CARD No. 51/52
Consideration of Protected Individual/Exposure Pathways

51.A.1 BACKGROUND

The Compliance Criteria include two general categories of quantitative requirements on the performance of the WIPP that are intended to ensure its safety. The first category consists of the containment requirements at Section 194.34, which implement the general containment requirements of the radioactive waste disposal regulations, Section 191.13. The containment requirements establish limits on the cumulative quantity of radioactive materials that may migrate beyond the specified, subsurface physical boundary that separates the WIPP repository area from the accessible environment. That is, they restrict to very low levels the amounts of radioactive materials that might escape from the WIPP.

The second category of quantitative requirements consists of the individual and groundwater protection requirements at Section 194.55, which implement Section 191.15. The individual and groundwater protection requirements place limitations on both the potential radiation exposure of individuals and the possible levels of radioactive contamination of groundwater due to disposal of waste in the WIPP. The individual protection requirement focuses on the annual radiation dose of a maximally exposed hypothetical person living on the surface just outside the boundary to the accessible environment. In particular, Section 194.55 requires that the WIPP be constructed in such a manner as to provide a reasonable expectation that, for 10,000 years after disposal, undisturbed performance of the disposal system will not cause the annual committed effective dose equivalent (hereafter simply called "dose") to exceed 15 millirems (150 microsieverts) to any member of the public in the accessible environment. "Undisturbed performance" means that no human activities such as drilling or mining disturb the disposal system. Section 194.55 also requires that underground sources of drinking water be protected at least to the extent prescribed by the Safe Drinking Water Act regulations at 40 CFR Part 141.

The containment requirements and individual and groundwater protection requirements are fundamentally different. The containment requirements apply to cumulative releases to the "accessible environment" over the 10,000-year regulatory period. To demonstrate compliance with the containment standards, DOE is required to consider human intrusion, such as deep drilling, shallow drilling, and mining. In contrast, the individual and groundwater protection requirements apply to the doses received by an individual over a human lifespan. Moreover, compliance assessments utilized to demonstrate compliance with the individual and groundwater protection requirements need not consider performance of the repository in the "disturbed" scenario. Thus, whereas releases resulting from human-initiated events such as drilling into the repository must be considered to demonstrate compliance with the containment requirements, such intrusion events are not considered in demonstrating compliance with the individual and groundwater protection requirements.

Section 194.55 requires the calculation of the concentrations of contaminants in ground water that might occur under different physical circumstances and the dose that would be received by a hypothetical individual making use of that water. Sections 194.51 and 194.52 provide specific directives for how those calculations are to be carried out. Section 194.51 requires that the individual be situated at the point of maximum exposure. Section 194.52 requires that all potential exposure pathways from the repository to the exposed individuals be considered in this dose calculation and that individuals be assumed to consume two liters of water per day. EPA has combined the discussion of these criteria in a single Compliance Application Review Document because they pertain to the same analysis.

51.A.2 Requirement

194.51 "Compliance assessments that analyze compliance with §191.15 of this chapter shall assume that an individual resides at the single geographic point on the surface of the accessible environment where that individual would be expected to receive the highest dose from radionuclide releases from the disposal system."

194.52 "In compliance assessments that analyze compliance with §191.15 of this chapter, all potential exposure pathways from the disposal system to individuals shall be considered. Compliance assessments with part 191, subpart C and §191.15 of this chapter shall assume that individuals consume two liters per day of drinking water from any underground source of drinking water in the accessible environment."

51.A.3 Abstract

Section 194.55 limits the possible radiation doses to individuals and the possible levels of radioactive contamination of groundwater that might result from emplacement of transuranic waste in the WIPP. Implementation of Section 194.55 involves the calculation of concentrations of contaminants in ground water that might occur under different physical circumstances, and also the computation of the radiation doses that might be received by a hypothetical individual making use of that water. Sections 194.51 and 194.52 provide specific, detailed directives on how those calculations are to be carried out. Section 194.51 requires that the individual be situated at the point of maximum exposure. Section 194.52 requires that all potential exposure pathways from the repository to the exposed individuals be considered in this dose calculation. It also requires that calculations of the individual annual committed effective dose and of the dose from the water ingestion pathway alone assume that individuals consume two liters of water per day.

DOE's performance assessment (PA) showed that the only possible release of radionuclides to the accessible environment for the undisturbed performance scenario results from contaminated brine flowing through the Salado Formation interbeds. The flow of contaminated brine through the Salado interbeds could occur if there were a significant buildup of gas and fluid pressure within the WIPP's waste panels. DOE conservatively assumed this saline water would be available for human use once it reached the subsurface boundary of the accessible environment. Water in the Salado interbeds is actually a highly concentrated brine, however, so DOE assumed it would have to be diluted with pure water sufficiently to bring down the total dissolved solids to a level that EPA considers acceptable for a potential source of drinking water. DOE assumed that this diluted water would be consumed at the rate of two liters per day and then calculated the dose resulting from this single pathway of water-ingestion. DOE also calculated the dose from three other exposure pathways: inhalation of contaminated dust, consumption by cattle of contaminated water, and consumption by humans of foods irrigated with contaminated water.

EPA evaluated DOE's overall conceptual approach to the issue of individual and ground-water protection and DOE's calculations intended to demonstrate the WIPP's compliance with Sections 194.51, 194.52, and 194.55. EPA also conducted an independent and complete set of calculations to confirm DOE's calculations. These calculations are described in EPA Technical Support Document: Dose Verification Evaluation (EPA, 1997).

51.A.4 COMPLIANCE REVIEW CRITERIA

DOE must demonstrate that there is a reasonable expectation that the undisturbed repository will result in radiation doses lower than the dose limit of 15 millirem per year established in the disposal regulations at Section 191.15 **(see CARD 55 -- Results of Compliance Assessments)**. This demonstration must incorporate the provisions of Sections 194.51 and 194.52, which require DOE to: identify the location of maximum potential exposure for an individual on the surface; consider all potential exposure pathways; and assume that drinking water from any contaminated underground source is consumed at the rate of two liters per day.

EPA's Compliance Application Guidance (CAG) states EPA's expectation that, in meeting the requirements of Sections 194.51 and 194.52, the CCA would:

- Present information on doses from individual pathways;
- Show the sum of the dose from all pathways;
- Discuss the methods used to identify the location of the maximally exposed individual;
- Document the results of the modeling used to determine the location;
- Identify the location and position of the individual receiving the dose relative to the controlled area and the disposal system, using map coordinates;
- Identify and consider all potential exposure pathways associated with undisturbed performance; and
- Discuss the assumptions, methodologies, and results of analyses of exposure pathways. (CAG, p. 66 to 67.)

The CAG also stated that, "detailed information on exposure parameters and dose conversions must be provided to the extent necessary to support the assumptions and models used in the compliance assessments. Simplified models may be used to estimate radiation doses to individuals. Such models would be adequate to demonstrate compliance if it can be shown that the simplified models are more conservative than more detailed and complex models are expected to be" (CAG, p. 67 to 68).

51.A.5 DOE METHODOLOGY AND CONCLUSIONS

Chapter 8.1 of the CCA describes DOE's approach to establishing that the potential individual dose from undisturbed operation of the WIPP will not exceed 15 millirem per year. To demonstrate a reasonable expectation that the WIPP will comply with this standard, DOE elected to show that even a highly improbable, conservative case will meet the regulatory requirements, thereby proving that any more probable case must also be in compliance. DOE referred to this approach as a bounding calculation because it is intended to identify an upper bound to any possible exposures.

The bounding analysis performed by DOE is rooted in the PA for the undisturbed scenario. DOE analyzed all potential routes of release of radioactive waste from the repository that could lead to an individual radiation exposure. This analysis included both existing and potential boreholes that may be constructed in the vicinity of the WIPP in the near future; see Chapter 8.1.1 (p. 8-2). Based on the results of the PA, DOE concluded that, under undisturbed conditions for 10,000 years, the only way a release to the accessible environment could occur would be by way of passage of contaminated water through the interbeds in the Salado Formation, where the WIPP is situated. Such a release might be caused by elevated pressure in waste panels from gas generation, forcing brine out of the waste panels into the marker beds.

The PA produced three hundred realizations in which there was no human intrusion. Radionuclides in the interbeds reached the boundary to the accessible environment in only nine of these realizations; the other 291 undisturbed scenarios led to releases with maximum concentrations of less than a cut-off level of 1×10^{-18} curies per liter (10^{-6} pCi/L). DOE's analysis found only four radionuclides to be significant: Am241, Pu239, Th230, and U234; see Table 8-1 (p. 8-7). DOE considered radionuclide concentrations less than the cut-off level to have negligible impact relative to those that were listed and so did not report them. The radionuclide concentrations in the brine in the interbeds at the subsurface boundary reported by DOE for the nine realizations are reproduced in Table 1 of this CARD.

Table 1
Radionuclide Concentrations in the Salado Interbeds at the Disposal System Boundary [a]

Realization Number	Maximum Concentration (Ci/L) [b]			
	Am241	Pu239	U234	Th230
1	1.4×10^{-17}	4.3×10^{-12}	5.8×10^{-13}	2.1×10^{-14}
2		5.1×10^{-14}	6.8×10^{-15}	1.9×10^{-17}
3		1.4×10^{-15}	1.7×10^{-16}	7.0×10^{-18}
4	1.3×10^{-17}	7.2×10^{-14}	9.8×10^{-15}	9.4×10^{-16}
5		6.2×10^{-18}		
6		5.2×10^{-16}	7.4×10^{-17}	
7	3.5×10^{-18}	3.1×10^{-13}	4.3×10^{-14}	1.1×10^{-16}
8	6.0×10^{-17}	7.4×10^{-14}	9.1×10^{-15}	2.3×10^{-15}
9	5.4×10^{-17}	5.9×10^{-12}	7.6×10^{-13}	4.7×10^{-15}

a. Source: Chapter 8, Table 8-1, p. 8-7.
b. Values have been rounded to two significant figures. Ra-226, in particular, was not found in concentrations above this cut-off value.

The nine sets of contaminant concentrations in Table 1 above serve as the starting point for DOE's individual annual dose calculations. In Chapter 8, DOE calculated a maximum annual committed effective dose due only to ingestion of drinking water for each of the nine cases where radionuclides reached the boundary of the accessible environment (Table 8-2, p. 8-9). Even though brine in the Salado is not potable, DOE postulated that an individual could use water drawn from these formations as a source of drinking water. The radioactive contaminants in the anhydrite interbeds were then assumed to be delivered directly to an individual residing on the surface.

DOE measured the average concentration of total dissolved (non-radioactive) solids (TDS) in Salado brine as 324,000 milligrams per liter (mg/L) (Chapter 8, p. 8-8). The high concentration of TDS in Salado brine required that DOE assume that water would be diluted at least to the level of 10,000 mg/L, which is the upper limit of TDS in an underground source of drinking water considered by EPA to be potable (p. 8-13). DOE applied a dilution factor of 32.4 to reduce the TDS from 324,000 mg/L to 10,000 mg/L. DOE then assumed that diluted water was consumed as drinking water, with no further treatment, at the rate of two liters per day, as prescribed in Section 194.52 (p. 8-8). The calculated doses due to consumption of contaminated drinking water ranged from a high of 4.7×10^{-1} millirem per year to a low of 5.1×10^{-7} millirem per year. DOE did not identify a single geographic point on the surface where an individual would receive the highest dose because "all of the contaminants reaching the accessible environment within the anhydrite interbeds during the year of maximum releases [were] assumed to be directly available to the receptor, regardless of the location of the receptor" (p. 8-8). In other words, DOE assumed that an individual would receive the maximum dose from drinking water regardless of where that individual resided on the surface of the accessible environment.

On February 26, 1997, DOE submitted supplementary information in response to an EPA request for additional information (Docket A-93-02, Item II-I-10, Enclosure 2h); see EPA Compliance Review below. The supplementary information discussed how DOE extended its initial bounding analysis to account for other pathways in addition to direct ingestion of contaminated water by humans, specifically: consumption of contaminated water by cattle (leading to contaminated milk and beef); consumption of crops irrigated with contaminated water; and inhalation of airborne dust from soil contaminated by irrigation (p. 4). DOE found that the contribution of these other pathways added 4.6 x 10^{-1} millirem per year to the calculated dose in the realization wherein the highest concentration of radionuclides reached the boundary of the accessible environment in undisturbed conditions. The maximum total dose calculated from all pathways was 0.93 millirem per year. Based on this analysis, DOE concluded that it had demonstrated the WIPP's compliance with Sections 194.51 and 194.52. (Docket Item II-I-10, Enclosure 2h, p. 10)

DOE individual dose assessment relied on the following assumptions (Chapter 8, p. 8-7 to 8-8, and Docket Item II-I-10, Enclosure 2h, p. 7):

- ♦ There are no intrusions into the area of the repository;
- ♦ Radioactively contaminated water (brine) is transported laterally along the anhydrite interbeds in the Salado Formation to the subsurface boundary of the accessible environment;
- ♦ Water at the subsurface boundary contains the maximum concentration of radionuclides and is directly available for consumption and agricultural use;
- ♦ All radioactive contamination in the brine within the anhydrite interbeds is available to the individual as a part of this source of water;
- ♦ Contaminated water is diluted to reduce the TDS in the water from 324,000 mg/L, which is the average concentration of TDS in the brine, to 10,000 mg/L, which is the upper limit of what is considered potable water; and
- ♦ Dose to the individual results from ingestion of drinking water, consumption of crops grown and/or animals raised using water contaminated with the radionuclides of interest, and breathing contaminated dust from the soil.

51.A.6 EPA COMPLIANCE REVIEW

EPA assessed the assumptions and analyses presented in Chapter 8 and the supplementary information provided by DOE in response to EPA's request for additional information to determine that DOE: (1) identified the single geographic point on the surface where an individual would receive the highest dose; (2) considered all potential exposure pathways; and (3) assumed that individuals consume 2 liters per day of drinking water taken from an underground source.

DOE argued that it was not necessary to identify a single point of greatest dose on the surface because its bounding analysis assumed conservatively that individuals would receive the maximum dose regardless of their location in the accessible environment. In other words, all points on the surface were considered to be the point of greatest dose. The PA employs a set of what are essentially two-dimensional models, allowing for calculations that involve the movement of brine vertically and in one horizontal direction. The horizontal coordinate for the system was selected to maximize the flow and transport of contaminated fluid from the repository. Since the concentrations of contaminants are found to decrease with distance from the waste panels, they will be at their maximum values just outside the site boundary of the accessible environment.

Thus, DOE stated that the assumption that individuals drink water taken at the down-stream boundary line is the most conservative possible: "If this unrealistic yet bounding analysis results in calculated doses to the receptor that were below the regulatory limit, compliance with the [15 millirem per year] standard is demonstrated." (p. 8-7). EPA agreed that this approach is very conservative and technically adequate for calculations of the dose resulting from drinking water and other pathways. Water would not be drawn from the anhydrites since other, less saline and more abundant water supplies are available. Also, it is unlikely that water from the anhydrites would reach a potable aquifer. EPA found that DOE assumed that individuals consume drinking water at a rate of 2 liters per day in calculations of both all-pathways and ingestion-only dose.

The CAG states, "simplified models may be used to estimate radiation doses to individuals. Such models would be adequate to demonstrate compliance if it can be shown that the simplified models are more conservative than the more detailed and complex models are expected to be" (p. 68). To ensure that the simple model employed by DOE constituted a conservative bounding estimate (Chapter 8.1.2.2, p. 8-4), EPA examined the following aspects of DOE's analysis and found them to be correct:

- ♦ For undisturbed scenarios, only nine of the 300 CCDF realizations showed any radioactive material reaching the accessible environment at any depth. EPA found that the analyses of both the individual doses from all pathways and the doses from ingestion alone were built upon the PA results for the 300 realizations involving the non-intrusion scenarios.

- ♦ The interbeds lie at a depth exceeding 2,000 feet, which is far deeper than individual dwelling groundwater wells are normally drilled in that region (several hundred feet).

- ♦ To maximize the calculated dose, the contaminated water from the Salado interbeds was assumed to be available to man at higher strata.

- ♦ The maximum TDS allowed for water to qualify as a source of drinking water is 10,000 mg/L. However, water with this amount of TDS is not likely to be consumed. This upper level is intended to identify the very worst quality of water that might be treated to make it drinkable. Public Health Service standards for bottled potable water, by contrast, have a requirement of no more than 500 mg/L for TDS and, if the dissolved solid is chloride (as is likely in this case), the standards prescribe a maximum level of 250 mg/L. The WIPP brine, even if diluted to 10,000 mg/L, would most likely require significant further treatment to make it consumable. Such treatment would also reduce the radionuclide content. EPA therefore accepts as reasonable DOE's assumption that water was diluted to 10,000 mg/L TDS before further use.

Section 194.52 requires that "all potential pathways from the disposal system to individuals shall be considered." The CAG explicitly states that all potential pathways be identified and considered and that the CCA discuss all assumptions related to the analysis of exposure pathways (p. 67). Thus, while EPA expected that the direct ingestion pathway would be by far the most significant, a comprehensive analysis of several other plausible pathways was required to demonstrate compliance with Section 194.52. In a December 19, 1996, letter, EPA requested that DOE submit "documentation which discusses why pathways other than consumption of potable water [were] not considered" (Docket A-93-02, Item II-I-1). DOE subsequently submitted supplementary information, dated February 26, 1997, that extended the previous assessment to include the radiation dose from consumption of contaminated agricultural products and inhalation of contaminated dust. (Docket A-93-02, Item II-I-10, Enclosure 2h). EPA determined that, with the additional information, the analysis included all pathways of potential significant exposure to humans, and found that the revised analysis was adequate to demonstrate compliance with Section 194.52.

To verify the adequacy of DOE's methodology, EPA evaluated the conceptual model in Chapter 8 that DOE used to estimate a maximum individual exposure in its bounding calculation. EPA determined that DOE's conceptual model and the use of the GENII-A computer code to calculate radiation doses were appropriate. EPA also commissioned an independent calculation of doses (EPA, 1997). This analysis adopted DOE's initial premise in the CCA that brine at the point of the accessible environment in the interbed would be available for human use. EPA's analysis confirmed both DOE's initial estimate of exposure from direct consumption of drinking water and the dose from the consumption of agricultural products and the inhalation of resuspended dust. EPA's analysis calculated that the maximum dose for drinking contaminated water was 4.9×10^{-1} millirem per year. The sum dose from all pathways totaled 6.5×10^{-1} millirem per year. A pathway specific comparison of the estimated maximum dose from the two assessments is shown in Table 2 of this CARD. The differences between the DOE assessment and the independent analysis may be due to such factors as ingestion dose conversion factors or assumptions on the consumption of agricultural products. Table 3 below contains a comparison of some of the key assumptions in the two assessments.

Table 2
Comparison of Calculated Individual Maximum Annual Committed Dose
for DOE and EPA Bounding Assessments

Exposure Pathway	DOE	EPA
Drinking Water Ingestion Dose (mrem)	0.47	0.49
Other Pathways (e.g., inhalation, ingestion)	0.46	0.16
Total Ingestion Dose (mrem)	0.93	0.65

Table 3
Comparison of Some Key Assumptions
for DOE and EPA Bounding Assessments

Assumption	DOE	EPA
Drinking water intake (liters/day)	2	2
Leafy vegetable intake (kilograms/year)	15	17
Meat intake (kilograms/year)	70	120
Irrigation rate (centimeters/year)	100	96
Leafy vegetable delay time, harvest to consumption (days)	14	24
Inhalation rate (cubic meters/year)	7,300	7,300

51.A.7 References

EPA 1997. U.S. Environmental Protection Agency. Technical Support Document for Sections 194.51, 194.52 and 194.55: Dose Verification Evaluation. 1997. (Docket A-93-02, Item III-B-25)

Consideration of Protected Individual/Exposure Pathways -- Sections 194.51 and 194.52

Issue A: The most probable release pathway in undisturbed conditions is through inadequately sealed vertical shaft excavations.

1. In the committee's view, the flow of radionuclide-contaminated brine through inadequately sealed vertical shaft excavations at WIPP is the most probable pathway for release of radionuclides from the repository to the accessible environment under undisturbed conditions. (NAS 41, p. 50)

Response to Issue A:

DOE evaluated contaminated brine migration both up the shafts and through the interbeds in the Salado to the boundary of the accessible environment. Through its probabilistic PA analysis, DOE determined that, in the undisturbed scenario, only the migration of brine through the anhydrite interbeds was a potential pathway during the 10,000 year compliance assessment period (Chapter 8, p. 8-3). The size of any potential release in this scenario was predicted to be very small. This conclusion was substantiated by the subsequent Performance Assessment Verification Test.

Issue B: DOE's calculations overestimate probable releases.

1. Three important features of early analyses are that water in the Culebra appears to be too saline for consumption by cattle, transport by colloids was not considered, and pathways to the Dewey Lake were not included. In addition, the analytical treatment of the behavior of the shaft seals and repository in this analysis appears to be conservative, that is, likely to over-estimate the releases. Taking all these considerations together, the committee concludes that the net effect will probably be to lower the already very low concentrations and doses indicated by DOE's analysis of radionuclide releases through shaft seals. (NAS 60, p. 29)

2. For the purposes of calculating dose to man, the CCA includes a bounding analysis. In order to perform this analysis, some bounding and quite unreasonable assumptions had to be made. The most notable of these unrealistic assumptions is that small releases through the Salado anhydride at the unit boundary, over 2,000 feet below ground level, are somehow transported to a potable drinking water source and ingested so as to allow for a chronic exposure. . . The construct and assumptions used in the dose calculations are described in Section 8.1.2 and the calculation results are . . . discussed in Section 8.1.3. (696) (II-H-22.21)

Response to Issue B:

In the final CCA, DOE considered changes in transport caused by the presence of colloids (Chapter 6.4.3.6, p. 6-109 to 6-111), the need to dilute the brine before consumption (Chapter 8, p. 8-8), and Dewey Lake transport (Chapter 6.4.6.6, p. 6-148). EPA found DOE's analytical treatment of the shaft seals to be conservative. DOE's final probabilistic analysis indicated that no migration of contaminated brine through the shafts would occur in the undisturbed scenario, and EPA concurs with this conclusion.

EPA agrees that DOE's assumption that Salado brine would be used as drinking water is not probable and is therefore appropriate to bound the pathway analysis. Such conservatism is valid, considering that the bounding analysis must compensate for the lack of a definitive analysis of the pathways involved in the calculation of drinking water concentrations and doses to individuals. This approach was endorsed by EPA's CAG, which states: "Simplified models may be used to estimate radiation doses to individuals. Such models would be adequate to demonstrate compliance if it can be shown that the simplified models are more conservative than more detailed and complex models are expected to be" (p. 68).