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6.0 CONTAINMENT REQUIREMENTS

6.0.1 Introduction

Because of the amount ***and complexity*** of ***the*** material presented in Chapter 6.0***,*** ~~and its complexity, the U.S. Department of Energy (DOE) has provided~~ an introductory summary ~~of Chapter 6.0~~ ***is provided below***. Detailed discussions of the topics covered in this summary are found in the remainder of the chapter, which is organized as follows.

- Section 6.1 – ~~t~~***T***he overall system performance assessment ***(PA)*** methodology used to evaluate compliance with the containment requirements.
- Section 6.2 – ~~a~~***A*** comprehensive list of features, events, and processes (FEPs) that might affect disposal system performance, the screening methodology applied to that list, and the results of the screening process.
- Section 6.3 – ~~d~~***D***evelopment of the scenarios ~~that are~~ considered in the system-level consequence analysis.
- Section 6.4 – ~~t~~***T***he conceptual and computational models used to perform the system-level consequence analysis ~~(performance assessment)~~***PA***, the overall flow of information in the ~~performance assessment~~***PA***, the scenario probabilities, and the construction of a performance measure for comparison with the standard.
- Section 6.5 – ~~t~~***T***he results of the ~~performance assessment~~***PA***.

Additional information supporting this chapter is provided in appendices. See Table ~~1-6~~ ***1-1*** ~~in Chapter 1.0~~ for a list of these appendices.

The U.S. Department of Energy (DOE) continues to use the same PA methodology for the recertification of WIPP. In general, changes that have been made since the U.S. Environmental Protection Agency (EPA) certified WIPP do not impact PA methodology.

6.0.2 Overview of Chapter 6.0

The ~~DOE has~~ ***EPA*** determined that the WIPP is in compliance with the Containment Requirements of Title 40 Code of Federal Regulations (CFR) § 191.13 ***in 1998 (EPA 1998a). The DOE has conducted a new PA for the WIPP. The WIPP Land Withdrawal Act (LWA), Public Law 02-579 as amended by Pubic Law No. 104-201, requires DOE to provide the EPA with documentation of continued compliance with the disposal standards within five years of first waste receipt and every five years thereafter. During review of the initial certification application, EPA required many changes to PA parameters, which have been included in the PA for this recertification application (EPA 1998b). The DOE has also made additional changes to the PA to better represent repository features, such as panel closures, and to account for new information. Table 6-1 summarizes the changes to the PA since the Compliance Certification Application (CCA); additional information is provided in Appendix PA (Attachment MASS, Section 2).***

Table 6-1. WIPP Project Changes and Cross References

WIPP Project Change	Cross Reference
Incorporation of 1997 Performance Assessment Verification Test (PAVT) Parameters	
Credit for Passive Institutional Controls	***6.4.12.1***
K_d (Dissolved-Actinide Matrix Distribution Coefficient)	***6.0.2.3.7, 6.4.6.2.2***
Probability of Encountering a Brine Reservoir	***6.0.2.3.8, 6.4.8, 6.4.12.6***
Brine Reservoir Rock Compressibility	***6.4.8***
Brine Reservoir Porosity	***6.4.8***
Drill String Angular Velocity	***Appendix PA, Attachment MASS (Section16) and Attachment PAR***
Waste Permeability	***6.4.3.2***
Waste Unit Factor	***Appendix TRU WASTE***
Long-term Borehole Permeability	***6.4.7.2***
Borehole Plug Permeability	***6.4.7.2***
Waste Shear Strength and Erodability	***Appendix PA, Attachment MASS (Section 16)***
DRZ	***6.4.5.3, 6.4.10.1***
Actinide Solubility	***6.4.3.5***
Inundated Steel Corrosion Rate	***6.4.3.3***
Operational Changes	
Option D Panel Closure	***6.4.3, 6.4.4***
Inventory Update	***6.4.3.1, 6.4.3.3***
Culebra Water Levels	***6.4.6.2, and Appendix PA, Attachment MASS***
Spallings Model	***6.0.2.3.2; Appendix PA (Section 4.6) and Attachment MASS (Section 16.0)***
Drilling Rate	***6.0.2.3, 6.2.5.2; Appendix DATA (Section 2 and Attachment A)***
Organic Ligands	***6.0.2.3.4, 6.4.3.4; Appendix PA, Attachments SOTERM and SCR***
FEPs Reassessment	***6.2.6; Appendix PA, Attachment SCR***
Borehole Plugs Configuration Probability	***6.4.7.2***
Mining Disposal Horizon to Clay G	***Appendix PA, Attachment MASS (Section 20)***

From this assessment, the DOE has demonstrated that the WIPP continues to comply with the Containment Requirements of 40 CFR § 191.13. The~~se requirements are~~ ***Containment Requirements are*** stringent and state that the DOE must demonstrate a reasonable expectation that the probabilities of cumulative radionuclide releases from the disposal system during the 10,000 years following closure will fall below specified limits. The ~~performance assessment~~***PA*** analyses supporting this determination must be quantitative and ~~must~~ consider uncertainties caused by all significant processes and events that may affect the disposal system, including ***future*** inadvertent human intrusion into the repository~~ during the future~~. A quantitative

~~performance assessment~~***PA*** is conducted using a series of linked computer models in which uncertainties are addressed by a Monte Carlo procedure for ~~the~~ sampling ~~of~~ selected input parameters.

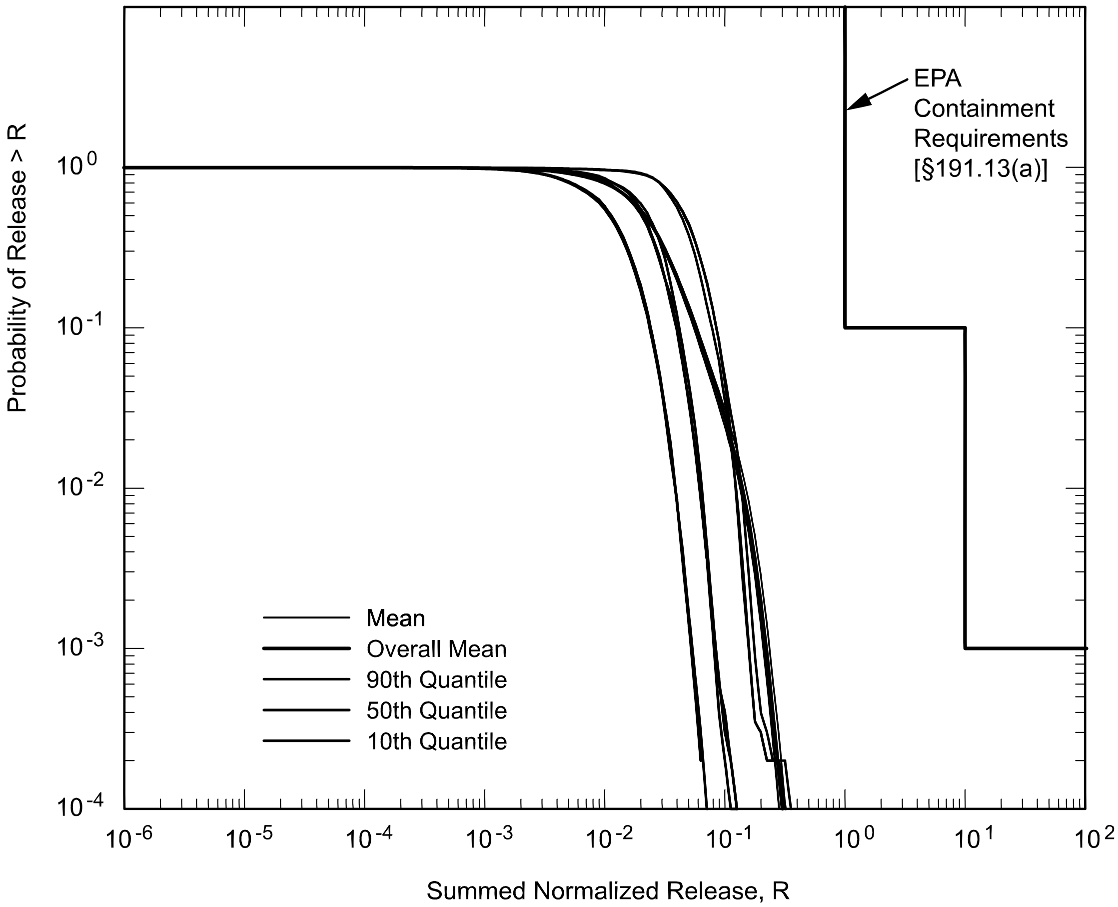
As required by regulation, results of the ~~performance assessment~~***PA*** are displayed as complementary cumulative distribution functions (CCDFs) that display the probability that cumulative radionuclide releases from the disposal system will exceed the values calculated for ~~each~~ scenario***s*** considered in the analysis. These CCDFs are calculated using reasonable and, in some cases conservative conceptual models ~~that are~~ based on the scientific understanding ~~of the behavior~~ of the disposal system***'s behavior***. Parameters used in these models are derived from experimental data, field observations, and relevant technical literature. ***Changes to the CCA's parameters and models that have been necessary since the original certification have been incorporated into the PA. Information on the waste already disposed and new estimates of current and projected waste inventories are also incorporated.*** The overall mean CCDF ***continues to*** lie~~s~~ entirely below ~~and to the left of~~ the specified limits, and the WIPP ~~is~~ therefore ~~in~~ ***continues to be in*** compliance with the containment requirements of 40 CFR Part 191***, Subpart B (see Section 6.5.2, Figure 6-1)***. Sensitivity analysis of results shows ***that*** the location of the mean CCDF is dominated by ~~of~~ radionuclide~~s~~ releases that could occur ~~directly at~~ ***on*** the ~~ground~~ surface during ~~the~~ ***an*** inadvertent penetration of the repository by a future drilling operation. Releases of radionuclides to the accessible environment resulting from transport in groundwater through the shaft seal systems and the subsurface geology are resulting negligible, with or without human intrusion, and make no contribution to the location of the mean CCDF. No releases whatsoever are predicted to occur at the ground surface in the absence of human intrusion. The natural and engineered barrier systems of the WIPP provide robust and effective containment of transuranic (TRU) waste even if the repository is penetrated by multiple borehole***s*** ~~intrusions~~.

A list of changes and a citation to where they are discussed is shown in Table 6-1.

6.0.2.1 Conceptual Basis for the Performance Assessment

The foundations of ~~the performance assessment~~***PA*** ~~lie in~~ ***are*** a thorough understanding of the disposal system and the possible future interactions ~~among~~ ***of*** the repository, ~~the~~ waste, and ~~the~~ surrounding geology. ~~This~~ ***The recertification*** application is organized ~~such~~ ***so*** that site characterization, facility design, and waste characterization are described separately in Chapters 2.0, 3.0, and 4.0***, respectively***. The DOE's confidence in the results of the ***recertification*** ~~performance assessment~~***PA*** is based in part on the strength of the ***original*** research done during site characterization, ***experimental results used to develop and confirm parameters and models,*** the robustness of the facility design, and the knowledge of the ***updated*** inventory. Quality assurance (QA) activities, described in Chapter 5.0, demonstrate that the information gathered during these activities is qualified to ***meet the QA criteria in 40 CFR 194.*** ~~support the compliance decision.~~

Chapters 2.0, 3.0, and 4.0 provide ~~the~~ basic descriptions of the ***disposal system*** main components ~~of the disposal system~~. The interactions of the repository and waste with the geologic system, and the response of the disposal system to possible future inadvertent human intrusion***,*** are described in Section 6.4.



Note: Mean, median, and 10th and 90th percentile CCDFs are shown together with the overall mean. These CCDFs are based on the distributions of CCDFs shown in Figure ~~6-35, 6-36, and 6-37~~ ***6-34, 6-35, and 6-36***.

Figure 6-1. Summary CCDFs for Replicates 1, 2, and 3

6.0.2.2 Undisturbed Performance

An evaluation of undisturbed performance, which is defined ~~by regulation (see 40 CFR § 191.15 and § 191.2)~~ to exclude human intrusion and unlikely disruptive natural events, is required by regulation (see ~~40 CFR § 191.12~~***Sections 191.15 and § 191.24***). Evaluation of past and present natural geologic processes in the region indicate that none has the potential to breach the repository within 10,000 years. ~~Behavior of the d~~**D**isposal system **behavior** is dominated by the coupled processes of ~~deformation of the~~ rock ***deformation*** surrounding the excavation, fluid flow, and waste degradation. Each of these processes can be described independently, but the extent to which each process occurs ~~will be~~ **is** affected by the others.

Deformation of the rock immediately around the repository begins as soon as excavation creates a disturbance in the stress field. Stress relief results in some degree of brittle fracturing and the formation of a disturbed rock zone (DRZ)***, which*** surround***s***~~ing~~ excavations in all deep mines***, including the repository.*** For the WIPP, the DRZ is characterized by an increase in permeability and a decrease in pore pressure, and may ultimately extend a few meters from the excavated region. Salt will also deform ~~due to deviatoric stress~~ by creep processes***, which are a result of***

deviatoric stress, causing the materials to ~~and~~ move inward to fill voids. ~~This~~ ~~process of~~ Salt creep will continue until deviatoric stress is dissipated and the system is once again at stress equilibrium.

The ability of salt to creep, thereby healing fractures and filling porosity, is one of ~~the~~ ***its*** fundamental advantages ~~of using it~~ as a medium for geologic disposal of radioactive waste and ~~is~~ one ~~of the~~ reason~~s~~ it was recommended ~~for use~~ by the National Academy of Sciences (NAS). ~~For the WIPP, s~~***S***alt creep provides the ***mechanism*** for ~~the design basis of the compacted~~ crushed salt ***compaction in*** ~~of~~ the shaft seal system ~~components that will compact~~***,*** ~~to~~ yield***ing*** properties approaching those of ~~the~~ intact salt within 200 years. ~~The s~~***S***alt creep will also cause the DRZ surrounding the shaft to heal rapidly around the concrete components of the seal system. In the absence of elevated ***gas*** pressure in the repository, salt creep would also ~~eventually result in~~ substantial***ly*** compact~~ion of~~ the waste and ~~the~~ heal~~ing of~~ the DRZ around the disposal region. ~~Understanding t~~***T***he coupling of salt creep with fluid flow and waste degradation processes ***results in*** ~~suggests that~~ fluid pressure within the waste disposal region ~~will be sufficient to~~ maintain***ing*** significant porosity within the disposal region throughout the performance period.

Characterization of the Salado Formation ***(hereafter referred to as the Salado)*** indicates that fluid flow does not occur on time scales of interest in the absence of an artificially imposed hydraulic gradient. This lack of fluid flow is the second fundamental reason for the choice of salt as a medium for geologic disposal of radioactive waste. Lack of fluid flow is a result of the extremely low permeability of the evaporite rocks that make up the Salado. Excavation of the repository has disturbed the natural hydraulic gradient and rock properties and has resulted in fluid flow. Small quantities of interstitial brine present in the Salado move toward regions of low hydraulic potential and brine seeps are observed in the underground. The slow flow of brine from halite into more permeable anhydrite marker beds and then through the DRZ into the repository is expected to continue as long as the hydraulic potential within the repository is below ***that of*** ~~the hydraulic potential in~~ the far field. The repository environment will also involve gas, and fluid flow ***that*** ~~there~~ must be modeled as a two-phase process. Initially, the gas***eous*** phase will consist primarily of air trapped at the time of closure, although other gases ~~will~~ ***may*** form ~~as a result of~~ ***from*** waste degradation. ***In the PA, t***~~T~~he gas***eous*** phase pressure will rise due to creep closure, gas generation, and brine inflow, creating the potential for flow ~~outward~~ from the excavated region.

Consideration of waste degradation processes indicates that ~~the role of~~ the gas***eous*** phase in fluid flow and the ***repository's*** pressure history ~~of the repository~~ will be far more important than ~~would be expected~~ if the initial air were the only gas present. ***Waste*** ~~D~~***d***egradation ~~of waste~~ can generate significant additional gas by two processes:

1. the generation of hydrogen ***(H_2)*** gas by anoxic corrosion of ~~iron, iron alloys~~***steels***, ***other iron-base (Fe-based) alloys,*** and aluminum ***(Al) and Al-based alloys***, and

2. the generation of carbon dioxide ***(CO_2)*** and methane ***(CH_4)*** by anaerobic microbial ***consumption*** ~~degradation~~ of waste containing cellulose***ic***, ~~rubber, or~~ plastic***, or rubber materials***.

~~The c~~***C***oupling ~~of~~ these gas-generation reactions to ~~the processes of~~ fluid flow and salt creep processes is complex. Gas generation will increase fluid pressure in the repository, thereby decreasing the hydraulic gradient and deviatoric stress between the far field and the excavated region and inhibiting the processes of brine inflow and salt creep. Anoxic corrosion will also consume brine as it breaks down water to oxidize ~~iron~~***steels and other Fe-based alloys*** and release ~~hydrogen~~***H_2*** ~~gas~~. Thus, corrosion has the potential to be a self-limiting process, in that as it consumes all water in contact with ~~iron~~***steels and other Fe-based alloys***, it will cease. ***Microbial reactions also require water, either in brine or the gaseous phase. It is assumed that microbial reactions will result in neither the consumption nor production of water.*** ~~Microbial reactions are also considered to be dependent on the presence of water to occur, although their net effect is uncertain. It is assumed that microbial reactions will result in neither the consumption nor creation of water.~~

The total volume of gas ~~that may be~~ generated by corrosion and microbial ~~degradation~~ ***consumption*** may be sufficient to result in repository pressures that approach lithostatic. Sustained pressures above lithostatic are not physically reasonable within the disposal system, and fracturing of the more brittle anhydrite layers is expected to occur if sufficient gas is present. The conceptual model implemented in the ~~performance assessment~~***PA*** causes permeability and porosity of the anhydrite marker beds to increase rapidly as pore pressure approaches and exceeds lithostatic. This conceptual model for pressure-dependent fracturing approximates the hydraulic effect of pressure-induced fracturing and allows gas and brine to move more freely within the marker beds at higher pressures.

Overall, the behavior of the undisturbed disposal system will result in extremely effective isolation of the radioactive waste. Concrete, clay, and asphalt components of the shaft seal system will provide an immediate and effective barrier to fluid flow through the shafts, isolating the repository until salt creep has consolidated the compacted crushed salt components ~~that will~~ ***and*** permanently seal***ed*** the shafts. Around the shafts, the DRZ in halite layers will heal rapidly because the presence of the solid material within the shafts will provide rigid resistance to creep. The DRZ around the shaft, therefore, will not provide a continuous pathway for fluid flow. ***Similarly, the Option D panel closure will provide rigid resistance to creep and rapidly eliminate the DRZ locally by a compressive state of stress.*** The DRZ is not expected to heal completely around the disposal region, or the operations and experimental regions, and pathways for fluid flow may exist indefinitely to the overlying and underlying anhydrite layers (***e.g.,*** Marker Bed~~s~~ (MB) ~~138 and~~ 139 and anhydrites a and b). Some quantity of brine ~~is expected to~~ ***will*** be present in the repository under most conditions and ~~this brine~~ may contain actinides (which dominate the radionuclide inventory and are therefore the elements of primary regulatory interest) mobilized as both dissolved and colloidal species. Gas generation by corrosion and microbial degradation is expected to occur and will result in elevated pressures within the repository. These pressures will not significantly exceed lithostatic, because fracturing within the more brittle anhydrite layers will occur and provide a pathway for gas to leave the repository. Fracturing ***due to high gas pressures may*** ~~is expected to~~ enhance gas and brine migration from the repository, but gas transport will not contribute to the release of actinides from the disposal system. Brine flowing out of the waste disposal region through anhydrite layers may transport actinides as dissolved and colloidal species, but the quantity of actinides that may reach the accessible environment boundary during undisturbed performance through the interbeds is insignificant and has no effect on the compliance determination. No migration of radionuclides whatsoever is expected to occur vertically through the Salado or through the shaft seal system.

6.0.2.3 Disturbed Performance

Performance assessment is required by regulation to consider scenarios that include intrusions into the repository by inadvertent and intermittent drilling for resources. ***In the CCA, t***~~T~~he probability of these intrusions ~~is~~ ***was*** based on a future drilling rate of 46.8 boreholes per square kilometer per 10,000 years. This rate ~~is~~ ***was*** based on ~~consideration of~~ the past record of drilling events in the Delaware Basin, consistent with regulatory criteria. ***Since the CCA, additional drilling in the Delaware Basin has raised the drilling rate to 52.5 boreholes per square kilometer per 10,000 years (see Appendix DATA, Section DATA-2.0 and Attachment A).*** Active institutional controls are assumed to be completely effective in preventing intrusion during the first 100 years after closure***.*** ~~and p~~***P***assive institutional controls ~~a~~ ***were*** ~~re~~ ***originally*** assumed ***in the CCA*** to ~~be~~ effective***ly*** ~~in recuding~~ ***reduce*** the drilling rate by two orders of magnitude for the 600 years ~~that~~ follow***ing*** the 100 years of active control***. However, in certifying the WIPP, EPA denied the application of credit for the effectiveness of passive controls for 600 years. Although the Compliance Recertification Application 2004 PA (2004 PA) does not include a reduced drilling intrusion rate to account for passive institutional controls, future PA may do so.*** Future drilling practices are assumed to be the same as current practice, also consistent with regulatory criteria. These practices include the type and rate of drilling, emplacement of casing in boreholes, and the procedures implemented when boreholes are plugged and abandoned.

~~Results of the performance assessment~~***PA results*** indicate that human intrusion provides the only ***potential*** mechanism for significant releases of radionuclides from the disposal system. These releases ~~may~~***could*** occur by five mechanisms:

(1) cuttings, which include material intersected by the rotary drilling bit;

(2) cavings, which include material eroded from the borehole wall during drilling;

(3) spallings, which include solid material carried into the borehole during rapid depressurization of the waste disposal region;

(4) direct brine releases, which include contaminated brine that may flow to the surface during drilling; and

(5) long-term brine releases, which include the contaminated brine that may flow through a borehole after it is abandoned.

The first four ~~of these~~ mechanisms operate immediately following the intrusion event and are collectively referred to as direct releases. The accessible environment boundary for these releases is the ground surface. The fifth mechanism, actinide transport by long-term groundwater flow, begins when concrete plugs are assumed to degrade in an abandoned borehole and may continue throughout the regulatory period. The accessible environment boundary for these releases may be the ~~land~~ ***ground*** surface or the lateral subsurface limit of the controlled area.

Repository conditions prior to intrusion will be the same as those ~~described~~ for undisturbed performance and all processes active in undisturbed performance will continue to occur following intrusion. Because intrusion provides a pathway for radionuclides to reach the ground surface and to enter the geological units above the Salado, additional processes will occur that are less important in undisturbed performance. These processes include the mobilization of radionuclides as dissolved and colloidal species in repository brine and groundwater flow, and actinide transport in the overlying units. Flow and transport in the Culebra Member of the Rustler Formation ***(hereafter referred to as the Rustler)*** are of particular interest because ***modeling indicates*** this is the unit to which ~~modeling indicates~~ most flow from a borehole ***may***~~will~~ occur.

6.0.2.3.1 Cuttings and Cavings

In a rotary drilling operation, the volume of material brought to the surface as cuttings is ***calculated as*** the cylinder defined by the thickness of the unit ~~being drilled~~ and the diameter of the drill bit. The quantity of radionuclides released as cuttings is therefore a function only of the ~~activity of the~~ intersected waste ***activity*** and the diameter of the intruding drill bit. Like all parameters that describe future drilling activities, the diameter of a drill bit that may intersect waste is speculative. The DOE uses a constant value of 0.311 m (12.25 in.), consistent with bits ***currently*** used at the WIPP depth in the Delaware Basin ~~today~~. The ~~activity of the~~ intersected waste ***activity*** may vary depending on the type of waste intersected, and the DOE considers random penetrations into remote-handled (RH)-TRU waste and each of the ***693*** ~~569~~ different waste ***streams***~~types~~ identified for contact-handled (CH)-TRU waste ***(569 waste streams were used in the CCA)***.

The volume of particulate material eroded from the borehole wall ***by the drilling fluids*** and brought to the surface as cavings may be affected by the drill bit diameter, the effective shear resistance of the intruded material, the speed of the drill bit, the viscosity of the drilling fluid and the rate at which it is circulated in the borehole, and other properties related to the drilling process. The most important of these parameters, after drill bit diameter, is the effective shear resistance of the intruded material. In the absence of data describing the reasonable and realistic future properties of degraded waste and ***magnesium oxide (MgO)*** ~~backfill~~, the DOE ~~has~~ used conservative parameter values based on the properties of fine-grained sediment. Other properties are assigned fixed values consistent with current practice. The quantity of radionuclides released as cavings depends on the volume of eroded material and its activity, which is treated in the same manner as the activity of the cuttings.

6.0.2.3.2 Spallings

Unlike releases from cuttings and cavings, which ~~will~~ occur with every ***modeled*** borehole intrusion, spalling releases will occur only if pressure in the waste-disposal region exceeds the hydrostatic pressure in the borehole. At lower pressures, below about 8 megapascals, fluid in the waste-disposal region will not flow toward the borehole. At higher pressures, gas flow toward the borehole may be sufficiently rapid to ***cause additional solid material to enter the borehole.*** ~~entrain particulate waste.~~ If spalling occurs, the volume of spalled material ~~is~~ ***will be*** affected by the physical properties of the waste, ~~specifically~~ ***such as*** its tensile strength and particle diameter. ~~As is the case for the effective shear resistance for the waste, WIPP-specific~~

~~experimental data are not available to support parameter values for the tensile strength and average particle diameter of degraded waste and backfill.~~ The DOE has based the parameter values used in the ~~performance assessment~~***PA*** on reasonable and conservative assumptions. ***Since the original certification, a revised conceptual model for the spallings phenomena has been developed (see Appendix PA, Section 4.6 and Attachment MASS, Section 16). Model development, execution, and sensitivity studies necessitated implementing parameter values pertaining to waste characteristics, drilling practices and physics of the process. The parameter range for particle size was derived by expert elicitation (EPA 1997, II-G-24).***

The quantity of radionuclides released as spalled material depends on the volume of spalled waste and its activity. Because spalling may occur at a greater distance from the borehole than cuttings and cavings, spalled waste is assumed to have the volume-averaged activity of CH-TRU waste rather than the sampled activities of individual waste streams. RH-TRU waste is isolated from the spallings process and does not contribute to the volume or activity of spalled material.

6.0.2.3.3 Direct Brine Flow

Radionuclides may be released to the accessible environment if repository brine enters the borehole during drilling and flows to the ground surface. The quantity of radionuclides released by direct brine flow depends on the volume of brine reaching the ground surface and the concentration of radionuclides contained in the brine. As ~~is the case for~~ ***with*** spallings, direct releases of brine will not occur if repository pressure is below the hydrostatic pressure in the borehole. At higher repository pressures, ~~if~~ mobile brine ~~is~~ present in the repository~~, it~~ will flow toward the borehole. If the volume of brine flowing from the repository into the borehole is small, it will not affect the drilling operation, and flow may continue until the driller reaches the base of the evaporite section and installs casing in the borehole. This ~~length of~~ time is estimated to be 72 hours, consistent with current practice. Larger brine flows or large gas flows could cause the driller to lose control of the borehole, and fluid flow, in this case, could continue until repository pressure drops or the hole is contained. The maximum length of time that such flow ~~would be allowed to~~ ***could*** continue before ~~the borehole would be controlled by~~ the driller ***controlled the borehole*** is ***estimated to be*** 11 days, consistent with ***observed***~~current~~ drilling ***events***~~practice~~ in the Delaware Basin ***(Appendix PA, Section PA-4.7.8 and Attachment MASS, Section 16.0)***.

6.0.2.3.4 Mobilization of Actinides in Repository Brine

Actinides may be mobilized in repository brine in two principal ways:

(1) as dissolved species, and

(2) as colloidal species.

The solubilities of actinides ***depend on their oxidation states,*** ~~differ among the different oxidation states in which they may~~ ***with the more reduced forms (for example, the +III and +IV oxidation states) being less soluble than the oxidized forms (+V and +VI).*** ~~With the more reduced forms (for example, Pu-II or Pu-IV rather than Pu-V or Pu-VI) being less soluble. Conditions within the repository will be reducing because of the large quantity of iron in the waste and containers and, in some cases, only the lower solubility oxidation states will be~~

~~present.~~ ***Conditions within the repository will be strongly reducing because of the large quantity of metallic Fe in the steel containers and the waste, and – in the case of plutonium (Pu) – only the lower-solubility oxidation states (Pu(III) and Pu(IV)) will persist. Microbial activity, if it occurs, will also create reducing conditions.*** Solubilities also vary with pH. The DOE ***is***~~will~~ therefore emplac***ing***~~e~~ ~~magnesium oxide~~ ~~(~~MgO~~)~~ in the waste***-***disposal region ~~along with the waste~~ to ensure conditions that favor minimum actinide ~~solubility~~ ***solubilities***. ***MgO consumes*** CO_2 ***and buffers pH, lowering actinide solubilities in WIPP brines.*** Solubilities in the ~~performance assessment~~***PA*** are based on ~~reducing conditions, MgO backfill, and~~ the chemistry of brines that ~~can~~ ***might*** be present in the waste-disposal region, ***reactions of these brines with the MgO engineered barrier, and strongly reducing conditions produced by anoxic corrosion of steels and other Fe-based alloys.***

The waste contains organic ligands that ***could increase*** ~~, under some circumstances, can enhance~~ actinide ***solubilities*** ~~concentrations in brine~~ by forming ~~soluble~~ complexes ***with dissolved*** ~~containing~~ actinide ***species***~~ions~~. ~~However, these organic ligands also bond strongly to other metals, such as magnesium, that will be present in far larger quantities in repository brine. Because of this competition effect, organic ligands will not have a significant effect on overall actinide concentrations in brine.~~ ***However, these organic ligands also form complexes with other dissolved metals, such as magnesium (Mg), calcium (Ca), Fe, vanadium (V), chromium (Cr), manganese (Mn), and nickel (Ni), that will be present in repository brines due to corrosion of steels and other Fe-based alloys. The CRA-2004 PA speciation and solubility calculations (Attachment SOTERM) confirmed that actinide solubilities are not significantly affected by organic ligands.***

Colloidal transport of actinides has been examined and four types have been determined to represent the possible behavior at the WIPP. These include microb***ial colloids***~~es~~, humic substances, actinide intrinsic colloids, and mineral fragments. Concentrations of actinides mobilized as these colloidal forms are included in the estimates of total actinide concentrations used in ~~the~~ ~~performance assessment~~***PA***.

6.0.2.3.5 Long-Term Brine Flow up an Intrusion Borehole

Long-term releases to the ground surface or ~~into~~ groundwater in the Rustler or overlying units may occur after the borehole has been plugged and abandoned. In keeping with regulatory criteria, borehole plugs are assumed to have ~~the~~ properties consistent with current practice in the basin. Thus, boreholes are assumed to have concrete plugs emplaced at various locations. Initially, concrete plugs ~~will be~~ effective***ly*** ~~in~~ limit~~ing~~ fluid flow in the borehole. However, under most circumstances, these plugs cannot be expected to remain fully effective indefinitely. For the purposes of ~~performance assessment~~***PA***, discontinuous borehole plugs above the repository are assumed to degrade 200 years after emplacement. From then on, the borehole is assumed to ~~be~~ fill~~ed~~ with a silty sand-like material containing degraded concrete, corrosion products ~~resulting~~ from ~~degradation of~~ ***degraded*** casing, and material that sloughs into the hole from the walls. Of six possible plugged borehole configurations in the Delaware Basin, three are considered either likely or found to adequately represent other possible configurations; one configuration (a two-plug configuration) is explicitly modeled.

If sufficient brine is available in the repository, and if pressure in the repository is higher than ~~that~~ in the overlying units, brine may flow up the borehole following degradation of the plugs. In principle, this brine could flow into any permeable unit or to the ground surface if repository pressure were high enough. For modeling purposes, brine is allowed to flow only into the higher permeability units and to the surface. Lower permeability anhydrite and mudstone layers in the Rustler are treated as if they were impermeable, to simplify the analysis while maximizing the amount of flow occurring into units where it ~~has a~~ ***could*** potential***ly*** ~~to~~ contribute to releases from the disposal system. Model results indicate that essentially all flow occurs into the Culebra, which has been recognized since the early stages of site characterization as the most transmissive unit above the repository and the most likely pathway for subsurface transport.

6.0.2.3.6 Groundwater Flow in the Culebra

Site characterization activities in the units above the Salado have focused on the Culebra. These activities have shown that the direction of groundwater flow in the Culebra varies somewhat regionally, but in the area that lies over the site, flow is southward. Regional variation in groundwater flow direction in the Culebra is influenced by the ~~regional variation in~~ transmissivity observed and also by the shape of and distribution of rock types in the groundwater basin ~~in which~~ ***where*** the WIPP is located. Site characterization activities have demonstrated that there is no evidence of karst groundwater systems in the controlled area, although groundwater flow in the Culebra is affected by the presence of fractures, fracture fillings, and vuggy pore features. ~~A zone of relatively high transmissivity in the Culebra in the southeast portion of the controlled area has been identified as the most important flow path away from the waste disposal panels, based on analysis of regional groundwater pumping tests.~~ Other laboratory and field activities have focused on the behavior of dissolved and colloidal actinides in the Culebra. These characterization and modeling activities conducted in the units above the Salado confirm that the Culebra is the most transmissive unit above the Salado. The Culebra is the unit into which actinides are likely to be introduced from long-term flow up an abandoned borehole.

Basin-scale regional modeling of three-dimensional groundwater flow in the units above the Salado demonstrates that it is appropriate, for the purposes of estimating radionuclide transport, to conceptualize the Culebra as a two-dimensional confined aquifer. ~~As modeled in the performance assessment, the steady-state flow field within the Culebra is affected only by the initial head distribution and the spatial variability of the transmissivity of the unit. Field data for both transmissivity and head are available from many locations in the Culebra.~~ Uncertainty in the flow field is incorporated in the analysis ~~through the use of~~ ***by using*** 100 different geostatistically-based transmissivity fields, each of which is consistent with available head and transmissivity data.

Groundwater flow in the Culebra is modeled as a steady-state process, but two mechanisms ~~are~~ considered in the ~~performance assessment~~***PA*** ~~that~~ could affect flow in the future. Potash mining in the McNutt Potash Zone (hereafter referred to as the McNutt) of the Salado, which occurs now in the Delaware Basin outside the controlled area and ~~which~~ may continue ~~to occur~~ in the future, ~~has the potential to~~ ***could*** affect flow in the Culebra if subsidence over mined areas causes fracturing or other changes in rock properties. Climatic changes during the next 10,000 years may also affect groundwater flow by altering recharge to the Culebra.

Consistent with regulatory criteria, mining outside the controlled area is assumed to occur in the near future, and mining within the controlled area is assumed to occur with a probability of 1 in 100 per century (adjusted for the effectiveness of ***active*** institutional controls during the first ***100*** ~~700~~ years following closure). Consistent with regulatory guidance, the effects of mine subsidence are incorporated in the ~~performance assessment~~***PA*** by increasing the transmissivity of the Culebra over the areas identified as mineable by a factor sampled from a uniform distribution between 1 and 1000. Transmissivity fields used in the ~~performance assessment~~***PA*** are therefore adjusted and steady-state flow fields calculated accordingly; once for ~~the case in which~~ mining ~~is assumed to~~ ***that*** occur***s*** only outside the controlled area, and once for ~~the case in which~~ mining ~~is assumed to~~ ***that*** occur***s*** both inside and outside the controlled area. Mining outside the controlled area is considered in both undisturbed and disturbed performance.

The extent to which ***the*** climate will change during the next 10,000 years and ~~the extent to which~~ ***how*** such ***a*** change will affect groundwater flow in the Culebra are uncertain. Regional three-dimensional modeling of groundwater flow in the units above the Salado indicates that flow velocities in the Culebra may ~~be~~ increase~~d~~ by a factor of ~~between~~ 1 ~~and~~ ***to*** 2.25 for reasonably possible future climates. This uncertainty is incorporated in the ~~performance assessment~~***PA*** by scaling the calculated steady-state specific discharge within the Culebra by a sampled parameter within this range.

6.0.2.3.7 Actinide Transport in the Culebra

Field tests have shown that the Culebra is best characterized as a double-porosity medium for ~~the purposes of~~ estimating contaminant transport in groundwater. Groundwater flow and advective transport of dissolved ***or colloidal*** species ~~or colloidal~~ ***and*** particles occurs primarily in a small fraction of the ***rock's*** total porosity ~~of the rock~~ and ~~thus~~ ~~corresponds~~ ***corresponding*** to the porosity of open and interconnected fractures and vugs. Diffusion and slower ***advective*** flow occur in the remainder of the porosity, which is associated with the low-permeability dolomite matrix. Transported species, including actinides, if present, will diffuse into this porosity.

Diffusion ~~out of~~ ***from*** the advective porosity into the dolomite matrix will retard actinide transport by two mechanisms. Physical retardation occurs simply because actinides that diffuse into the matrix are no longer transported with the flowing groundwater. Transport is interrupted until they diffuse back into the advective porosity. In situ tracer tests have been conducted to demonstrate this phenomenon. Chemical retardation also occurs within the matrix as actinides are sorbed onto dolomite grains. The relationship between sorbed and liquid concentrations is assumed to be linear~~,~~ and ***reversible. T***~~t~~he distribution coefficients (K_ds) that characterize the extent to which actinides will sorb on dolomite ~~are~~ ***were*** based on experimental data***. Based on their review of the CCA, the EPA required the DOE to use the same ranges but to change the distribution from uniform to log uniform. The DOE continues to use EPA's distributions in CRA-2004 PA. The DOE also corrected a minor error in the calculation of*** K_d***s (see Appendix PA, Attachment PAR).***

Modeling indicates that physical and chemical retardation, as supported by field tests and laboratory experiments, will be extremely effective in reducing the transport of dissolved actinides in the Culebra. Experimental work has demonstrated that transport of colloidal actinides is not a significant mechanism in the Culebra. As a result, actinide transport through the Culebra to the subsurface boundary of the controlled area is not a significant pathway for releases from the WIPP. As discussed in Section 6.5.3, the location of the mean CCDF that demonstrates compliance with the containment requirements of 40 CFR § 191.13 is, determined entirely by direct releases at the ground surface during drilling (cuttings, cavings, and spallings).

6.0.2.3.8 Intrusion Scenarios

Human intrusion scenarios evaluated in the ~~performance assessment~~***PA*** include both single intrusion events and combinations of multiple boreholes. Two different types of boreholes are considered:

(1) those that penetrate a pressurized brine reservoir in the underlying Castile Formation ***(hereafter referred to as the Castile)***, and

(2) those that do not.

The presence of a brine reservoir under the repository is speculative, but cannot be ruled out ~~by available~~ ***on the basis of current*** information. A pressurized brine reservoir was encountered at the WIPP-12 borehole within the controlled area to the northwest of the disposal region and other pressurized brine reservoirs that are associated with regions of deformation in the Castile have been encountered elsewhere in the Delaware Basin. Based on a geostatistical analysis of the distribution of brine encounters in the region, the DOE has estimated that there was a 0.08 probability that a~~ny~~ random borehole that penetrates waste in the WIPP will also penetrate an underlying brine reservoir. ***Upon their review of the CCA, the EPA determined that the DOE should treat this probability as uncertain, ranging from 0.01 to 0.60 in the PAVT. This recertification application uses the EPA's PAVT range (see Appendix PA, Section PA-3.5).*** ~~Properties are assigned to the hypothetical reservoir (for example, its pressure and volume) that are consistent with the available information from tests at WIPP-12 and other boreholes. These properties are also made consistent with the hypothetical reservoir's location under the waste disposal region.~~ ***The EPA also required the DOE to modify the assumptions concerning Castile properties to increase the brine reservoir volumes (EPA 1998 VII.B.4.d). The EPA determined that changing the rock compressibility of the Castile and the Castile porosity effectively modified the sampled brine reservoir volume to include the possibility of larger brine reservoir volumes like those encountered by the WIPP-12 borehole.***

The primary consequence of penetrating a pressurized reservoir ~~will be~~ ***is*** to provide an additional source of brine beyond that which ***might*** flow~~s~~ into the repository from the Salado. Direct releases at the ground surface resulting from the first ~~intrusion into the~~ repository ***intrusion would*** ~~will~~ be unaffected by ~~the presence of~~ additional Castile brine even if it flow~~s~~***ed*** to the surface, because brine moving straight up a borehole will not mix significantly with waste. ***However, t***~~T~~he presence of Castile brine ~~has the potential to~~ ***could*** increase radionuclide releases significantly in two ways~~, however~~. First, the volume of contaminated brine that could flow to the surface may be greater for a second or subsequent intrusion into a repository that has already been connected ***by a previous borehole*** to a Castile reservoir. Second, the volume of contaminated brine that may flow up an abandoned borehole after plugs have degraded may be greater for combinations of two or more boreholes that intrude the same panel if one of the boreholes penetrates a pressurized reservoir. Both processes are modeled in the ~~performance assessment~~***PA***.

6.0.2.4 Compliance Demonstration Method

The DOE's approach to demonstrating ***continued*** compliance is the ~~performance assessment~~***PA*** methodology described in Section 6.1. The ~~performance assessment~~***PA*** process ~~is based on a~~ comprehensive***ly*** ~~consideration of~~ ***considers*** the FEPs ~~that are~~ relevant to disposal system performance. Those FEPs ~~that are~~ shown by screening analyses to ~~have the~~ potential***ly*** ~~to~~ affect performance are included in quantitative calculations using a system of linked computer models to describe the interaction of the repository with the natural system, both with and without human intrusion. Uncertainty is incorporated in the analysis ~~through~~ ***by*** a Monte Carlo approach in which multiple simulations (or realizations) are completed using sampled values for ***64*** ~~57~~ imprecisely known or naturally variable input parameters. Distribution functions are constructed that characterize the state of knowledge for these parameters, and each realization of the modeling system uses a different set of sampled input values. A sample size of 100 results in 100 different values of each parameter. Therefore, there are 100 different sets (vectors) of input parameter values. Quality assurance (QA) activities, described in Chapter 5.0, demonstrate that the parameters, software, and analysis used in the ~~performance assessment~~***PA*** were the result of a rigorous process conducted under controlled conditions.

~~Probabilities of s~~***S***cenario~~s~~ ***probabilities*** composed of specific combinations of FEPs are estimated based on regulatory criteria (~~applying~~ ***applied*** to the probability of future human action) and the understanding of the natural and engineered systems. Cumulative radionuclide releases from the disposal system are calculated for each scenario considered and ~~probabilities of the~~ scenario~~s~~ ***probabilities*** are summed for each ~~of the~~ modeling system realization to construct distributions of CCDFs. ~~Sampling of the i~~***I***nput parameter~~s~~ ***sampling*** was performed in three separate replicates, resulting in three independent distributions of CCDFs and allowing the construction of three independent mean CCDFs, each based on 100 individual CCDFs.

6.0.2.5 Results of the Performance Assessment

Section 6.5 addresses the Containment Requirements of 40 CFR Part 191 and the associated criteria of 40 CFR § 194.34. Section 6.5 presents distributions of CCDFs for each replication of the analysis, mean CCDFs, and an overall mean CCDF~~, together~~ with the 95 percent confidence interval estimated from the ~~of the~~ three independent mean~~s~~ distribution***s***.

Families of CCDFs and mean CCDFs for each of the three replicates are also shown in Section 6.5. All 300 individual CCDFs lie below and to the left of the limits specified in 40 CFR § 191.13(a). The overall mean CCDF determined from the three replicates lies entirely below and to the left of the limits specified in 40 CFR § 191.13(a). Thus, the WIPP ***continues to comply*** ~~is in compliance~~ with the containment requirements of 40 CFR Part 191. ~~Comparison of~~ ***Comparing*** the results of the three replicates indicates that the sample size of 100 in each replicate is sufficient to generate a stable distribution of outcomes. Within the region of regulatory interest (that is, at probabilities greater than $10^{-3}/10^{4}$ yr), the mean CCDFs from each replicate are essentially indistinguishable from the overall mean.

As discussed in Section 6.5, ~~examination of~~ ***examining*** the normalized releases ~~resulting~~ from cuttings and cavings, spallings, and direct brine release provides insight into the relative importance of each release mode***'s*** ~~in terms of its~~ contribution to the ~~location of the~~ mean CCDF***'s location*** and the compliance determination. Releases from cuttings and cavings dominate the mean CCDF. Spallings make a small contribution. Direct brine releases are less important and have very little effect on the location of the mean. Subsurface releases resulting from groundwater transport are less than 10^{-6} EPA units and make no contribution to the ~~location of the~~ mean CCDF***'s location***.

Uncertainties characterized in the natural system and the interaction of waste with the disposal system environment have little effect on the location of the mean CCDF, providing additional confidence in the compliance determination. The natural and engineered barrier systems of the WIPP provide robust and effective containment of TRU waste even if the repository is penetrated by multiple borehole intrusions.

6.1 Performance Assessment Methodology

The EPA, in 40 CFR Part 191, specifies the generally applicable environmental standards for ~~the protection of~~ ***protecting*** public health and the environment ~~for~~ ***from*** the disposal of TRU and high-level radioactive wastes. In this ~~chapter~~ ***section***, the DOE addresses compliance with the Containment Requirements of 40 CFR § 191.13 and the associated portions of 40 CFR Part 194 ***for TRU waste***.

~~The complete text of the 40 CFR §~~***Section*** 191.13 ~~Containment Requirements follows~~***states***:

> (a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation, based on performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:
>
> (1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A); and
>
> (2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A).
>
> (b) Performance assessments need not provide complete assurance that the requirements of § 191.13(a) will be met. Because of the long time period involved and the nature of the events and processes of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with § 191.13(a) will be achieved.

The term accessible environment is defined as***:*** "(1) The atmosphere; (2) land surfaces; (3) surface waters; (4) oceans; and (5) all of the lithosphere that is beyond the controlled area" (40 CFR § 191.12). Further, controlled area means***:*** "(1) A surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system; and (2) the subsurface underlying such a surface location" (40 CFR § 191.12). The controlled area established by the LWA is shown in Figure 3-1 ~~(see Chapter 3.0)~~. The release limits listed in Appendix A of 40 CFR Part 191 are reproduced as Table ~~6-1~~***6-2***.

For a release to the accessible environment that involves a mix of radionuclides, the limits in Table ~~6-1~~***6-2*** are used to determine a normalized release (*nR*) of radionuclides for comparison with the release limits

$$nR = \sum_i \left(Q_i / L_i\right)\left(1 \times 10^6\ Ci/C\right), \qquad (\textbf{\textit{6}}.1)$$

where

Q_i = cumulative release in curies (Ci) of radionuclide i into the accessible environment during the 10,000-year period following ~~of the~~ repository closure.
L_i = release limit in curies for radionuclide i given in
C = amount of ~~curies of~~ TRU waste ***curies to be*** emplaced in the repository~~.~~ (~~A~~***a***s described in Section 4.1, TRU wastes contain alpha-emitting transuranic radionuclides with half-lives greater than 20 years~~.~~)**.**

As indicated in Note 1(e) to Table 1 in Appendix A of 40 CFR Part 191, the "other unit of waste" for TRU waste shall be "an amount of transuranic wastes containing 1 million curies of alpha-emitting transuranic radionuclides with half-lives greater than 20 years."

~~Performance assessments~~***PAs*** are the basis for addressing the containment requirements. 40 CFR § 191.12 defines performance as follows:

> "Performance assessment" means an analysis that: (1) identifies the processes and events that might affect the disposal system; (2) examines the effects of these processes and events on the performance of the disposal system; and (3) estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events.

The DOE's methodology for ~~performance assessment~~***PA*** uses information about the disposal system and the waste to evaluate performance in a regulatory context over the 10,000-year regulatory time period.

The general theory for conducting a ~~performance assessment~~***PA*** is presented in this section together with details specific to the ~~performance assessment~~***PA*** conducted for the WIPP. Figure 6-2 illustrates the general, high-level steps used by the DOE for this final ~~performance assessment~~***PA*** of the WIPP. In this figure, the sections of this chapter are indicated ~~in which these steps~~ ***that*** ~~are~~ discusse~~d~~ ***these steps*** in detail, and ~~it shows~~ several important features of the WIPP ~~performance assessment~~***PA are shown***. ~~It indicates the points at which regulatory standards and guidance (40 CFR Part 191 and related documents) are most influential, and it shows that there can be an iterative process between site characterization and performance assessment that facilitates improvement in both characterization data and performance assessment. Through this process, the DOE has used early site characterization information and~~

Table *6-2*~~6-1~~. Release Limits for the Containment Requirements (EPA 1985, Appendix A, Table 1)

Radionuclide	Release Limit L_i per 1,000 MTHM~~[a]~~*[1]* or Other Unit of Waste (curies)
^{241}Am or ^{243}Am	100
^{14}C	100
^{135}Cs or ^{137}Cs	1,000
^{129}I	100
^{237}Np	100
^{238}Pu, ^{239}Pu, ^{240}Pu, or ^{242}Pu	100
^{226}Ra	100
^{90}Sr	1,000
^{99}Te	10,000
^{230}Th or ^{232}Th	10
^{126}Sn	1,000
^{233}U, ^{234}U, ^{235}U, ^{236}U, or ^{238}U	100
Any other alpha-emitting radionuclide with a half-life greater than 20 years	100
Any other radionuclide with a half-life greater than 20 years that does not emit alpha particles	1,000

~~[a]~~ *[1]* Metric tons of heavy metal exposed to a burnup between 25,000 megawatt-days per metric ton of heavy metal (MWd/MTHM) and 40,000 MWd/MTHM.

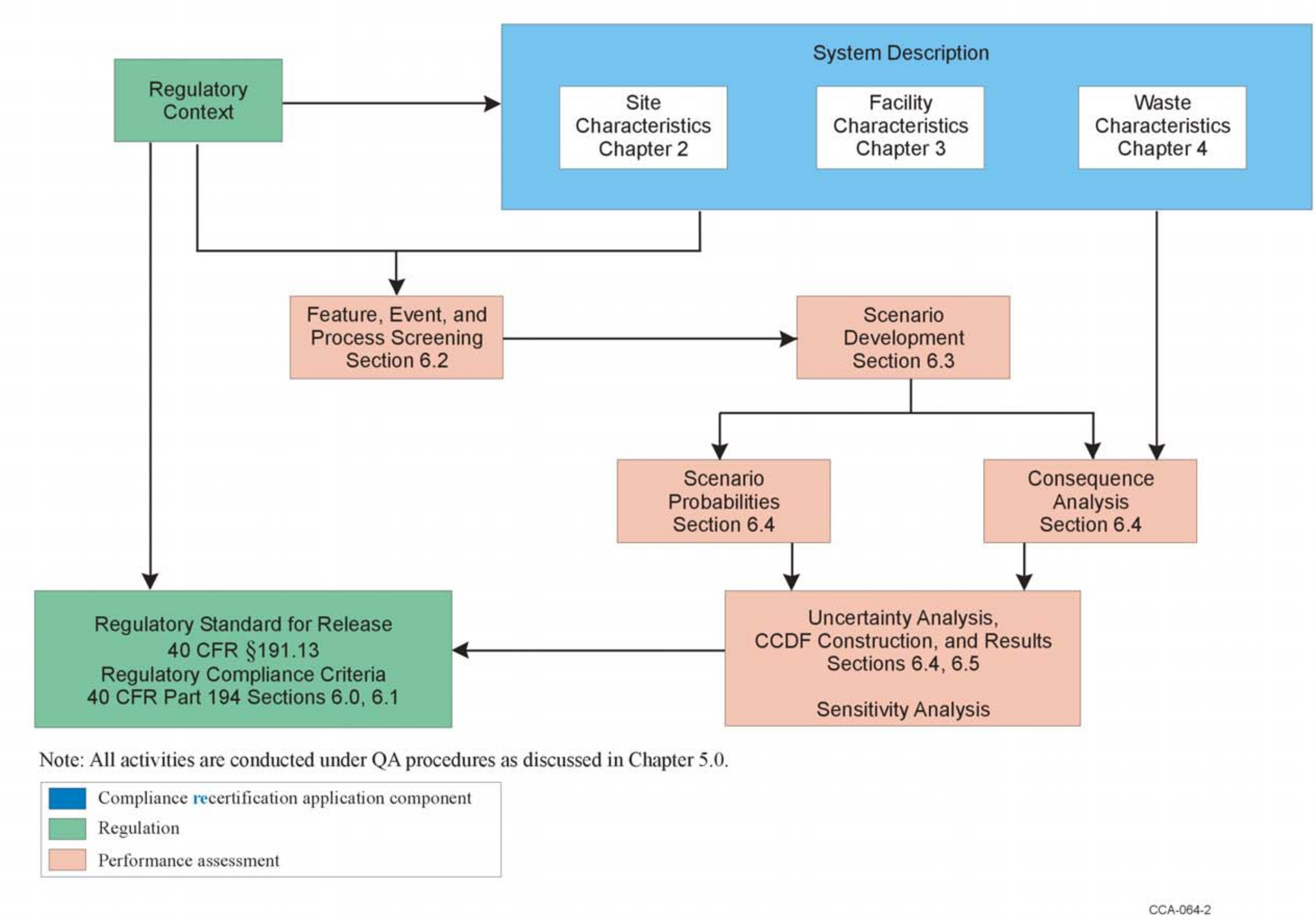
~~design specifications to develop preliminary performance assessments, from which sensitivity analyses were used to guide further characterization of important of the site data collection features on specific topics and to further develop the repository design.~~ Section 6.1 presents the basis for the methodology shown in Figure ~~6-1~~*6-2*. Section 6.1.1 presents the conceptualization of risk, Section 6.1.2 discusses the characterization of uncertainty in risk, Section 6.1.3 discusses regulatory criteria for the quantification of risk, Section 6.1.4 discusses calculation of risk, and Section 6.1.5 discusses techniques for probabilistic analysis.

6.1.1 *Conceptualization of Risk*

The WIPP ~~performance assessment~~***PA*** is fundamentally concerned with ~~the evaluation of~~ ***evaluating*** risk, for which comparative measures are defined by regulatory standards. ~~For comparison with these standards, t~~***T***he DOE uses a conceptualization for risk similar to that developed for risk assessments of nuclear power plants. This description provides a structure on which both the representation and calculation of risk can be based.

Kaplan and Garrick (1981, 11-12) have ~~presented the representation of~~ ***represented*** risk as a set of ordered triples. The DOE uses this representation and defines risk to be a set R of the form

$$\mathrm{R} = \left[\left(S_i,\ pS,\ \mathbf{c}\mathbf{S}_i \right),\ i = 1, \ldots, nS \right], \qquad (\mathbf{\mathit{6}}.2)$$



Note: All activities are conducted under QA procedures as discussed in Chapter 5.0.

Figure ~~6-1~~*6-2*. Methodology for ~~performance assessment~~*PA* of the WIPP

where

S_i = a set of similar occurrences
pS_i = probability that an occurrence in set S_i will take place
$\mathbf{cS}_i$ = a vector of consequences associated with S_i
nS = number of sets selected for consideration

and the sets S_i have no occurrences in common (that is, the S_i are disjoint sets). This representation formally decomposes risk into what can happen (the S_i), how likely things are to happen (the pS_i), and the consequences of what can happen (the $\mathbf{cS}_i$). In the WIPP ~~performance assessment~~***PA***, the S_i are scenarios, the pS_i are scenario probabilities, and the vector $\mathbf{cS}_i$ contains consequences associated with scenario S_i. ***Scenario*** ~~D~~***d***evelopment ~~of the scenarios~~ for the WIPP is discussed in Sections 6.1.2, 6.2, and 6.3. Scenario probabilities and consequence determination are discussed in Section 6.4.

As discussed in the following sections~~ of this chapter~~, risk in the set R can be displayed using CCDFs, as required by the EPA. As stated in 40 CFR § 194.34(a),

> The results of performance assessments shall be assembled into "complementary, cumulative distribution functions" (CCDFs) that represent the probability of exceeding various levels of cumulative release caused by all significant processes and events.

In the context of Equation ***(6.***2***)***, CCDFs provide information about the consequences $\mathbf{cS}_i$ and the probabilities pS_i associated with the scenarios S_i. The probability that $\mathbf{cS}$ exceeds a specific consequence value x is determined by the CCDF F defined by

$$F\left(x\right)=\sum_{j=i}^{nS} pS_j, \qquad (6.3)$$

where the particular consequence result $\mathbf{cS}$ under consideration is ordered so that $\mathbf{cS}_i \leq \mathbf{cS}_{i+1}$ for $i = 1, \ldots, nS-1$, and i is the smallest integer such that $\mathbf{cS}_i > x$. The function F represents the probabilities that consequence values plotted on the abscissa will be exceeded. A***n*** ~~diagrammatic~~ example ~~of an~~ estimation of F is shown in Figure ~~6-2~~***6-3***. The steps in the CCDF shown in Figure ~~6-2~~***6-3*** result from the evaluation of F with a discrete number of possible occurrences (that is, futures) represented in the sets S_i. Unless the underlying processes are inherently disjoint, ~~the use of~~ ***using*** more sets S_i will tend to reduce the size of these steps and, in the limit, ~~will~~ result in a smooth curve. To avoid a broken appearance, the DOE plots estimated CCDFs with vertical lines added at the discontinuities.

6.1.2 Characterization of Uncertainty in Risk

~~The DOE defines~~ ***U***~~u~~ncertainty in the analysis ***can be*** ~~as~~ either stochastic ~~uncertainty~~ or subjective ~~uncertainty~~. Stochastic uncertainty derives from lack of knowledge about the future. Subjective uncertainty derives from lack of knowledge about quantities, properties, or attributes ~~that are~~ believed to have single or certain values. Stochastic uncertainty can be further subdivided into completeness, aggregation, and stochastic variation. Completeness refers to the extent that a ~~performance assessment~~***PA*** includes all possible occurrences ***that could affect performance*** for the system under consideration. In terms of the risk representation in Equation

(***6.***2), completeness deals with whether all significant occurrences are included in the union of the sets S_i. The DOE addresses completeness in its development of scenarios, discussed here and in Sections 6.2 and 6.3. Aggregation refers to the division of the possible occurrences into the sets S_i. Resolution is lost if the S_i are defined too coarsely (for example, if nS is too small). Computational efficiency is affected if nS is too large. Aggregation gives rise to the steps in a single CCDF, as shown in Figure ~~6-2~~***6-3***. The DOE addresses aggregation uncertainty in Sections 6.1.4 and 6.4.13. Stochastic variation is represented by the probabilities pS_i, which are functions of the many factors that affect the occurrence of the individual sets S_i. The DOE addresses stochastic variation in Sections 6.1.4 and 6.4.12.

Stochastic uncertainty ***is taken into account*** ~~can be characterized~~ in ~~performance assessment~~***PA*** by evaluating the probability of future events (for example, by assuming that the occurrence of certain future events will be random in space and time), and by ~~consideration of~~ ***considering*** imprecisely known system properties directly associated with the future events. These imprecisely known system properties can be expressed as variables represented by the vector

$$\mathbf{x_{st}} = [x_{st,1}, x_{st,2}, \ldots, x_{st,nV(st)}] \, , \tag{6.4a}$$

where each $x_{st,j}$ [$j = 1, 2, \ldots, nV(st)$] is an imprecisely known property required in the analysis, nV is the total number of such properties associated with stochastic uncertainty, and the subscript st denotes stochastic uncertainty.

Subjective uncertainty results from incomplete data or measurement uncertainty. These uncertainties are addressed in Section 6.4. Subjective quantities, properties, or attributes may be associated with stochastic uncertainties (events that might occur in the future).

Subjective uncertainty can be characterized in ~~performance assessment~~***PA*** by ~~consideration of~~ ***considering*** system properties that are imprecisely known. These imprecisely known system properties can be expressed as variables represented by vectors

$$\mathbf{x_{su}} = [x_{su,1}, x_{su,2}, \ldots, x_{su,nV(su)}] \, , \tag{6.4b}$$

where each $x_{su,j}$ [$j = 1, 2, \ldots, nV(su)$] is an imprecisely known property required in the analysis, nV is the total number of such properties associated with subjective uncertainty, and the subscript su denotes subjective uncertainty.

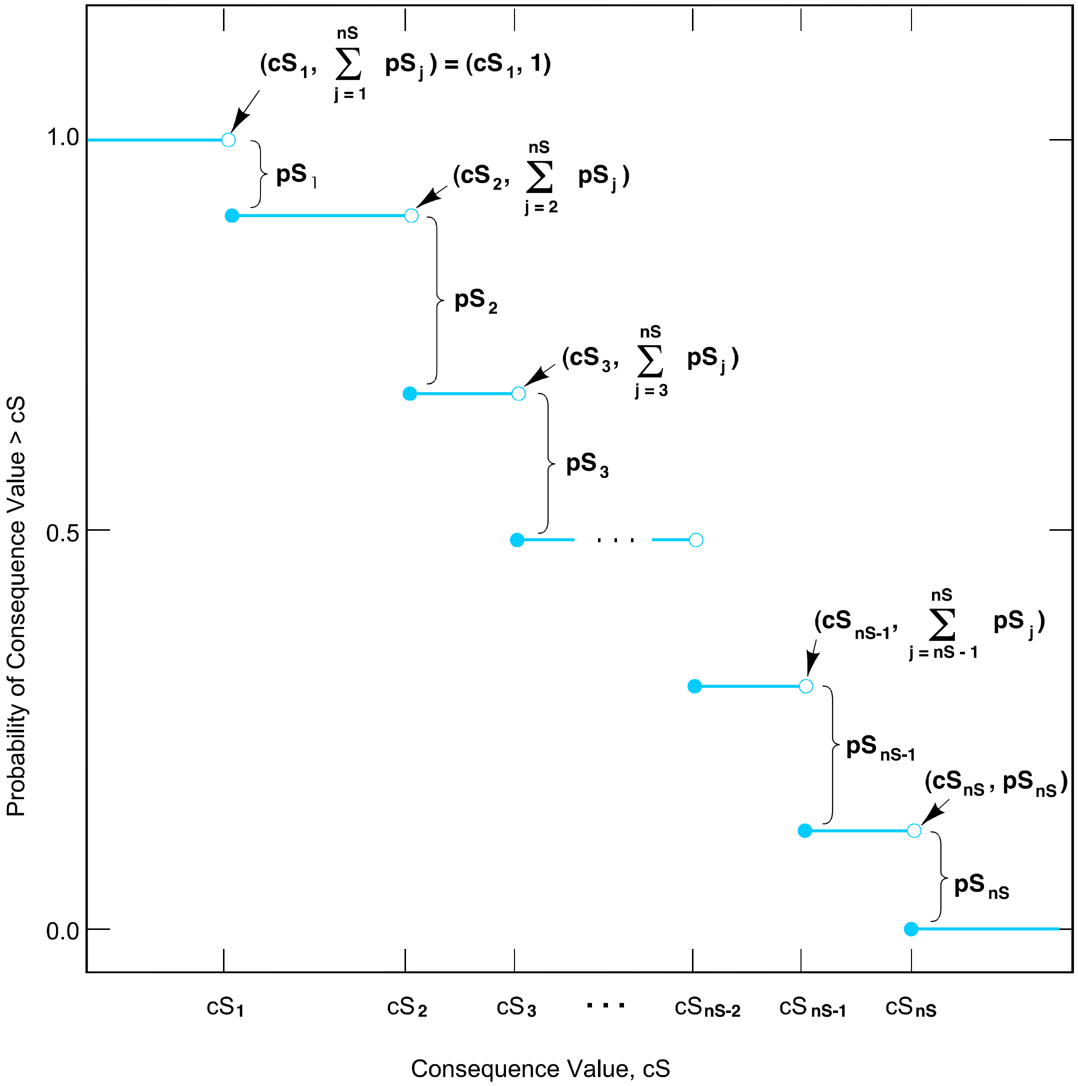
If the analysis has been developed ~~such~~ ***so*** that each x_j is a quantity for which the overall analysis requires a single value, the representation for risk in Equation ***6.***2 can be restated as a function of $\mathbf{x_{st}}$ and $\mathbf{x_{su}}$:

$$\mathrm{R}(\mathbf{x}_{\mathrm{su}}) = [S_i(\mathbf{x}_{\mathrm{su}}), pS_i(\mathbf{x}_{\mathrm{su}}), \mathbf{cS}_i(\mathbf{x}_{\mathrm{st,i}}, \mathbf{x}_{\mathrm{su}}), i = 1, \ldots, nS(\mathbf{x}_{\mathrm{st}}, \mathbf{x}_{\mathrm{su}})] \, , \tag{6.5}$$

where $\mathrm{x}_{st,i}$ is included in S_i. Probability distributions are then assigned to the individual variables $x_{su,j}$ and $x_{st,j}$, as defined in Equation ***6.***4. These probability distributions are of the form

$$D_{st,1}, D_{st,2}, \ldots, D_{st,nV(st)} \, , \tag{6.6a}$$

$$D_{su,1}, D_{su,2}, \ldots, D_{su,nV(su)} \, , \tag{6.6b}$$



Note: The open and solid circles at the discontinuities indicate the points included on (solid circles) and excluded from (open circles) the CCDF.

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Figure ~~6-2~~*6-3*. Estimated CCDF For Consequence Results

where the D_js are the distributions developed for the variables $x_j, j = 1, 2,...nV$, and the subscripts *st* and *su* denote distributions associated with $\mathbf{x}_{st}$ or $\mathbf{x}_{su}$. The definition of these distributions may also be accompanied by the specification of correlations and various restrictions that further define the possible relations among the x_j. These distributions (along with specified correlations or restrictions) probabilistically specify what the appropriate input to use in the ~~performance assessment~~*PA* calculations might be, given that the analysis is structured so that only one value can be used for each variable, x_j, under consideration for a particular calculation.

Monte Carlo techniques can be used to determine the uncertainty in R($\mathbf{x}_{su}$) associated with both $\mathbf{x}_{st}$ and $\mathbf{x}_{su}$. The theory of this technique is similar for ~~characterization of~~ ***characterizing*** both stochastic and subjective uncertainty. This technique as applied to determining the risk $R(\mathbf{x}_{su})$ associated with $\mathbf{x}_{su}$ is developed in the following paragraphs.

Once the distributions in Equation ***6.***6b have been developed, a sample

$$\mathbf{x}_k = (x_{k1}, x_{k2}, \ldots, x_{k,nV}),\ k = 1, \ldots, nK \qquad (6.7)$$

is generated according to the specified distributions and restrictions where nK is the size of the sample. ~~Performance assessment~~***PA*** calculations are then performed for each sample element $\mathbf{x}_k$, which yields a sequence of risk results of the form

$$R(\mathbf{x}_k) = \{[S_i(\mathbf{x}_k), pS_i(\mathbf{x}_k), \mathbf{cS}_i(\mathbf{x}_k)], i = 1, \ldots, nS(\mathbf{x}_k)\}\ . \qquad (6.8)$$

Each set $R(\mathbf{x}_k)$ is the result of one complete set of calculations performed with a set of inputs (that is, $\mathbf{x}_k$) obtained from the distributions assigned in Equation ***6.***6b. Further, associated with each risk result $R(\mathbf{x}_k)$ in Equation ***6.***8 is a weight[1] that can be used in making probabilistic statements about the distribution of $R(\mathbf{x})$.

A single CCDF can be produced for each set $R(\mathbf{x}_k)$ of results shown in Equation ***6.***8, yielding a family of CCDFs of the form shown in Figure ~~6-3~~***6-4***. The distribution of CCDFs in Figure 6-4 can be summarized with the mean and percentile curves shown in Figure ~~6-4~~***6-5***. These curves result from connecting the mean and percentile values corresponding to individual consequence values on the abscissa of Figure ~~6-3~~***6-4***. The percentile curves ~~provide a~~ probabilistic***ally*** represent~~ation of~~ the estimated exceedance probability given a fixed consequence value. For example, the probability is 0.8 that the exceedance probability for a particular normalized release is located between the 10 and 90 percentile curves.

To summarize, ~~consideration of~~ ***considering*** a family of CCDFs allows a distinction between stochastic uncertainty that controls the shape of a single CCDF and subjective uncertainty that results in a distribution of CCDFs. The stepwise shape of a single CCDF reflects aggregation of future events into similar groups. A family of CCDFs arises from imperfect knowledge of quantifiable properties, or, in other words, subjective uncertainty. The distribution arising from subjective uncertainty involves an infinite number of CCDFs; a family of CCDFs is a sample of finite size.

6.1.3 Regulatory Criteria for the Quantification of Risk

The representation for risk in Equation ***6.***2 provides a conceptual basis for ~~the calculation of~~ ***calculating*** the CCDF ~~for~~ ***of*** normalized releases specified in 40 CFR § 194.34(a). Further, this representation provides a structure that can be used for both the incorporation of uncertainties and the representation of the effects of uncertainties, as stated in 40 CFR § 194.34.

---

[1] In random or Latin hypercube sampling (LHS), this weight is the reciprocal of the sample size (that is, $1/nK$) and can be used in estimating means, cumulative distribution functions, and other statistical properties. This weight is often referred to as the probability for each observation (that is, sample $\mathbf{x}_k$). However, this usage is not technically correct. If continuous distributions are involved, the actual probability of each observation is zero.

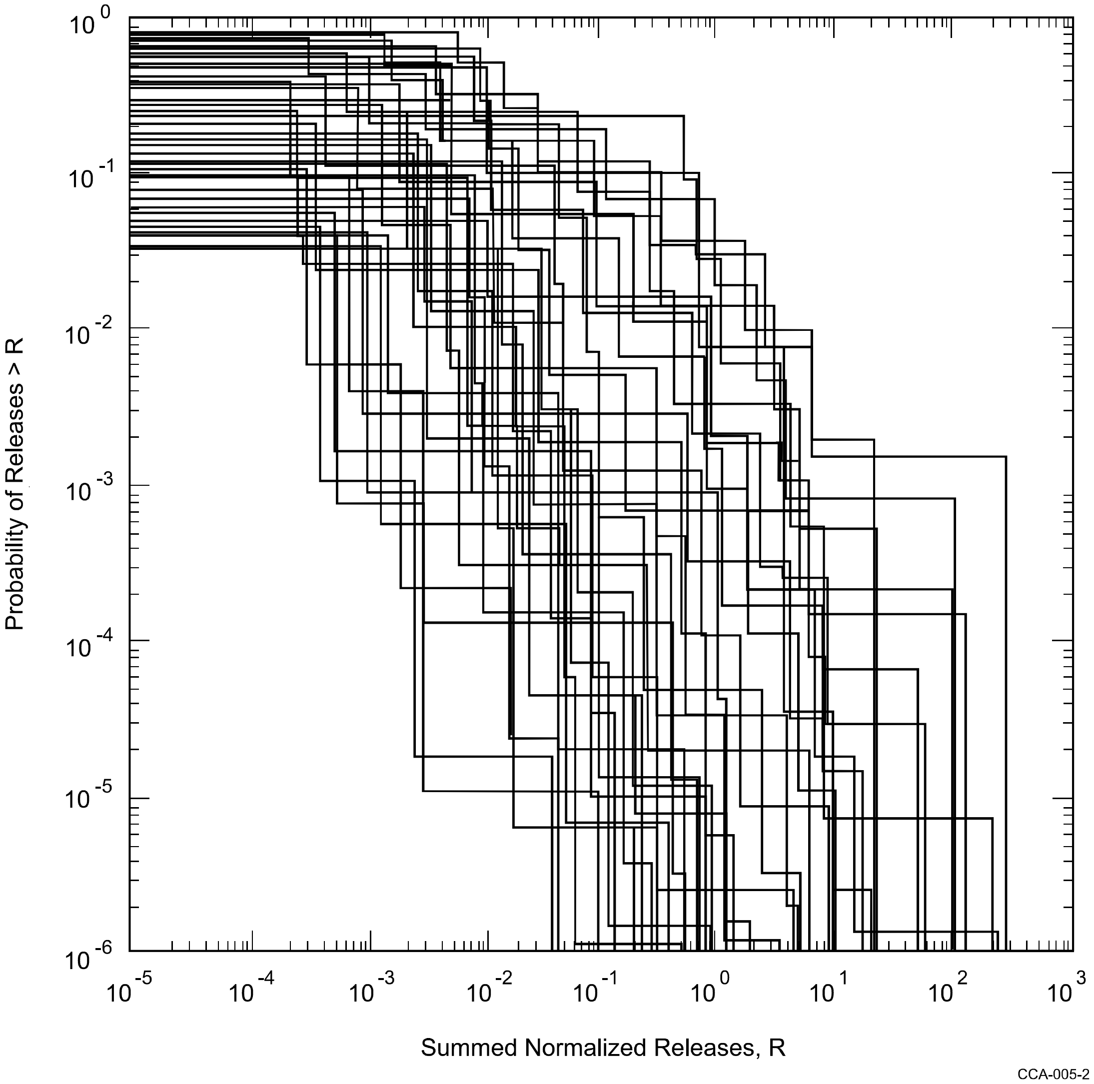
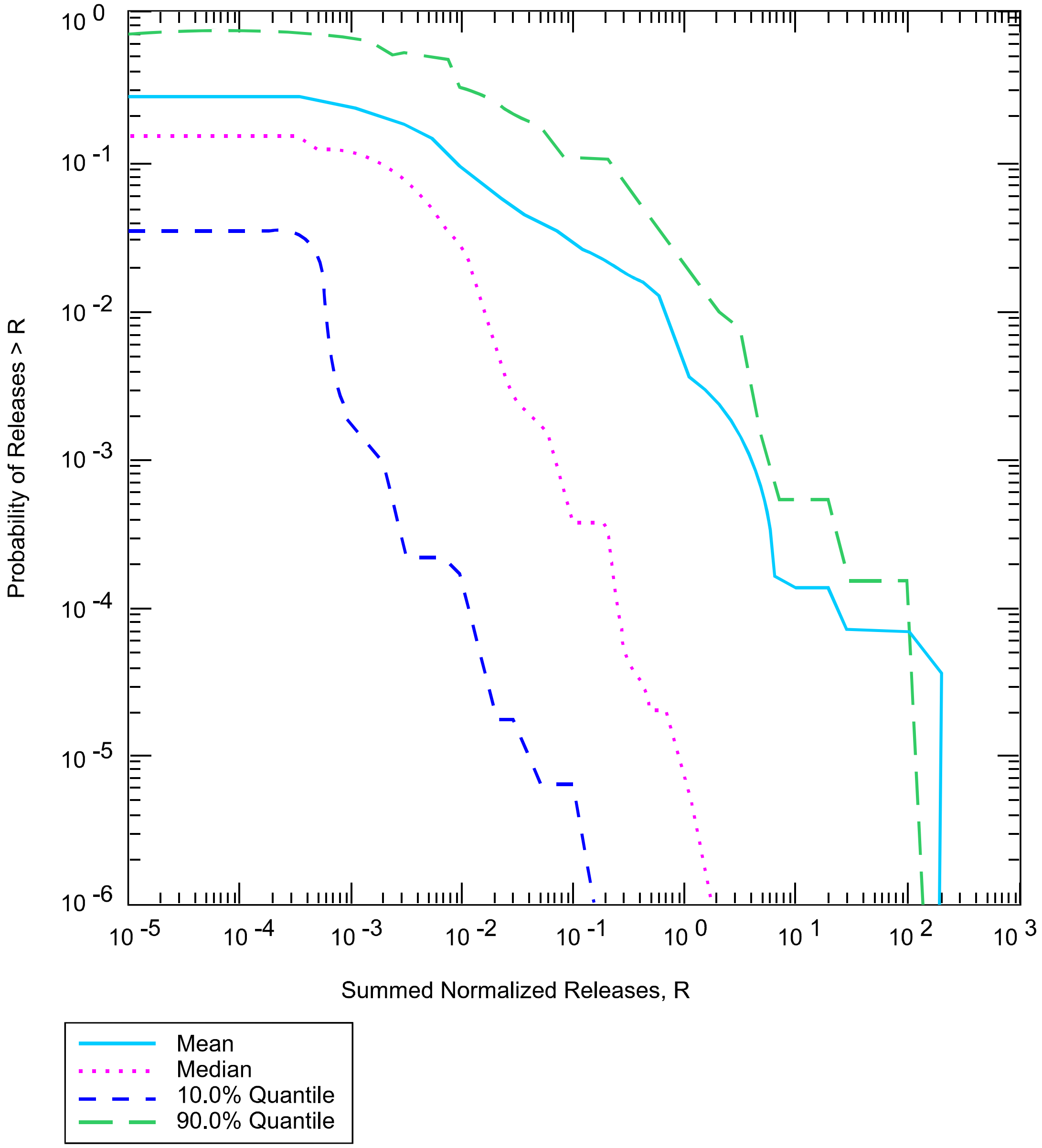


Figure ~~6-3~~*6-4*. Example Distribution of a Family of CCDFs Obtained by Sampling Imprecisely Known Variables

In 40 CFR § 194.34(b), the EPA states that "probability distributions for uncertain disposal system parameter values used in performance assessments shall be developed and documented in any compliance application." The treatment of uncertain parameter values in the performance assessment is discussed in Sections 6.1.4, 6.1.5, and 6.4. Further discussion of distributions assigned to uncertain parameter values is provided in Appendix ***PA, Attachment PAR*** ~~PAR (Section PAR.2)~~.

In 40 CFR § 194.34(c), the EPA states that documentation of the computational techniques used to generate random samples shall be provided. The sampling techniques used are discussed in Section 6.1.5.2. Sampled values are reproduced in tabular form in Appendix ***PA, Attachment PAR*** ~~IRES (Section IRES.1)~~.



Note: The curves in this figure were obtained by calculating the mean and the indicated percentiles for each consequence value on the abscissa in Figure 6-3. The 90th-percentile curve crosses the mean curve because of highly skewed distributions for exceedance probability. This skew also results in the mean curve being above the median curve.

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Figure ~~6-4~~*6-5*. Example Summary Curves Derived from an Estimated Distribution of CCDFs

In 40 CFR § 194.34(d), the EPA states that "the number of CCDFs generated shall be large enough such that, at cumulative releases of 1 and 10, the maximum CCDF generated exceeds the 99th percentile of the population of CCDFs with at least a 0.95 probability." The CCDFs resulting from this ~~performance assessment~~***PA*** are provided in Section 6.5,~~ together~~ with a demonstration that the total number of CCDFs is sufficiently large.

In 40 CFR § 194.34(e), the EPA states that "any compliance application shall display the full range of CCDFs generated." The full range of CCDFs generated is displayed in Section 6.5.

In 40 CFR § 194.34(f), the EPA states that "any compliance application shall provide information which demonstrates that there is at least a 95 percent level of confidence that the mean of the population of CCDFs meets the containment requirements . . . ." Section 6.5 contains a display of the mean CCDF and evidence demonstrating level of confidence.

6.1.4 Calculation of Risk

The methodology presented in Sections 6.1.1and 6.1.2 is based on the work of Kaplan and Garrick (1981) and is one way to estimate the effects of uncertain but characterizable futures. In ***the*** Kaplan and Garrick ***(1981)*** procedure, the possible futures are defined as literal entities (S_i), and each is associated with a probability of occurrence (pS_i) and a consequence of occurrence ($\mathbf{cS}_i$). ~~Preliminary performance assessments of the WIPP have used this procedure~~ ***[***~~for example, see Sandia National Laboratories 1991; 1992-1993, Vol. 1,~~ ***(***~~Section 4~~***)***~~], but~~ definition of ~~the futures S_i as discrete entities resulted in a great number of possible futures to~~ be ~~defined. The method of analysis used in preliminary performance assessments was called importance sampling.~~

~~For this performance assessment an alternative method for calculating futures~~ has been used that is ~~based on developing futures by direct probabilistic sampling of the possible events leading to uncertain futures rather than a priori definition of possible futures. This modification from the calculational techniques of previous preliminary performance assessments is consistent with the fundamental concepts of Kaplan and Garrick and does not alter the results of the analysis. Both techniques will lead to the same CCDF. Adoption of this new procedure was prompted by two practical considerations. First, it is difficult to define futures as literal entities, as required by importance sampling, and to develop probabilities for each one. Second, generation of the futures by probabilistic methods allows~~ for ~~greater resolution in a CCDF, for equal effort, than the importance sampling procedure used in preliminary performance assessments.~~

~~The concept of a scenario is important in this performance assessment. There is a universe of possible futures, which is the set of all possible occurrences within the 10,000-year regulatory time frame. For analysis, this universe is divided into subsets of occurrences—scenarios—that are defined practically to include similar future occurrences. It should be noted that scenarios would not necessarily have to be defined as subsets of similar future occurrences, but by defining a scenario as a subset of similar futures, the DOE gains a practical advantage because the consequences of futures falling within one scenario can be calculated with the same model configuration. Because the term scenario is defined simply as a subset of futures with similar occurrences, any size subset of similar futures can be called a scenario. In general, applying the term scenario for larger subsets of futures is useful in discussions of concepts, whereas applying the term scenario for smaller subsets of futures is useful when constructing a CCDF.~~

~~The calculation of~~ ***Calculating*** the probabilities and consequences of future occurrences begins ~~with the determination of~~ ***by determining*** the sets S_i, which are the scenarios to be analyzed. Scenarios are determined through a formal process similar to that proposed by Cranwell et al.

(1990, 5-10) and the process used in preliminary ~~performance assessments~~***PAs*** for the WIPP. This process has four steps.

1. ***The*** FEPs potentially relevant to the WIPP are identified and classified.
2. Certain FEPs are eliminated according to well-defined screening criteria as ~~not~~ ***un***important or ~~not~~ ***ir***relevant to the performance of the WIPP.
3. Scenarios are formed from the remaining FEPs in the context of regulatory performance criteria.
4. Scenarios are specified for consequence analysis.

Through steps ~~(1)~~ ***1*** and ~~(2)~~ ***2*** of the scenario development process, the DOE identifies "all significant processes and events that may affect the disposal system" as required by 40 CFR § 191.13(a) and as further addressed in 40 CFR § 194.32. These steps are described in Section 6.2. The grouping of retained FEPs to form scenarios, and the specification of scenarios for consequence analysis, is presented in Section 6.3.

These four steps were used to develop the PA and compliance assessment used in the CCA. This CRA uses the same PA method and basis as that used in the CCA. The steps outlined here were revisited to determine that the basis for the original PA has not been impacted by events, additional information, or regulatory changes that have occurred since the original demonstration of compliance with EPA's disposal standard (as discussed in the following paragraphs).

As discussed in Section 6.2, the DOE ~~has~~ developed a comprehensive initial list of FEPs for ~~this performance assessment~~***PA***. This ~~comprehensive initial~~ list assure***d***~~s~~ that the identification of significant processes and events is complete, ~~that~~ potential interactions between FEPs are not overlooked, and ~~that~~ responses to possible questions are available and well documented. ***For the CRA-2004, DOE has revisited the initial FEPs list to determine if the screening decisions should be changed as a result of information collected since the EPA certification decision. Specifically, 120 FEPs required updates to their FEP descriptions and/or screening arguments, and seven of the original baseline FEP screening decisions required a change from their original screening decision. Four of the original baseline FEPs have been deleted or combined with other closely related FEPs. Finally, two new FEPs have been added to the baseline. These two FEPs were previously addressed in an existing FEP; they have been separated for clarity. Table SCR-1 summarizes the changes in the FEP baseline since the CCA. The evaluation of the CCA FEPs list is discussed in Appendix PA, Attachment SCR.***

Once scenarios ~~have been~~ ***are*** defined, a calculational methodology for evaluating their consequences must be developed. The calculational methodology must address stochastic uncertainty related to aggregation and stochastic variation, and subjective uncertainty, because of (for example) measurement difficulties or incomplete data. The DOE uses a system of linked computer models to calculate scenario consequences cS_i. As discussed in Section 6.4, these computer models are based on conceptual models that describe the processes relevant to disposal system performance for the defined scenarios. These conceptual models are, in turn, based on site-specific experimental and observational data and the general scientific understanding of natural and engineered systems.

For practical purposes, the DOE separates the calculation of risk because of stochastic uncertainty (represented in an individual CCDF) from risk because of subjective uncertainty ~~which is~~ (represented by the family of CCDFs). This can be represented mathematically as a double integral of a function with the function representing the probability of exceedance associated with any particular consequence. The inner integral evaluates stochastic uncertainty, or the probability of exceedance associated with any particular consequence***.***~~; t~~***T***he outer integral evaluates subjective uncertainty and leads to a distribution of exceedance probabilities for any given consequence value. ***An analytical method for its solution is not available*** ~~B~~***b***ecause of the complexity of this double integral for the WIPP~~, and an analytical method for its solution is not available~~. Instead, the DOE approximates the solution of this double integral with a linked system of computer codes. In this computational framework, the ~~performance assessment~~***PA*** analysis can be thought of as a double sum, presented here in a stylized form for clarity ***as***

$$\sum_{su}\sum_{st} F(x). \tag{6.9}$$

Here, $F(x)$ is a procedure for estimating the normalized release to the accessible environment associated with each scenario that could occur at the WIPP site. The inner sum denoted with the subscript *st* is a probabilistic characterization of the uncertainty associated with parameters used to characterize stochastic uncertainty (the $\mathbf{x}_{\mathbf{st}}$ and D_{st} in Equations ***6.***4a and ***6.***6a, respectively). It is the evaluation of $F(x)$ through the inner sum that develops an individual CCDF, as shown in Figure ~~6-2~~***6-3***. The outer sum denoted with the subscript *su* is a probabilistic characterization of the uncertainty associated with parameters used to characterize subjective uncertainty (the $\mathbf{x}_{\mathbf{su}}$ and D_{su} in Equations ***6.***4b and ***6.***6b, respectively). It is the combined evaluation in the outer sum of the inner sum with $F(x)$ that develops the family of CCDFs, as shown in Figure ~~6-3~~***6-4***.

A separate probabilistic analysis is required to evaluate each sum. Associated with each analysis are parameter distributions representing uncertainty (the D_{st} and D_{su} of Equations ***6.***6a and ***6.***6b). For example, uncertainty in the number and time of intrusion boreholes may be associated with the inner sum. The outer sum includes a probabilistic characterization of site properties, such as the permeability of specific rock types.

For the methodology adopted by the DOE ~~for the evaluation of~~ ***to evaluate*** stochastic uncertainty in the inner sum, consequence calculations are required for model configurations with a set of fixed values for subjective parameters $\mathbf{x}_{\mathbf{su}}$ taken from their distributions D_{su}, as well as for defined sequences and times of events associated with scenarios. These calculations are referred to in Section 6.4.11 and later sections as deterministic calculations (or deterministic futures). ~~For the evaluation of~~ ***To evaluate*** stochastic uncertainty and construct~~ion of~~ a CCDF, the consequences of futures generated probabilistically by random sampling (probabilistic futures) are evaluated in the context of these deterministic futures. This process is discussed in detail in Sections 6.4.12 and 6.4.13.

In certain cases, it may not be obvious whether a particular uncertainty should be classified as subjective or stochastic. For example, whether currently observed geologic properties persist through time could be thought of as either subjective or stochastic uncertainty. For the WIPP, the DOE treats uncertainty associated with significant future human actions as stochastic (for example, drilling for natural resources), and uncertainty in disposal system properties ~~that are~~ subject to ongoing physical processes as subjective (for example, climate change or gas generation). In particular, ~~the~~ DOE's formal separation of ~~the evaluation of~~ ***evaluating*** stochastic uncertainty from subjective uncertainty into different probabilistic analyses allows clear understanding ~~as to~~ ***of*** how ~~any~~ ***a*** particular uncertainty is incorporated.

Once the scenarios ~~have been~~ ***are*** determined and their consequences calculated using the appropriate conceptual and computational models, scenario probabilities must be determined for a CCDF to be constructed. This process is described in Section 6.4.12. CCDF construction is also described in Section 6.4.13.

6.1.5 *Techniques for Probabilistic Analysis*

Once scenarios ~~have been~~ ***are*** defined, conceptual models ***are*** defined, and the computational modeling system developed, ~~the~~ DOE uses probabilistic techniques to evaluate the double sum presented above. Monte Carlo analysis is the ~~general name for the~~ technique used for probabilistic analysis of the WIPP. Monte Carlo analyses can involve five steps:

1. ~~(1)~~ ~~selection of~~ ***selecting*** the variables to be examined and the ranges and distributions for their possible values,

2. ~~(2)~~ ~~generation of~~ ***generating*** the samples to be analyzed,

3. ~~(3)~~ ~~propagation of~~ ***propagating*** the samples through the analysis,

4. ~~(4)~~ ***performing the*** uncertainty analysis, and

5. ~~(5)~~ ***conducting a*** sensitivity analysis.

These steps are described briefly in the following sections.

Within the general framework of Monte Carlo analysis, ~~performance assessment~~***PA*** uses two methods ~~for generating~~***, random sampling and Latin Hypercube Sampling (LHS), to generate*** the samples propagated through the model system. ***Random sampling*** ~~One method~~ is used ~~for the~~ ***to generate samples for*** ~~assessment of~~ stochastic uncertainty, and ***LHS*** ~~another method~~ is used ~~for the~~ ~~characterization of~~ ***to characterize*** subjective uncertainty. Each of these methods ~~utilizes~~ ***uses*** the five steps summarized in the preceding paragraph, but differs in ~~methodology in~~ ~~S~~***s***teps ***(***2***)*** through ***(5) to account for both subjective and stochastic uncertainty***.

6.1.5.1 Selection of Variables and Their Ranges and Distributions

Monte Carlo analyses use a probabilistic procedure for the selection of model input. Therefore, the first step in a Monte Carlo analysis is ~~the selection of~~ ***to select*** uncertain variables and ~~the~~ assign~~ment of~~ ranges and distributions that characterize them. These variables are typically input parameters to computer models, and the impact of the assigned ranges and distributions can be great; for a given set of conceptual and mathematical models, ~~performance assessment~~***PA*** results are largely controlled by the choice of input. Results of uncertainty and sensitivity analyses, in particular, strongly reflect the characterization of uncertainty in the input data.

Information ***used in the CCA*** about the ranges and distributions of possible values ***were***~~can be~~ drawn from a variety of sources, including field data, laboratory data, and literature. ~~In instances~~

~~w~~***W***here sufficient data ***were***~~are~~ not available, the documented solicitation of experts ***was***~~may be~~ used. A review process ***led***~~leads~~ from the available data to the construction of the distribution functions ~~used in the~~ ***that*** ~~to~~ characterize uncertainty in input parameters ***in PA (Appendix PA, Attachment PAR, PAR.2)***. ~~In part, t~~***T***his ~~review process~~ addresse***d***~~s~~ the scaling of data collected at experimental scales of observation to the ~~development of the~~ parameter ranges applied to scales of interest in the disposal system. ~~Because of t~~***T***he nature of the available data and the type of analysis ~~this review process~~ unavoidably involve***d***~~s~~ some judgment ~~of the~~ ***from*** investigators and analysts involved. ~~For this performance assessment, a~~ ***A*** discussion of parameter ranges developed by this process ***for the CRA-2004 PA*** is provided in ~~Appendix~~ ***Appendix PA, Attachment*** PAR (Section~~s~~ ~~PAR.1, PAR.2, and PAR.~~3). The QA procedures associated with this review process are identified in Section ~~5.1.4~~ ***5.4.2*** and Appendix PA***, Attachment PAR*** (Section ~~PAR.1~~***2***).

The outcome of the review process is a cumulative distribution function (CDF) $D(x)$ of the form shown in Figure ~~6-5~~***6-6*** for each independent variable of interest. For a particular variable x_j, the function D is defined such that

$$prob(x < x_j \le x+\Delta x) = D(x+\Delta x) - D(x) . \tag{6.10}$$

That is, $D(x+\Delta x) - D(x)$ is equal to the probability that the appropriate value ~~to use~~ for x_j in the particular analysis under consideration falls between x and $x+\Delta x$.

6.1.5.2 Generation of the Sample

Various techniques are available for generating samples from the assigned distribution functions for the variables, including random sampling, stratified sampling, and LHS. The DOE's ~~performance assessment~~***PA*** for WIPP uses random sampling and LHS.

Random***ly*** sampling ~~of~~ the occurrence of possible future events is used to generate the possible futures (probabilistic futures) that comprise a CCDF. This sampling is used to select values of uncertain parameters associated with future human activities, or in other words, ~~it is used~~ to incorporate stochastic uncertainty into the WIPP ~~performance assessment~~***PA***. This sampling is used for parameters evaluated in the inner sum of the double sum and included in the parameter set $\mathbf{x}_{st}$ with associated distributions D_{st}, as shown in Equations ***6.***4a and ***6.***6a respectively. ~~Generation of the~~ ***Generating*** futures comprising a CCDF by random sampling, rather than importance or stratified sampling, as used in previous preliminary ~~performance assessments~~***PAs***, largely eliminates errors from aggregation.

LHS, in which the full range of each variable is subdivided into intervals of equal probability and samples are drawn from each interval, is used to select values of uncertain parameters associated with the physical system being simulated. In other words, LHS incorporates subjective uncertainty into the WIPP ~~performance assessment~~***PA***. This sampling is used for parameters that are evaluated in the outer sum of the double sum and are included in the parameter set $\mathbf{x}_{su}$ with associated distributions D_{su}, as shown in Equations ***6.***4b and ***6.***6b, respectively. The restricted pairing technique of Iman and Conover (1982, 314-319) is used to prevent spurious correlations within the sample.