deep drilling that occurred in the Delaware Basin. The CCA identified resources for which deep drilling is used and estimated the number of drilling events that occurred over the past 100 years as 46.765 boreholes per square kilometers. EPA found that DOE's methodology was sufficiently explained and that DOE adequately documented sources of supporting information. EPA concluded that DOE's results for the total rate of deep drilling are consistent with available data. EPA disallowed credit for PICs. Therefore, DOE did not take credit for PICs in the PAVT calculations (DOE 1997a, 1997b). The results of the PAVT were comparable to the original CCA results in which PICs credit was employed; therefore, EPA concluded that the PICs credit was not significant to WIPP's compliance with the disposal standards.

EPA found that DOE's sources of information on deep drilling were reliable and that DOE's confidence in the industry database was appropriate, based on EPA's independent review of industry activity in the area (EPA 1998a). DOE identified all resources relevant to deep drilling, and well databases are understood to contain all well types possible in the area, including both exploratory and development wells.

Public comments on the proposed decision to certify WIPP raised questions about DOE's calculated deep drilling rate because commenters believed that the drilling rate used by DOE was too low with respect to current drilling rates. EPA concluded that the deep drilling rate used by DOE was consistent with the requirements of 40 CFR Part 194; see EPA's Response to Comments Document, Section 8 (Docket A-93-02, Item V-C-1).

33.E.1 REQUIREMENT

(b) "The following assumptions and process shall be used in assessing the likelihood and consequences of drilling events, and the results of such process shall be documented in any compliance application:

> (4) The frequency of shallow drilling shall be calculated in the following manner:
>
> (i) Identify shallow drilling that has occurred for each resource in the Delaware Basin over the past 100 years prior to the time at which a compliance application is prepared.
>
> (ii) The total rate of shallow drilling shall be the sum of the rates of shallow drilling for each resource.
>
> (iii) In considering the historical rate of all shallow drilling, the Department may, if justified, consider only the historical rate of shallow drilling for resources of similar type and quality to those in the controlled area."

33.E.2 ABSTRACT

The CCA must adequately and accurately characterize the frequency of shallow drilling within the Delaware Basin, as well as support all assumptions and determinations, particularly those that limit consideration of shallow drilling events based on the presence of resources of similar type and quantity found in the controlled area. Shallow drilling events were reported by DOE to include water wells, potash coreholes, sulfur coreholes, brine extraction (solution mining), and stratigraphic coreholes. DOE calculated a shallow drilling rate of 21.821 shallow holes per square kilometer (0.39 square mile), based upon the number of shallow water wells, potash coreholes, brine extraction (solution mining) wells, and stratigraphic coreholes (exclusive of stratigraphic coreholes installed during the WIPP investigation process).

EPA reviewed Appendices DEL, SCR, GCR, FAC, HYDRO, and other references (e.g., NMBMMR 1995) to determine if DOE appropriately identified shallow drilling resources and the number of drilling events for each resource over the past 100 years. EPA reviewed the CCA for information on how the frequency of shallow drilling was calculated, including information sources, and appropriately calculated this frequency. EPA did not collect an independent shallow well database for comparison with DOE's data because EPA concurred with DOE's screening of shallow drilling from PA calculations.

33.E.3 Compliance Review Criteria

The CCA must adequately characterize the frequency of shallow drilling in the Delaware Basin by gathering data collected on all drilling in the Delaware Basin for resources of type and quality similar to those in the WIPP controlled area. As stated in the CAG, EPA expected the compliance application to:

- Identify the resources for which shallow drilling is used.
- Estimate the number of shallow drilling events for each resource that has occurred over the past 100 years.
- Discuss the methodology used to calculate the frequency of the shallow drilling rate.
- Identify the sources of information used to estimate the number of shallow drilling events.
- Identify the total rate of shallow drilling.

If DOE considers only resources of similar type and quality to those in the controlled area, the compliance application should:

- Include a discussion of resources in the controlled area and their type and quality.
- Discuss the use of resources of similar type and quality in the Delaware Basin.
- List the sources used to estimate the type and quality of resources and the nature of the use of similar resources in the Delaware Basin.

If DOE does not limit consideration of shallow drilling to only resources of similar type and quality to those in the controlled area, the compliance application need not address the quality of the resources in the controlled area (CAG, pp. 49-50).

33.E.4 DOE METHODOLOGY AND CONCLUSIONS

DOE examined the resources present within the Delaware Basin and determined that the shallow resources identified in the Delaware Basin are water, potash, sulfur, oil/gas, and brine wells (salt water "wells") (Appendix DEL.4, Table DEL-5. Note: This table also presents stratigraphic and core test holes, but these apply to investigations associated with the five resources). DOE examined these resources and determined that no shallow oil or gas is present in the controlled area or near WIPP, and no minable sulfur reserves are present in the controlled area or near WIPP (p. DEL-81). DOE also examined the possibility of brine extraction (solution mining) but excluded it from consideration in PA based upon low consequence. DOE concluded that water and potash are potential resources within the controlled area but nevertheless included drilling for oil/gas, brine extraction (solution mining), and stratigraphic test holes (exclusive of those installed as part of the WIPP site characterization program) in its shallow drilling rate calculations.

DOE identified a total of 5,536 shallow boreholes that have been installed in the Delaware Basin, including those for sulfur coreholes (495 coreholes) but excluding those boreholes installed as part of the WIPP site characterization program (Appendix DEL, Table DEL-5, p. DEL-83). See Section 194.32(c) in **CARD 32—Scope of Performance Assessments** for more information regarding the evaluation of resources in the controlled area.

DOE's methodology for calculating shallow drilling rate was first to collect comprehensive information on shallow drilling in the Delaware Basin, including drilling for hydrocarbons, sulfur, potash, stratigraphic tests, water, and brine extraction (solution mining) wells (Appendix DEL, Table DEL-5). DOE stated that information regarding shallow drilling in the Delaware Basin was obtained from commercial and government sources. DOE collected water well data from a commercial database developed by Whitestar Corporation of Englewood, Colorado; potash well data from BLM records; and sulfur corehole data from a database developed jointly by Whitestar Corporation and Petroleum Information Corporation of Denver, Colorado (Tables DEL-3, DEL-4 and DEL-7). Sources used to determine the type and quality of resources include those used to determine the drilling rate.

DOE calculated the total rate of shallow drilling as the sum of the rates of shallow drilling for resources in the Delaware Basin of type and quality similar to those in the WIPP controlled area. DOE excluded consideration of the 495 sulfur drill holes when calculating the drilling rate, since no economically extractible sulphur is located within the WIPP land withdrawal area (Appendix DEL, pp. DEL-25 and DEL-81, and NMBMMR 1995). Also, DOE excluded consideration of shallow drill holes created as part of the WIPP site characterization efforts, on the basis of consistency with EPA guidance (Appendix DEL, p. DEL-81). However, DOE included drilling for oil/gas and brine solution mining in its rate calculations, even though DOE indicated that it was not necessary to do so. DOE calculated a shallow drilling rate over the past 100 years of 21.821 shallow holes per square kilometer (0.39 square mile) (Appendix DEL 7.4, p. 81). DOE presented the shallow drilling rate for each resource in Table DEL-5 (p. DEL-83). DOE indicated in a footnote to Table DEL-5 (p. DEL-83) that the number of shallow holes per square kilometer is calculated as follows:

$$\text{Drilling Rate} = \frac{(\text{Total \# of boreholes - Sulfur coreholes}) \times \text{Regulatory Period.}}{\text{Area of the Delaware Basin}} \times \frac{1}{100 \text{ yrs}}$$

$$= \frac{(5536\text{-}495)\ 10{,}000 \text{ yrs.}}{23102.1\text{km}^2} \times \frac{1}{100\text{yrs.}}$$

= 21.821 shallow holes per square kilometer or 0.39 square mile

DOE concluded in Appendix SCR that shallow drilling (Section SCR3.2, Table SCR-3) could be screened from PA based on low consequence. As a result, DOE did not include shallow drilling in its PA drilling rate calculations and did not include any reduction in shallow drilling rates during the active and passive institutional control periods.

33.E.5 EPA COMPLIANCE REVIEW

EPA reviewed Appendices DEL, SCR, GCR, FAC, HYDRO, and other references (e.g., NMBMMR 1995) and determined that DOE appropriately identified shallow drilling resources and the number of drilling events for each resource over the past 100 years. EPA concluded that DOE's exclusion of sulfur coreholes from drilling was consistent with geologic data indicating that sulfur resources are not present in the area. Also, DOE's exclusion of site-investigation coreholes is consistent with EPA guidance. DOE adequately discussed the basis for and calculation of the frequency of shallow drilling. EPA concluded that DOE properly calculated both the frequency of shallow drilling, using the historical rate of shallow drilling, and the sum of shallow drilling for all resources (whichever are used in the area, such as potash and water only).

EPA reviewed information in Chapter 6 and Appendix DEL, but did not collect an independent database for comparison with DOE's data because EPA concurred with DOE's screening of shallow drilling from PA calculations (as presented in Appendix SCR, Section SCR.3, and summarized in Table SCR-3). DOE stated that since shallow boreholes would not penetrate the repository, the effects of boreholes on repository performance, including hydraulic effects of drilling-induced flow (e.g., SCR 3.3.1.1.3, pp. 113-114), could be excluded due to low consequence. This exclusion precluded the need for a detailed evaluation of data used by DOE to determine shallow drilling rate, including whether DOE's rates included exploratory and development wells (although assessments included both). DOE stated, "The effects of future shallow drilling within the controlled area have been eliminated from performance assessment calculations on the basis of low consequence" (Chapter 6, p. 6-61). As such, the shallow drilling rate was not added to the deep drilling rate to obtain the total drilling rate used in the PA. See Section 194.32(a) in **CARD 32—Scope of Performance Assessments** for further discussion of DOE's screening of shallow drilling events from PA.

EPA noted that DOE took a combined approach relative to resources in the controlled area. That is, DOE considered all the resources present in the area in shallow drilling rate calculations. Only drilling for potash and water wells fall in the shallow category (less than 2,150 feet from the surface); thus, only these two resources were used in the calculation of shallow drilling rate for the controlled area. EPA concluded that DOE adequately discussed resources within the controlled area for those resources included, and justified the exclusion of other resources from consideration.

33.F.1 Requirement

(c) “Performance assessments shall document that in analyzing the consequences of drilling events, the Department assumed that:

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

33.F.2 Abstract

EPA examined whether the PA considered drilling/borehole related information such as borehole degradation, drilling practices, drilling fluids, and borehole sealants. These factors, along with the determination of resources identified in the Delaware Basin over the past 100 years and variation of drilling/sealing practices for different resources, must be consistent with current practices and technology.

DOE assumed that current drilling and borehole-related factors, such as borehole degradation, drilling practices, drilling fluids, and borehole sealants, will remain consistent with current practices in the Delaware Basin. DOE also considered the determination of resources and variation of drilling and sealing practices for different resources consistent with current practices and technology.

DOE stated in Appendix DEL that modern rotary drilling techniques, with a variety of mud systems, have been used to complete wells present in the vicinity of WIPP (Appendix DEL 5.1, pp. 26-35). DOE also indicated that well installation is dependent upon depth of the producing formation, which can range from 4,000 to more than 14,000 feet below ground surface (Appendix DEL 4.2, pp. DEL-10 to DEL-20), depending on the intended hydrocarbon producing formation targeted. DOE assumed, as stated in Chapter 6.4.7.2 and Appendix MASS 16-1, that all oil-and-gas related boreholes in the WIPP area were plugged, or scheduled to be plugged, according to applicable regulations. DOE’s assumption was based on well records for intrusions on federal lands, wherein NMOCD data showed all wells to be plugged or scheduled to be plugged per regulatory requirements. DOE also indicated that 100 percent of wells drilled and then abandoned since 1988 were, or are, in the process of being plugged per applicable standards. EPA informed DOE that the information presented on borehole plugs was insufficient, and that the effect of non-plugged boreholes must be included in intrusion scenarios.

EPA reviewed the data presented in Chapter 6 and Appendices DEL and MASS to determine if DOE assumed that future drilling practices and technology will remain consistent with current practices in the Delaware Basin. In addition, EPA reviewed the CCA to determine if DOE performed appropriate assessments of future drilling practices and technologies, including the types/amounts of drilling fluids, borehole dimensions, the fraction of such boreholes that are sealed, etc., and that the assessments were consistent with data presented in the relevant CCA appendices. EPA's evaluation of state files, private database records, and independent industry practice information confirmed DOE's assumptions regarding future drilling practices and technologies, including the types/amounts of drilling fluids, and borehole dimensions (EPA 1998a).

33.F.3 COMPLIANCE REVIEW CRITERIA

As stated in the CAG (p. 50), EPA expected the compliance application to identify:

- Current drilling practices in the Delaware Basin.
- The current drilling practices that affect performance assessments.
- Types and amounts of drilling fluids.
- Borehole depths typically used.
- Borehole diameters typically used.
- Seals typically used.
- The fraction of boreholes sealed by humans today.
- The source(s) of the above information.

To comply with Section 194.33(c), the PA must consider drilling/borehole related information, such as borehole degradation, drilling practices, drilling fluids, and borehole sealants. These factors, along with the determination of resources and variation of drilling/sealing practices for different resources, must be consistent with current practices and technology.

33.F.4 DOE METHODOLOGY AND CONCLUSIONS

In Appendix DEL 5.1 (p. 26), DOE stated that modern rotary drilling techniques, with a variety of mud systems, have been used for well completions in the vicinity of WIPP. DOE indicated that drilling depths range from 4,000 to more than 14,000 feet in depth, depending on the hydrocarbon producing formation targeted. As stated in DEL.4.2, DOE took information regarding the depths of wells and probable resources primarily from Chapter IX of NMBMMR 1995. DOE stated that wells designed to penetrate the deeper Atokan natural gas plays (over 14,000 feet below ground surface) tend to start at surface with larger bits and conductor casings, and are completed with a long string of 4 ½" or 5 ½" casing. In such wells, the larger casing string present through the lower salt sections tends to be 8 e", 9 e" or larger in diameter. DOE indicated that wells intended for completion in the relatively shallower (approximately 5,000 to 8,000 feet deep) Delaware Group are drilled with similar technology and mud systems through the salt sections. Long string casing present across the Bell Canyon varies from 4 ½" to 13 d".

Completions may use 2 d" or 2 f" tubing strings. Standard completion technology for both the Delaware Group and Atokan wells includes perforation of the long string casing with a hydraulic fracture treatment using a variety of gelled fluids to emplace sand proppant into the fractures. DOE indicated that acid treatments and acid fracture treatments are frequently used, especially for Brushy Canyon completions (Appendix DEL 5.1.9, p. 40). Drilling practices that potentially could affect PA and the natural process of degradation are discussed respectively under Section 194.33(c)(1) and (2) in **CARD 32—Scope of Performance Assessments**. Borehole plugs are discussed further under Section 194.14(a) in **CARD 14—Content of Compliance Certification Application**.

DOE assumed that all oil and gas related boreholes in the area will be plugged according to current applicable regulations. DOE based this assumption on records for wells drilled on Federal lands, for which the New Mexico Oil Conservation Division (NMOCD) data showed that all wells were either plugged or scheduled to be plugged in accordance with regulatory requirements. A DOE study, provided as Appendix MASS 16-1, indicated that 100 percent of wells drilled and abandoned since 1988 were, or are, in the process of being plugged per applicable BLM or NMOCD regulatory standards pertaining to technical requirements. DOE's own verification activities indicated that plugging was completed all but four wells on Federal lands.

For the remaining wells, operators had filed an "intent to plug" form with the state. Of these wells, two were field verified as plugged, one was in the process of being plugged, and one was approved for plugging on December 5, 1995. Appendix DEL.6.2.3 (p. DEL-71) discusses post-1988 boreholes declared shut-in or temporarily abandoned that have been plugged. This is consistent with data indicating that 100 percent of the wells drilled since 1988 were plugged or are in the process of being plugged to meet standards (see Appendix MASS).

33.F.5 EPA Compliance Review

Based on review of the data presented in Chapter 6.4.7.2 and Appendices DEL and MASS, EPA found that DOE has assumed that future drilling practices and technology will remain consistent with current practices in the Delaware Basin. In addition, EPA determined that DOE performed appropriate assessments of future drilling practices and technologies—including the types/amounts of drilling fluids and borehole dimensions—and that the assessments were consistent with data presented in the above referenced CCA appendices. EPA's evaluation of state files, private database records, and independent industry practice information confirmed DOE's assumptions regarding future drilling practices and technologies, including the types/amounts of drilling fluids, and borehole dimensions (EPA 1998a).

During the public comment period for the proposed certification decision, EPA received comments which stated that air drilling is current practice in the Delaware Basin. As a result of these questions, EPA performed additional analyses of air drilling to determine whether it is common practice in the Delaware Basin. See EPA's Analysis of Air Drilling at WIPP (EPA 1998b) and Response to Comments, Section 8 (V-C-1). Based on this analysis, EPA again determined that the use of mud as the drilling fluid is the current practice for drilling through the salt section (the Salado and Castile Formations) and that air drilling through the salt section is not consistent with current drilling practices in the Delaware Basin. Thus, DOE properly excluded air drilling through the salt section from consideration in the WIPP performance assessment.

EPA informed DOE in a letter dated December 19, 1996, that the Department was required to provide detailed information about the large number (7,428) of unaccounted boreholes (Table DEL-2 of Appendix DEL) and about the inclusion of the effects of unplugged boreholes in the PA (Docket A-93-02, Item II-I-01). EPA required this information because the unplugged/abandoned borehole issue was not clearly presented in the CCA. DOE's response to this comment are presented in three subparts (see Docket A-93-02, Item II-I-03):

- Totaling of the boreholes from DEL-2 is not consistent with the record keeping system of NMOCD (data source). Because the categorization of data does not take into consideration the temporarily abandoned boreholes, service wells, injection wells, and dry wells. Also, data came from different sources and different assumptions were made.

- The current regulatory process was in part designed to address the issue of unplugged boreholes. EPA believes that DOE appropriately identified that there are no unaccounted wells within the land withdrawal area. Wells in the land withdrawal area are either shallow or deep research boreholes drilled by DOE, or several abandoned but plugged wells (see Appendix DEL, p. DEL-21). DOE plans to follow State of New Mexico requirements in plugging boreholes drilled into the disposal system.

- DOE stated that considering the changes in plug properties with time and to a final degradation of silty sand accounted for the issue of unplugged holes. The changes in properties were included in PA. EPA agrees that boreholes will degrade, but EPA believes that the permeability range should be different than that selected by DOE (see below).

The Agency found that the CCA did in fact address this issue, although its presentation was not clear. EPA found DOE's discussion to be technically adequate, because the boreholes in question are outside of the Land Withdrawal Area and are not expected to affect the disposal system's capability to contain radionuclides. EPA concluded that DOE appropriately screened out abandoned boreholes drilled just meters away from the waste because of the limited communication between boreholes away from the waste and the borehole due to the low permeability of the halite (EPA 1998e).

DOE included in the performance assessment boreholes drilled into the waste areas. DOE assumed that abandoned boreholes would have permeability of silty sand. EPA agreed that the high permeability assumed by DOE was appropriate. However, EPA believes that it is possible for abandoned boreholes to have low permeability, similar to a recently plugged borehole (EPA 1998c). EPA therefore required DOE to include a larger range of long-term concrete plug permeability values in the PAVT (Docket A-93-02, II-I-27). This range is from 1×10^{-11} to 5×10^{-17} m^2, which EPA believes covers the behavior of plugs in the Delaware Basin. The PAVT findings indicated that even with these change in the borehole permeability, the releases did not violate the containment requirements.

33.G.1 REQUIREMENT

(c) "Performance assessments shall document that in analyzing the consequences of drilling events, the Department assumed that:

(2) Natural processes will degrade or otherwise affect the capability of boreholes to transmit fluids over the regulatory time frame."

33.G.2 ABSTRACT

EPA expected any compliance application to identify the processes that are expected to affect boreholes over time, discuss portions of the borehole that will degrade, discuss the effects that natural degradation will have on the borehole plug, and identify models in which borehole degradation is addressed.

DOE stated in Appendix MASS and Chapter 6 that plugging configurations in the Delaware Basin can be generalized into three categories: a two-plug configuration (68 percent probability of occurrence), a three-plug configuration (30 percent probability of occurrence) and a continuous cement plug (2 percent probability of occurrence). DOE assumed that borehole plugs would exhibit variable permeability through time and concluded that permeability for each of the three types of plug systems never exceeds that of silty sand (10^{-11} to 10^{-14} square meters).

EPA evaluated DOE's assumptions, calculations, and data values for borehole degradation and associated permeability changes, including borehole degradation processes, location in the borehole, and models that implement degradation. EPA evaluated whether DOE assumed that the fluid transmission capabilities of boreholes would degrade over time due to natural processes, and also determined the validity of DOE's assumptions, calculations, and data values for borehole degradation over time.

33.G.3 COMPLIANCE REVIEW CRITERIA

The PA must consider borehole degradation and associated permeability changes. DOE's assumptions, calculations, and data values should be comparable with industry practice, standards, and observations. As stated in the CAG (p. 50), EPA expected any compliance application to:

- ♦ Identify the processes that are expected to affect boreholes over time.

- ♦ Discuss the portions of the borehole over which particular processes are expected to act. For example, creeping of the salt is one process that could affect a bore-hole in the salt section, while other processes may affect other portions of a borehole.

- Discuss the effects that natural degradation are expected to have on the capability of boreholes to transmit fluids.

- Identify the models in which borehole degradation is addressed.

33.G.4 DOE METHODOLOGY AND CONCLUSIONS

Appendix DEL, Attachment 7 (Inadvertent Intrusion Borehole Permeability), addressed borehole permeability variation based largely on a study by the Westinghouse Waste Isolation Division. The WID report used published literature, plugging field tests, and oil and gas companies' experience to assess borehole permeability. The report addressed wells that were plugged since 1988, when the State of New Mexico adopted new drilling and plugging regulations. Boreholes existing prior to 1988 are extremely limited in number within the WIPP Land Withdrawal Area. DOE accounted for the risk and uncertainties associated with boreholes drilled prior to 1988 in the PA by using various behaviors of plugs in the Delaware Basin (as discussed in Section 33.F.4 of this CARD). Borehole plug life was considered in PA calculations (two plugs configuration) for 200 years; beyond that period permeability was equivalent to marine silty sand and was held constant during the regulatory period. This topic is discussed further in relation to plugging configurations below.

DOE assumed that processes that affect boreholes include steel casing corrosion and concrete plug alteration. Refer to Appendix DEL, Attachment 7, for DOE's detailed evaluation of these degradation mechanisms.

DOE described different portions of the borehole over which degradation would act by first assigning plugging configurations for deep drilling in the Delaware Basin to one of three categories: a two-plug configuration, a three-plug configuration, and a continuous cement plug. DOE evaluated the frequency of plug configurations based on those of 188 Delaware Basin wells installed since 1988. This provides an adequate database for analysis. Based on this study, DOE assigned the following frequencies for each configuration (Chapter 6.4.12.7, p. 6-198):

- One continuous plug through the evaporite sequence: probability of 0.02.

- Two plugs—one in the Bell Canyon (below the potential brine reservoirs) and one in the Rustler Formation (between the Culebra aquifer and the repository): probability of 0.68.

- Three plugs—two as described for the two-plug form and a third plug in the Salado Formation: probability of 0.30.

DOE estimated that this plug system was expected to have an initial permeability of 5×10^{-17} m^2. DOE assumed that casings would corrode due to the saline groundwater environment (Appendix DEL, Attachment 7, Appendix B) and that concrete plugs would degrade when sufficient water entered a plug to cause matrix degradation (Appendix DEL, Attachment 7, Appendix C). DOE also assumed that shallower casing and cement plugs will degrade in about 200 years, allowing for more potential fluid flow earlier in the regulatory period in shallower horizons when compared to deeper casing, which was assumed to fail approximately 5000 years after installation. DOE assumed that the "corroded casing and degraded plug will fill the hole with material with a permeability approximating that of silty sand (10^{-11} to 10^{-14} m^2), and over time any of this material below the repository will compress through creep closure of the borehole to a permeability about one order of magnitude lower" (Appendix DEL, Attachment 7, p. 19). Plug configurations do not apply explicitly to shallow drilling, except that abandoned shallow boreholes typically are continuously cemented and "are expected to have no effect on the performance of the WIPP" (Appendix DEL5.2, p. DEL-41).

DOE concluded in Appendix DEL.7.4 that permeability for each of the three types of plug systems never exceeded that of silty sand (10^{-11} to 10^{-14} square meters) over the 10,000 year regulatory period[1]. DOE offered the following borehole permeability changes over time, with the higher permeabilities the result of natural borehole degradation that would also potentially allow for increased fluid flow:

- One plug: 5×10^{-17} square meters for 10,000 years

- Two plugs
  - -- Between the repository and the surface
    - 5×10^{-17} square meters for 200 years
    - 10^{-11} to 10^{-14} square meters after 200 years
  - -- Between the Castile and the repository
    - "very high" permeability to 200 years (10^{-9} m^2)
    - 10^{-11} to 10^{-14} square meters up to 1,200 years
    - 10^{-12} to 10^{-15} square meters after 1,200 years

- Three plugs
  - -- Between the intermediate plug and the surface
    - 5×10^{-17} square meters for 200 years
    - 10^{-11} to 10^{-14} square meters after 200 years
  - -- Intermediate plug
    - 5×10^{-17} square meters for a median time of 5,000 years
  - -- Borehole between the Castile and the repository
    - 10^{-11} to 10^{-14} square meters for 1,000 years (after 5,000 years)
    - 10^{-12} to 10^{-15} square meters after 6,000 years.

[1] Long-term borehole permeability was incorporated into PA modeling via the BH_SAND parameter (parameter ID 3184), used in BRAGFLO. See **CARD 23--Models and Computer Codes**.

Dimensions of cement plugs for the scenarios above were assumed by DOE to be:

- One plug: 3,000 feet (900 meters), 50 tons of concrete (20 cubic meters); and

- Other plugs: 150 feet (45.73 meters), 2.5 tons of concrete (1 cubic meter).

DOE assumed that plug system permeability will change over time in 98 percent of the configurations and will not change in 2 percent of the configurations. DOE assumed that permeability change with time behaved according to the following relationship:

$$D K = Ki * 10^{7.39 DN} - Ki$$

where:

D K = change in permeability
Ki = initial hydraulic conductivity
D N = change in porosity from mineral alterations.

DOE assumed that the permeability of plug systems is never greater than 10^{-11} m^2. Assumptions made by DOE regarding borehole plug permeability and casing corrosion are presented in Appendix DEL, Attachment 7.

33.G.5 EPA Compliance Review

EPA reviewed Appendices DEL and MASS and determined that DOE sufficiently identified natural borehole degradation mechanisms that will affect boreholes over time. EPA also examined the plug configurations presented by DOE and compared these generalized configurations with those for oil/gas and potash resource boreholes in the WIPP vicinity, as evidenced by the resources targeted and necessary plugging techniques. EPA determined that DOE's plug configurations (which directly impact the portions of the borehole over which degradation processes are expected to act) and plug probabilities are adequate representations of the plugs in the WIPP area (EPA 1998c).

EPA evaluated the effects that natural degradation of long-term borehole plugs would have on the plug system and the potential for increased transmissivity of abandoned well plugs due to such degradation. EPA disagreed with DOE's lower borehole plug permeability. Although DOE's permeabilities assigned for the various plug configurations were based on plausible data, EPA believed that DOE assumed a low-end permeability that was too high. For further discussion of EPA's analysis of borehole permeabilities see the Parameter Justification Report (EPA 1998c).

If degraded boreholes are assumed to be filled with materials analogous to unconsolidated silt to silty sand, the permeabilities of $1x10^{-11}$ to $1x10^{-14}$ m^2 (1 to 10,000 md) used by DOE are not unreasonable estimates of values per industry standards (Freeze and Cherry 1979). (For purposes of comparison, the permeability range reported for shale and unweathered marine clay varies from

$1x10^{-21}$ to $1x10^{-17}$ m^2 ($1x10^{-5}$ to 0.1 md). See Appendix MASS Attachment 16.) However, as discussed below, EPA investigated this assumption and found that permeability values could be lower than DOE assumed. Lower values allow for greater gas pressurization of the WIPP and a subsequent increase in releases due to mechanisms such as spallings (EPA 1998c, Section 5.17).

EPA began by investigating the permeability of borehole materials and drilling fluids in the petroleum industry. Literature values for permeability of cement used in borehole applications can range from $9x10^{-21}$ to $1x10^{-16}$ m^2 ($1x10^{-5}$ to 0.1 md); these values are also cited in some of the publications referenced in the CCA. EPA also investigated drilling muds. Filter cake and compacted clay-based drilling muds can yield permeabilities of less than $9.9x10^{-22}$ m^2 ($1x10^{-6}$ md) from field data for 11 ppg mud (EPA 1998c, Section 5.17).

EPA concluded that drilling mud circulated in Delaware Basin boreholes may not have the degree of clay-based solids loading typically experienced elsewhere (as discussed in Appendix MASS 16-3, Appendix C); however, natural cuttings could contribute to lower borehole permeability than that postulated by DOE. Lower initial permeabilities, more effective plug segments, mixed layers between plug components that would take time to degrade, and lower fluid velocities than DOE assumed in its calculations could significantly retard plug degradation and could maintain the effective seal of the plug sequences for hundreds or thousands of years beyond that assumed by DOE in Appendix MASS, Attachment 16.

DOE provided a variety of plausible mechanisms to increase plug permeability, and EPA believes that this high range of permeability may be attained. However, EPA also believes that there is a limited probability that the lower borehole permeability (over several hundred vertical feet of borehole) would reach the relatively large permeabilities estimated by DOE. Since permeability through any given borehole will actually be controlled by the permeabilities of all zones through which fluids must pass, the effective average permeability could be dominated by small sections of remaining competent plug or other low permeability material. If complete degradation does not occur throughout a well, or if natural materials and mud provide additional layers with sealing properties, it is possible that the effective average permeability over several hundred feet of abandoned borehole could remain in the range of $9x10^{-21}$ to $1x10^{-16}$ m^2 ($1x10^{-5}$ to 0.1 md) over a period of hundreds, if not thousands, of years.

EPA concluded that the borehole permeabilities assigned in the CCA (Appendix MASS, Appendix 16) were consistent with the broad range of available permeability data, but DOE did not adequately consider the total range of permeability conditions that could exist in boreholes. Permeabilities assigned by DOE may therefore overestimate the degree to which plugs would lose effectiveness. EPA concluded that an alternative case could be made in which many of the plugs would retain a larger degree of effectiveness. As such, a lower maximum permeability value of *approximately* $1x10^{-17}$ m^2 ($1x10^{-2}$ md) is quite possible (particularly for long-term conditions) and may have an impact on PA results. As a result, EPA included both long- and short-term plug permeability changes in the Performance Assessment Verification Test. EPA required that PA simulations be conducted with lower permeabilities (CONC_PLG maximum of $10^{-19}m^2$, BH_SAND maximum of $5 \times 10^{-17}m^2$) to account for possible cases in which complete degradation does not occur throughout a well, or natural materials and mud provide additional layers with sealing properties. See the discussion of Section 194.23(a) in **CARD 23--Models and**

Computer Codes for more information regarding the permeability values assigned by EPA in the PAVT. Results of the PAVT indicate that lower borehole permeability allows greater pressure build-up in the repository and, hence, greater release potential from mechanisms such as spallings. However, releases predicted by the PAVT were still well below EPA's release limits (DOE 1997a, 1997b). For further discussion of EPA's evaluation of the PAVT, see EPA Technical Support Document: Overview of Major Performance Assessment Issues (EPA 1998d).

In summary, EPA agreed that the high permeabilities assumed by DOE were generally appropriate; however, EPA believed that it is also possible for abandoned boreholes to have a lower permeability, similar to that of a recently plugged borehole (EPA 1998c). Therefore, EPA required DOE to include larger ranges of undegraded concrete plug and long-term borehole filling permeability values in the PAVT (Docket A-93-02, II-I-27). The range of 1×10^{-17} to 1×10^{-19} m^2 was used in the PAVT for an undegraded concrete plug, and the range of 1×10^{-11} to 5×10^{-17} m^2 was used in the PAVT for a degraded borehole filling. EPA found that these ranges adequately cover the behavior of plugs in the Delaware Basin. The results of the PAVT indicated that even with these changes in the range of permeabilities for degraded borehole plugs, releases did not violate EPA's containment requirements.

EPA believes that its detailed review of DOE's borehole plugging assumptions provided an adequate basis for the Agency's conclusion that DOE's assumptions were acceptable. Although EPA originally questioned many of those assumptions, further investigations substantiated many of DOE's assumptions, and the use of modified permeability ranges in the PAVT did not cause releases to exceed regulatory limits.

33.H.1 REQUIREMENT

(d) "With respect to future drilling events, performance assessments need not analyze the effects of techniques used for resource recovery subsequent to the drilling of the borehole."

33.H.2 ABSTRACT

Section 194.33 (d) permits DOE not to analyze the effects of techniques used for resource recovery subsequent to the drilling of the borehole. In the PA, DOE assumed that future drilling practices would be the same as current practices and screened out the effects of techniques used for resource recovery subsequent to the drilling of a borehole on the basis of low consequence.

33.H.3 COMPLIANCE REVIEW CRITERIA

Section 194.33(d) permits DOE to exclude from PA the effects of techniques used for resource recovery subsequent to the drilling of the borehole. EPA expected that the discussion of drilling would occupy a separate part of the CCA. This section of the application should cross-reference other sections that use this information or have closely related information, such as the discussion that addresses the requirements for models and codes (CAG, pp. 50-51). See Section 194.23(a) in **CARD 23—Models and Computer Codes** for additional discussion of DOE's exclusion of resource recovery techniques from the PA.

33.H.4 DOE Methodology and Conclusions

DOE assumed that future drilling practices will be the same as current practice in terms of the type and rate of drilling, emplacement of casing in boreholes, and procedures for plugging and abandonment. DOE did not include the impact of resource recovery subsequent to future drilling of boreholes on the basis of low consequence. See Section 194.32(a) in **CARD 32—Scope of Performance Assessments** for additional information.

DOE did not include the effects of resource recovery techniques in the PA analysis of future human intrusion. Also, in the deep drilling disturbed performance scenario, DOE examined three drilling-only scenarios, but these did not incorporate resource recovery techniques. DOE stated in Chapter 6 (p. 6-60) that the PA did not analyze the effects of techniques used for resource recovery subsequent to the drilling of the borehole.

33.H.5 EPA Compliance Review

EPA determined that the PA did not analyze the effects of resource recovery techniques in future drilling events.

33.I References

DOE 1997a. U.S. Department of Energy. Summary of EPA-Mandated Performance Assessment Verification Test (Replicate 1) and Comparison with the Compliance Certification Application Calculations. July 25, 1997. (Docket A-93-02, Item II-G-26)

DOE 1997b. U.S. Department of Energy. Supplemental Summary of EPA-Mandated Performance Assessment Verification Test (All Replicates) and Comparison with the Compliance Certification Application Calculations (WPO #46702). August 8, 1997. (Docket A-93-02, Item II-G-28)

DOE 1997c. U.S. Department of Energy. Conceptual Models Third Supplementary Peer Review Report. April 1997. (Docket A-93-02, Item II-G-22)

EPA 1998a. U.S. Environmental Protection Agency. Technical Support Document for 194.32: Fluid Injection Analysis. 1997. (Docket A-93-02, Item V-B-22)

EPA 1998b. U.S. Environmental Protection Agency. Technical Support Document: EPA's Analysis of Air Drilling at WIPP, Rev. 1. 1998. (Docket A-93-02, Item V-B-29)

EPA 1998c. U.S. Environmental Protection Agency. Technical Support Document for Section 194.23: Parameter Justification Report. 1998. (Docket A-93-02, Item V-B-14)

EPA 1998d. U.S. Environmental Protection Agency. Technical Support Document: Overview of Major Performance Assessment Issues. 1998. (Docket A-93-02, Item V-B-5)

EPA 1998e. U.S. Environmental Protection Agency. Technical Support Document for Section 194.32: Scope of Performance Assessments. 1998. (Docket A-93-02, Item V-B-21)

Freeze, R.A., and J.A. Cherry. Groundwater. Englewood Cliffs, NJ: Prentice Hall. 1979. (CCA Reference #257)

NMBMMR 1995. New Mexico Bureau of Mines and Mineral Resources. Evaluation of Mineral Resources at the Waste Isolation Pilot Plant (WIPP) Site, Final Report. 1995. (CCA Reference #460)