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Addendum 1

Performance Assessment for the Area 5 Radioactive Waste Management Site at the Nevada Test Site Nye County, Nevada

Reevaluation of the Chronic Inadvertent Human Intrusion Scenarios To Resolve the Disposal Authorization Statement Issues

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Prepared by

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ACRONYMS and ABBREVIATIONS

BN	Bechtel Nevada
Bq	Becquerel
Bq/m3	Becquerel per cubic meter
Ci	Curie
Ci/g	Curies per gram
Ci/m3	Curies per cubic meter
DAS	Disposal Authorization Statement
DOE/HQ	U.S. Department of Energy/Headquarters
ft	foot
ft2	feet square
FY	fiscal year
IHI	Inadvertent Human Intrusion
LFRG	Low-Level Waste Disposal Facility Federal Review Group
LLW	Low-Level Waste
μCi	microCurie
m	meter
m2	meter square
mrem	millirem (milliroentgen equivalent man; unit of dose)
NNSA/NV	National Nuclear Security Administration Nevada Operations Office
NTS	Nevada Test Site
PA	Performance Assessment
RWMS	Radioactive Waste Management Site
SME	Subject Matter Expert
TEDE	Total Effective Dose Equivalent
WM	Waste Management
WCL	Waste Concentration Limit

EXECUTIVE SUMMARY

A disposal authorization statement (DAS) was issued by the U.S. Department of Energy/ Headquarters (DOE/HQ) on December 5, 2000, authorizing the National Nuclear Safety Administration Nevada Operations Office (NNSA/NV) to continue the operation of the Area 5 Radioactive Waste Management Site (RWMS) at the Nevada Test Site for the disposal of low-level waste and mixed low-level waste. The Area 5 RWMS DAS identifies two performance assessment issues and requires that NNSA/NV provide to the Low-Level Waste Federal Review Group (LFRG) the resolution of these issues in an addendum or a revision to the Performance Assessment (PA) within one year of the signed DAS. This report, the first addendum to the Area 5 RWMS PA, is prepared to fulfill that requirement.

The DAS cites the following two conditions and requirements for resolution:

- *As a result of the post-drilling intruder scenario as stated in Section 5.1 of the 1998 PA, the specific radionuclide concentration or inventory limits shall be imposed on Pit 6 to ensure that performance objectives will not be exceeded. A quantitative dose estimate shall be calculated using the reduced inventory to demonstrate compliance with the performance objective.*

- *The closure plan shall require a closure cap thickness of at least 4 meters as stated in Section 5.1 of the 1998 PA to ensure that performance objectives for the agricultural scenario will not be exceeded. A quantitative dose estimate shall be calculated using the 4-meter cap to demonstrate compliance with the performance objective.*

The DAS also states:

> *Nevada Operations Office shall assure that these measures are implemented and revised dose estimates are provided to the LFRG as an addendum or a revision to the PA within one year of the signed DAS. Alternative measures which achieve an equivalent result will be considered for approval by the LFRG*.

NNSA/NV has identified multiple options for responding to the conditions of the DAS. The approach used in this resolution response document is to demonstrate and document multiple approaches (cases) that fulfill the DAS conditions. The intent is to obtain LFRG concurrence that each of the alternative approaches meets the DAS conditions. A decision by NNSA/NV of the specific option to follow will be based on subsequent analyses, including cost, schedule, and facility impacts that will be carried out under the PA maintenance program (Bechtel Nevada [BN], 2000a) and submitted to the LFRG.

The approach that NNSA/NV used in this reevaluation consists of five steps:

1. Identify multiple approaches/cases that satisfy the DAS conditions.

2. Compute the conditional total effective dose equivalent (TEDE) for each case, assuming that the intrusion scenario will occur (a probability of one); assess whether the performance objective is met.

3. Assess the probability of occurrence of the intrusion scenario, if it is applied to the case.

4. Compute the scenario TEDE as the conditional TEDE times the probability of occurrence of the intrusion scenario.

5. Assess compliance comparing the scenario TEDE against the chronic intruder performance objective of 100 mrem in a year.

The compliance period used in the 1998 PA was 10,000 years after closure, as specified in the U.S. Department of Energy (DOE) Order 5820.2A (DOE, 1988), which is superceded by DOE Order 435.1 (DOE, 1999). DOE Order 435.1 changed the compliance period from 10,000 years to 1,000 years after closure. In this reevaluation of the two intrusion scenarios, NNSA/NV uses the 1,000-year period as the required compliance period established in DOE O 435.1 and also uses the 10,000-year period for comparison with past PA calculations.

Two cases were evaluated for the resolution of the first PA condition, showing that the dose to the chronic post-drilling intruder to the lower cell of Pit 6 will remain less than the 100 mrem performance objective. For Case 1, the scenario dose was calculated based on the waste concentration limits developed in the 1998 PA for the inventory disposed in Pit 6 through 2000. The potential intruder dose based on the current disposed inventory is estimated to be 69 mrem, below the performance objective. The 1998 PA had shown that the application of waste concentration limits would ensure that the dose will always remain less than the 100 mrem yr^{-1} performance objective (equivalent to an inventory limit of 174 Ci of ^{232}Th). As part of the performance assessment/composite analysis maintenance program, the inventory at closure of the Area 5 RWMS has been reevaluated in fiscal year (FY) 2001, incorporating the actual disposals since 1993 through 2000. (The 1995 PA and the 1998 PA both had evaluated the inventory at closure, derived from the disposal records through 1993.) The new inventory at closure for ^{232}Th is estimated to be 99 Ci. Becuse this is less than the inventory limit of 174 Ci determined in the 1998 PA, there is added assurance that the intruder performance objective will be readily met.

For Case 2, the conditional TEDE was estimated assuming that the drilling scenario occurs, as described in the 1998 PA. The scenario TEDE for the post-drilling intruder to Pit 6 is estimated as the conditional TEDE times the probability of the scenario. The maximum scenario dose to the intruder, under both the1,000- and 10,000-year compliance periods, is shown to be below the 100-mrem yr^{-1}

compliance dose limit. The probability of drilling intrusion to Pit 6 is 0.009 for the 1,000-year compliance period; and 0.08 for the 10,000-year compliance period. The maximum dose in the 1,000-year compliance period is 1.5 mrem in a year. Likewise, the maximum dose in the 10,000-year compliance period is 1.4 mrem in a year. Therefore, the PA inventory of Pit 6 complies with the chronic inadvertent intrusion performance objective by applying the probability of intrusion.

The second PA condition was addressed through quantitative analyses to demonstrate compliance with the 100-mrem performance objective for the Intruder-Agriculture Scenario. Two cases were evaluated: (1) Reduction of the Intruder Doses Through Construction of a 4-meter-thick Closure Cap, and (2) No Change in Closure Cap Thickness and the Intruder Doses are Weighted by the Probability of the Intrusion Scenario.

The PA intruder model was run with a 4-meter cap for Case 1. It is shown that the scenario dose is 4.4×10^{-2} mrem yr^{-1} at 1,000 years after closure and 0.74 mrem yr^{-1} at 10,000 years after closure. This evaluation demonstrates that the chronic intruder performance objective of 100 mrem in a year is met with a 4-meter-thick closure cap.

For Case 2, a probabilistic evaluation was performed. The conditional TEDE (assuming the intrusion occurs) was calculated in the revised Area 5 PA to be 84 mrem yr^{-1} at 100 years and 157 mrem yr^{-1} at 10,000 years, the assumed compliance period in the PA. The PA model was rerun in this reevaluation to provide the dose estimate at 1,000 years after closure. The TEDE at 1,000 years is 77 mrem yr^{-1}. The scenario TEDE is computed as the conditional TEDE times the probability of scenario occurrence. The probability of the scenario occurrence is 0.06 for the 1,000-year compliance and 0.54 for the 10,000-year compliance period. The maximum scenario dose is 4.6 mrem in a year for the 1,000-year compliance period and 85 mrem in a year for the 10,000-year compliance period. Because the scenario TEDE (weighted with the probability of the scenario) is less than the 100-mrem yr^{-1} dose limit for both the 1,000- and 10,000-year compliance periods, the compliance with the chronic intruder performance objective is demonstrated.

1.0 INTRODUCTION

A disposal authorization statement (DAS) was issued by the U.S. Department of Energy/ Headquarters (DOE/HQ) on December 5, 2000, authorizing the National Nuclear Safety Administration Nevada Operations Office (NNSA/NV) to continue the operation of the Area 5 Radioactive Waste Management Site (RWMS) at the Nevada Test Site (NTS) for the disposal of low-level waste and mixed low-level waste. The Area 5 RWMS DAS identifies two performance assessment issues and requires that NNSA/NV provide to the Low-Level Waste Federal Review Group (LFRG) the resolution of these issues in an addendum or a revision to the Performance Assessment (PA) within one year of the signed DAS. This report, the first addendum to the Area 5 RWMS PA, is prepared to fulfill that requirement.

The DAS cites the following two conditions and requirements for resolution:

- *As a result of the post-drilling intruder scenario as stated in Section 5.1 of the 1998 PA, the specific radionuclide concentration or inventory limits shall be imposed on Pit 6 to ensure that performance objectives will not be exceeded. A quantitative dose estimate shall be calculated using the reduced inventory to demonstrate compliance with the performance objective.*

- *The closure plan shall require a closure cap thickness of at least 4 meters as stated in Section 5.1 of the 1998 PA to ensure that performance objectives for the agricultural scenario will not be exceeded. A quantitative dose estimate shall be calculated using the 4-meter cap to demonstrate compliance with the performance objective.*

The DAS also states:

> *Nevada Operations Office shall assure that these measures are implemented and revised dose estimates are provided to the LFRG as an addendum or a revision to the PA within one year of the signed DAS. Alternative measures which achieve an equivalent result will be considered for approval by the LFRG.*

NNSA/NV has identified multiple options for responding to the conditions of the DAS. The approach used in this resolution response document is to demonstrate and document multiple approaches (cases) that fulfill the DAS conditions. The intent is to obtain LFRG concurrence that each of the alternative approaches meets the DAS conditions. A decision by NNSA/NV of the specific option to follow will be based on subsequent analyses, including cost, schedule, and facility impacts that will be carried out under the PA maintenance program and submitted to the LFRG.

The original 1995 PA (Shott *et al.*, 1995) and the revised 1998 PA (Shott *et al.*, 1999) evaluated two highly conservative intruder scenarios that were assumed to occur (probability of one) any time between 100 years and 10,000 years after closure of the RWMS (institutional control was assumed to be in effect for 100 years after closure). The compliance period used in the 1998 PA was 10,000 years after closure, as specified in U.S. Department of Energy (DOE) Order 5820.2A (DOE, 1988), which is superceded by DOE Order 435.1 (DOE, 1999). DOE Order 435.1 changed the compliance period from 10,000 years to 1,000 years after closure. In this reevaluation of the two intrusion scenarios, NNSA/NV uses the 1,000-year period as the required compliance period established in DOE O 435.1 and also uses the 10,000-year period for comparison with past PA calculations.

Calculated doses in the 1998 PA for two of a total of six scenario assessments exceed the intruder performance objective of 100 mrem yr^{-1} for the chronic scenario. Those scenarios, as noted in the DAS statement, are the post-drilling scenario for Pit 6 (resulting in 162 mrem at 100 years to 178 mrem yr^{-1} at 10,000 years) and the agriculture scenario for the shallow land burial sites (resulting in 84 mrem at 100 years to 157 mrem yr^{-1} at 10,000 years).

Responses to each of the two DAS conditions are given in Section 3.0, following a description of the NNSA/NV's approach to the reevaluation of the inadvertent human intrusion (IHI) scenarios at the NTS disposal facilities in Section 2.0. The evaluations of the probabilities of the occurrence of the IHI scenarios are provided in Appendices A through C.

2.0 METHODOLOGY

NNSA/NV reevaluated these scenarios, recognizing that adoption of generic IHI scenarios considered for all sites in the DOE complex to a particular site must be based on the site-specific characteristics of that site. This recognition is based on two sources of information:

1. Section 4.3 of the "Attachment to the Conditional Acceptance of the Nevada Test Site Area 5 Radioactive Waste Management Complex Performance Assessment" (DOE, 1996) notes that ". . . a resident in the Area 5 RWMS is not considered a credible scenario. Therefore, these chronic exposure scenarios are not considered credible and useful in the establishment of waste acceptance limits."

2. As stated in DOE guidance by Wood *et al*. (1994):

    Projection of impacts from disposal sites frequently goes far into the future, so that long-term processes and infrequent events may need to be considered. The events and processes are highly site-specific, so each site should choose to include only those that are pertinent to the individual site.

NNSA/NV adopted the generic IHI scenarios in the original Area 5 PA for consistency with the other DOE sites, but explored the site-specific characteristics of the NTS disposal sites to demonstrate that the chances of occurrence of these scenarios at the NTS are rather small. For example, consider the hypothetical scenario in which an individual drills for water at a disposal site anytime after the period of active institutional control. An individual inadvertently drilling for water at a disposal site at an East Coast location is a highly probable scenario because the water table is known to be close to the ground surface and the human population density is high. However, at the NTS where the water table is deep and the human population density is low, the same scenario has a much lower probability of occurrence. Such site specificity should be considered in applying the generic IHI scenarios. NNSA/NV argues that the likelihood of occurrence of scenarios for IHI should be assessed on a site-specific basis.

NNSA/NV recognized as early as 1996 the need to develop site-specific scenarios for the NTS assessments instead of relying on generic scenarios used across the DOE complex. At that time, NNSA/NV convened an independent panel to conduct an expert judgment elicitation that evaluated the probability of drilling intrusion (referred as the post-drilling scenario in the PA) at the NTS. The study is summarized in Black *et al*., 2000; and in Black *et al*., 2001. This study evaluated the probability of post-drilling intrusion at the NTS, and the effectiveness of institutional controls. The mean probability of a post-drilling intrusion over a 1,000-year interval is calculated to be 0.11 at the Area 5 RWMS trenches and 0.009 at Pit 6. See Appendix A for a summary of the derivation of the probability of post-drilling intrusion at the NTS; see Appendix B for application of the results to the NTS disposal sites. The mean probability of a post-drilling intrusion over a 10,000-year interval is calculated to be 0.66 at the Area 5 RWMS trenches and 0.08 at Pit 6.

The probability of post-drilling intrusion was presented in the development of the PA for the Area 3 RWMS, which was reviewed and accepted by the LFRG. The Area 5 RWMS PA was developed two years before the Area 3 RWMS PA.

In FY 2001, NNSA/NV evaluated the probability of IHI at the NTS via construction of a basement, which is part of the agriculture intrusion scenario described in the PA. (see Appendix C for a detailed summary of the derivation of the probability of intrusion via basement construction).

The approach that NNSA/NV used in this reevaluation consists of five steps:

1. Identify multiple approaches/cases that satisfy the DAS conditions.

2. Compute the conditional TEDE for each case, assuming that the intrusion scenario will occur (a probability of one); assess whether the performance objective is met.

3. Assess the probability of occurrence of the intrusion scenario, if it is applied to the case.

4. Compute the scenario TEDE as the conditional TEDE times the probability of occurrence of the intrusion scenario.

5. Assess compliance comparing the scenario TEDE against the chronic intruder performance objective of 100 mrem in a year.

The application of this stepped approach to each of the IHI scenarios cited under the Area 5 DAS conditions is summarized below.

3.0 RESOLUTION OF THE CONDITIONS

3.1 Resolution of Condition 1: A quantitative analysis to demonstrate compliance with the 100-mrem yr^{-1} performance objective for the Post-Drilling Scenario for Pit 6

Case 1: Implementation of Specific Radionuclide Concentration or Inventory Limits for Pit 6

The intruder post-drilling scenario assumes that an intruder builds a residence on an area contaminated with drill cuttings from the disposal site. This scenario was applied to Pit 6 by summing the results for a 6.2-meter (m) (6.5 foot [ft])-deep trench with the lower cell filled with thorium waste, which contributes 99 percent of the predicted dose. The dose estimated in the 1998 Area 5 PA was 178 mrem yr^{-1} at 10,000 years.

Pit 6 is currently receiving waste and its final radionuclide inventory at closure is unknown. Waste disposed to date in Pit 6 (end of FY 2000) corresponds to a TEDE of about 69 mrem and currently meets the intruder performance objective (Table 1). One acceptable approach (Case 1) for managing the Pit 6 disposal unit is to set waste concentration limits that ensure the TEDE at closure does not exceed the 100-mrem yr^{-1} performance objective. If Pit 6 were filled with waste having the same concentration as waste already disposed, the dose (considering the current inventory) can be estimated from the sum of fractions as:

$$H = 100 \sum_{i=1}^{n} \frac{C_i}{WCL_i}$$

where

H	=	post-drilling intruder TEDE (mrem),
Ci	=	waste concentration of radionuclide i (Bq/m^3), and
WCLi	=	waste concentration limit of radionuclide i (Bq/m^3)

The 1998 PA back-calculated a ^{232}Th inventory limit of ≤ 174 Ci for the lower cell of Pit 6 to ensure that the dose to the post-drilling intruder would not exceed the 100-mrem performance objective. We conclude that the potential intruder dose from the Pit 6 disposal sites based on disposed inventory (69 mrem [*Table 1*]) remains below the performance objective. Further, the application of waste concentration limits ensures that the dose will always remain less than the 100-mrem yr^{-1} performance objective (equivalent to a ^{232}Th inventory limit of 174 Ci). The lower cell of Pit 6 is allocated for thorium waste (deep disposal). Future waste disposed there will be

Table 1 Estimated Pit 6 (P06U) Inventory and Total Effective Dose Equivalent (inventory as of the end of FY 2000)

Concentration (Bq/m^3)	Concentration (Bq/m^3)	Concentration (Bq/m^3)	Concentration (Bq/m^3)	Concentration (Bq/m^3)
Sr-90	1.5E+12	5.3E+03	3.6E-09	3.6E-07
Tc-99	1.1E+11	2.4E+05	2.2E-06	2.2E-04
Pb-210	7.8E+11	2.2E+06	2.9E-06	2.9E-04
Ra-226	1.7E+09	3.9E+06	2.3E-03	2.3E-01
Th-229	4.1E+09	6.8E+05	1.7E-04	1.7E-02
Th-230	1.7E+09	1.4E+08	8.1E-02	8.1E-00
Th-232	1.1E+09	6.5E+08	5.9E-01	5.9E+01
Pa-231	1.4E+09	8.9E+02	6.4E-07	6.4E-05
U-233	3.1E+10	2.7E+08	8.7E-03	8.7E-01
U-234	3.7E+10	2.8E+07	7.5E-04	7.5E-02
U-235	1.2E+10	1.6E+06	1.3E-04	1.3E-02
U-236	1.2E+11	3.3E+04	2.7E-07	2.7E-05
U-238	5.9E+10	3.7E+07	6.3E-04	6.3E-02
Np-237	7.0E+08	2.0E+02	2.8E-07	2.8E-05
Pu-238	1.2E+11	7.1E+05	5.9E-06	5.9E-04
Pu-239	2.3E+10	5.1E+02	2.2E-08	2.2E-06
Pu-241	5.2E+11	1.9E+06	3.6E-06	3.6E-04
Am-241	1.8E+10	1.6E+05	8.8E-06	8.8E-04
Total				**6.9E+01**

the same as the previously disposed waste. Following each shipment and disposal of waste, a sum of fractions is calculated to estimate the dose to make sure that the inventory limit for the cell is not exceeded.

Case 2: Probabilistic Assessment of the Inadvertent Human Intruder

For Case 2, the conditional TEDE was estimated assuming that the drilling scenario occurs as described in the 1998 PA. The 1998 PA estimated the resulting conditional TEDE for the intruder from drilling through Pit 6 to be 178 mrem yr^{-1} at 10,000 years after closure (assuming the lower cell of Pit 6 would be filled with 277 Ci of ^{232}Th, as shown in Table 3.8 of the PA). The dose at 1,000 years was not reported in the 1998 PA. The intruder model was rerun for this reevaluation to calculate the dose to the intruder at 1,000 years after closure. The conditional TEDE is estimated to be 165 mrem in a year at 1,000 years after closure.

The scenario TEDE for the post-drilling intruder to Pit 6 is estimated as the conditional TEDE times the probability of the scenario. The probability of intrusion varies as a function of the compliance period, as discussed in Appendices A through C. Table 2 summarizes the maximum dose for the post-drilling intrusion into Pit 6 for the 1,000- and 10,000-year compliance periods.

Table 2 Dose Results for the Post-Drilling Intrusion to Pit 6

Compliance Period	Conditional TEDE (mrem yr^{-1})	Probability of Intrusion	Scenario TEDE (mrem yr^{-1})
1,000 years	165	0.009	1.5
10,000 years	178	0.08	14

As shown in the table, the maximum scenario dose to the intruder, under both the 1,000- and 10,000-year compliance periods, is below the 100 mrem yr^{-1} compliance dose limit. Therefore, the PA inventory of Pit 6 complies with the chronic inadvertent intrusion performance objective by applying the probability of intrusion.

3.2 Resolution of Condition 2: A quantitative analysis to demonstrate compliance with the 100-mrem performance objective for the Intruder-Agriculture Scenario

The intruder-agricultural scenario, as described in the Area 5 PA (Shott *et al*., 1998), assumes that an intruder constructs a residence over the shallow disposal trenches and exhumes waste from construction excavations. The excavated soil (including waste) is then spread over a garden plot where the intruder engages in agricultural activities. The intruder produces and consumes produce, fruit, meat, and milk. The results of the Area 5 RWMS PA show that the intruder-agriculture dose rises from 84 mrem at 100 years to 157 mrem at 10,000 years, assuming that intrusion will occur. The intruder-agriculture scenario evaluated in the 1998 PA assumed that the entire PA inventory would be located in a virtual shallow disposal unit, equivalent to the shallow burial trenches and pits at the Area 5 RWMS. The closure cover over the virtual unit was assumed to be 2.4 m (7.8 ft) thick (thickness of the operation covers). Most construction excavations are 2 to 3 m (6.5 to 9.8 ft) thick in Clark County and Nye County in southern Nevada.

Final closure of the 23 disposal units at the Area 5 RWMS must consider the closure requirements for other applicable regulations such as the hazardous waste disposals under the Resource Conservation and Recovery Act, which is under state control (BN, 2000b). Each disposal unit will be further evaluated during its closure for compliance with all applicable regulations, and the closure cover designs (thickness, surface type, surface slope) will be tailored to each unit's hazardous chemical and radionuclide inventory, as well as its geometry and other requirements that address long-term concerns such as erosion and run-on control.

Case 1: Reduction of the intruder doses through construction of a 4-m- (13-ft)-thick closure cap.

The PA model was modified and rerun to address the case of constructing a closure cover of 4-m (13-ft) thickness. The intruder is assumed to construct a 200-m^2 (2,152.7-ft^2) house with a 2.5-m-(8.2-ft)-deep basement, with excavation assumed to be 3 m (9.9 ft) deep with a slab of concrete placed at the bottom of the excavation. The excavation will generate 600 m^3 (21,188 ft^3) of soil that will be spread over a 2,500-m^2 (26,909.7-ft^2) area, which the receptor will use to perform agricultural activities. (The scenario is described in more detail in Section 3.3.2.1 of the PA.) This excavated soil would have been contaminated only with radionuclides that moved from the waste zone to the closure cover by means of the biointrusion pathways (plant uptake and burrowing animal activity). No waste would have been brought to the surface during the excavation. The amount of radionuclides brought to the top cover soil would be less for a 4-m (13-ft) cover than for a 2.4-m (7.8-ft) cover because a proportionately smaller amount of the waste would have been accessed by plant roots and burrowing animals. Therefore, the topsoil concentrations over the compliance period will be proportionately less under the thickened cap scenario.

The PA model was run with the values of some of the model parameters that control the bioturbation release pathways changed to evaluate the 4-m (13-ft) cap, as discussed below. These parameters are listed in Table 3. The 1998 PA assumed that the maximum rooting depth of plants, which sets the depth extent of plant uptake and burrowing animal activity, is 4.4 m (14.4 ft). For a 2.4-m (7.8-ft) cap (evaluated in the 1998 PA), the waste zone where bioturbation is effective is 2 m (6.5 ft). For a 4-m (13-ft) cap, the waste zone contacted by plant roots and burrowing animals is 0.4 m (1.3 ft). The fraction of the perennial shrub roots in waste and the amount of soil excavated by each ant colony in the waste zone are scaled based on the ratio of the old and new waste zone thickness accessible by the roots.

The new model runs are performed for the intruder-agriculture scenario and the dose results are summarized in Table 4. Note that only those radionuclides contributing significantly to the total dose or those that are part of the decay-chains are evaluated. The scenario dose is 4.4×10^{-2} mrem yr^{-1} at 1,000 years after closure and 0.74 mrem yr^{-1} at 10,000 years after closure. This evaluation demonstrates that the chronic intruder performance objective of 100 mrem in a year is met with a 4-m-(13-ft)-thick closure cap.

Table 3 Parameters Affected By Cover Thickness

Parameter Description	2.4-meter Cover (Table 3.16 of the 1998 PA)	4-meter Cover
F_{rs}, Fraction of perennial shrub roots in the shallow soils compartment	0.42	0.25
F_{ru}, Fraction of perennial shrub roots in the subsufrace soils compartment	0.53	0.74
F_{rw}, Fraction of perennial shrub roots in waste	0.05	0.01
H_s, Depth of the shallow soils compartment, m	1	1
H_u, Depth of the subsurface soils compartment, m	1.4	3
H_w, Depth of the waste accessible to roots and burrowing animals, m	2	0.4
A_b, Amount of soil excavated by each ant colony in the waste zone, g yr^{-1}	100	20

Table 4 Conditional TEDE (mrem/yr) for the Intruder-Agriculture Scenario with 4-meter Closure Cover

Radionuclide	At 100 years	At 1,000 years	At 10,000 years
^{3}H	2.9E-3	2.6E-24	0.0
^{14}C	5.6E-4	4.9E-3	1.3E-2
^{36}Cl	8.4E-10	8.2E-9	5.5E-8
^{90}Sr+D	1.1E-4	3.5E-13	0.0
^{99}Tc	2.3E-5	2.2E-4	1.7E-3
^{126}Sn+D	2.6E-9	2.5E-8	2.1E-7
^{137}Cs+D	2.3E-5	2.1E-13	0.0
^{239}Pu	6.2E-4	5.9E-3	4.1E-2
^{235}U	2.3E-4	2.3E-3	2.0E-2
^{231}Pa	1.7E-5	9.5E-5	7.1E-3
^{227}Ac	7.3E-6	4.5E-4	3.5E-2
^{241}Pu	9.9E-8	1.5E-25	0.0
^{241}Am	2.4E-4	5.6E-4	2.7E-9
^{237}Np+D	1.8E-5	2.2E-4	2.0E-3
^{233}U	1.4E-9	1.5E-8	3.1E-7
^{229}Th+D	4.3E-10	3.7E-8	3.5E-6
^{238}U	1.9E-3	1.8E-2	0.16
^{238}Pu	3.5E-5	2.8E-7	0.0
^{234}U	5.7E-4	5.6E-3	5.1E-2
230Th	2.5E-6	1.2E-4	9.5E-3
^{226}Ra+D	1.3E-5	1.2E-3	0.35
^{210}Pb+D	5.7E-7	5.8E-5	1.7E-2
^{240}Pu	1.2E-4	1.1E-3	3.8E-3
^{236}U	8.3E-7	8.1E-6	7.3E-5
^{232}Th	2.1E-5	2.1E-4	1.9E-3
^{228}Ra+D	1.1E-4	1.0E-3	9.3E-3
228Th	1.7E-4	1.6E-3	1.5E-2
Total	**7.7E-3**	**4.4E-2**	**0.74**

Case 2: No change in closure cap thickness and the intruder doses are weighted by the probability of the intrusion scenario.

The conditional TEDE (assuming the intrusion occurs) was calculated in the revised Area 5 PA to be 84 mrem yr^{-1} at 100 years and 157 mrem yr^{-1} at 10,000 years, the assumed compliance period in the PA. The PA model was rerun in this reevaluation to provide the dose estimate at 1,000 years after closure. The TEDE at 1,000 years is 77 mrem yr^{-1}. The dose results are shown in Table 5. The scenario TEDE is computed as the conditional TEDE times the probability of scenario occurrence, yielding the results shown in Table 6.

Table 5 Conditional TEDE (mrem/yr) for the Intruder-Agriculture Scenario with 2.4-meter Closure Cover

Radionuclide	At 100 Years	At 1,000 Years	At 10,000 Years
^{3}H	2.4	2.2E-22	0.0
^{14}C	0.4	0.37	0.072
^{36}Cl	4.9E-8	4.9E-8	4.8E-8
^{90}Sr+D	0.13	4.1E-11	0.0
^{99}Tc	0.057	0.056	0.056
^{126}Sn+D	4.9E-5	4.9E-5	4.6E-5
^{137}Cs+D	0.36	0.33	0.0
^{239}Pu	12.0	11.7	8.8
^{235}U	4.4	4.4	4.4
^{231}Pa	0.034	0.19	1.6
^{227}Ac	0.14	0.89	7.7
^{241}Pu	1.9E-3	3.0E-21	0.0
^{241}Am	4.0	0.95	0.0
^{237}Np+D	0.037	0.049	0.051
^{233}U	2.6E-5	2.7e-5	3.4E-5
^{229}Th+D	8.2E-6	6.9e-5	5.4E-4
^{238}U	36.	36.0	36.0
^{238}Pu	5.1	4.0E-3	0.0
^{234}U	11.0	11.0	11.0
^{230}Th	0.048	0.24	2.1
^{226}Ra+D	0.25	2.45	76.0
^{210}Pb+D	0.011	0.11	3.6
^{240}Pu	2.4	2.2	0.85
^{236}U	0.016	0.016	0.016
^{232}Th	0.42	0.42	0.41
^{228}Ra+D	2.1	2.1	2.1
^{228}Th	3.3	3.3	3.2
Total	**84**	**77**	**157**

Table 6 TEDE for the Intruder-Agriculture Scenario

Compliance Period	Conditional TEDE (mrem yr^{-1})	Probability of The Scenario Occurrence	Scenario TEDE (mrem yr^{-1})
1,000 years	77	0.06	4.6
10,000 years	157	0.54	85

The scenario TEDE (weighted with the probability of the scenario) is less than the 100-mrem yr^{-1} dose limit for both the 1,000- and 10,000-year compliance periods; therefore, the compliance with the chronic intruder performance objective is demonstrated.

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APPENDIX A

A COMMON-SENSE PROBABILISTIC APPROACH TO ASSESSING INADVERTENT HUMAN INTRUSION INTO LOW-LEVEL RADIOACTIVE WASTE AT THE NEVADA TEST SITE

by

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ABSTRACT

The United States Department of Energy (DOE) Order 5820.2A requires each site disposing of low-level radioactive waste to prepare and maintain a site-specific performance assessment (1) to determine potential risks posed by waste management systems to the public, and the environment, and (2) to compare these risks to established performance objectives. An *inadvertent human intruder* is a person who, without knowledge or intent, disturbs the waste after the period of institutional control ceases (assumed to be 100 years) and is exposed to radioactivity. The DOE Nevada Operations Office, Waste Management Program recently completed a one-year study of site-specific scenarios for inadvertent human intrusion by drilling into buried low-level radioactive waste sites, as part of ongoing performance assessment studies. A process involving participation of stakeholders, public, and scientists was used to develop likely homestead and community scenarios for inadvertent human intrusion at the Nevada Test Site (NTS) Area 3 and Area 5 Radioactive Waste Management Sites. Intrusion scenarios focus on possible penetration of buried waste through drilling for sources of groundwater. Past performance assessments of low-level radioactive waste sites at the NTS were deterministically based, assuming that inadvertent human intrusion will occur at a probability of 100 percent during the 10,000-year evaluation period. This expert elicitation was conducted as a first step towards bringing a probabilistic perspective to this aspect of a performance assessment. The Nevada Test Site approach to site-specific inadvertent human intrusion determination is not dependent on the waste form, and may be applicable to other DOE or commercial facilities.

A Subject Matter Expert panel, comprised of ten disciplines ranging from the social sciences to engineering and drilling, was convened to assess the site-specific probability of inadvertent human intrusion through a formal process of expert elicitation. The probability of drilling penetration into waste was judged to be driven primarily by two settlement scenarios: (1) scattered individual homesteaders, and (2) a community scenario consisting of a cluster of settlers that share drilling and distribution systems for groundwater.

Management control factors that may affect inadvertent human intrusion were developed in the stakeholder workshop and defined during the Subject Matter Expert elicitation sessions. Management control factors include institutional control, site knowledge, placards and markers, surface barriers, and subsurface barriers. The Subject Matter Experts concluded that institutional control and site knowledge may be important factors

The important factors affecting probabilistic assessment of the settlement and community scenarios are the remoteness of the alluvial valleys of the Nevada Test Site, and the presence of playas and surface-subsidence craters, which are unlikely to be settlement sites. The highest probability of intrusion was driven by a secondary community scenario. This scenario was described as a community settlement that develops from location of an industrial-technological complex in Jackass Flats (located in the southwest portion of the Nevada Test Site). Homestead and community scenarios were considered by the panel to render a site-specific probability of around 10 percent for inadvertent human intrusion. If management controls are designed and implemented effectively, then the probability of inadvertent human intrusion can be reduced to less than one percent.

INTRODUCTION

The U.S. Department of Energy, Nevada Operations Office (DOE/NV) operates, oversees, and has responsibility for future closure of Radioactive Waste Management Sites (RWMSs) located in Frenchman Flat and Yucca Flat at the Nevada Test Site (NTS; Figure 1). The DOE/NV Waste Management Program provides low-level radioactive disposal capability for NTS-generated waste and other DOE-approved waste generators. Radioactive waste disposal operations began at the NTS in 1961. Low-level radioactive, transuranic, mixed, hazardous, and classified wastes have been disposed in pits, trenches, landfills, and greater confinement disposal boreholes.

A requirement for operation of low-level radioactive waste disposal sites under DOE Order 5820.2A is the preparation and maintenance of a site-specific performance assessment (PA). A PA is a series of analyses conducted (1) to determine potential risks posed by waste management systems to the public and the environment, and (2) to compare these risks to established performance objectives (dose thresholds). Results of the PA are used to effect regulatory decisions regarding disposal site design, operation, safety, waste acceptance criteria, and site characterization. A PA has been conducted, and tentatively approved, for the post-1988 disposal units within the Area 5 RWMS, located in northern Frenchman Flat (Figures 1 and 2; Shott et al., 1995). A second PA is in preparation for the Area 3 RWMS, located in southern Yucca Flat (Figures 1 and 2).

Each PA must evaluate facility operation based on four performance objectives, briefly summarized as follows:

1. Protect public health and safety in accordance with applicable environmental standards and DOE Orders.
2. Assure that an effective dose equivalent to any member of the public does not exceed 25 millirem per year (mrem/yr).
3. Assure that an effective dose equivalent received by an individual who inadvertently intrudes into the waste after loss of institutional control (assumed to be 100 years) will not exceed 100 mrem/yr for continuous exposure and 500 mrem/yr for a single acute dose.
4. Protect groundwater resources consistent with Federal, state and local regulations and requirements.

The third performance objective evaluates the likelihood that disposed radioactive waste may adversely impact an inadvertent human intruder at some time during the next 10,000 years (the evaluation period). An inadvertent human intruder is a person who, without knowledge or intent, disturbs or uncovers disposed radioactive waste and receives radiological exposure, either directly or through secondary pathways.

This paper describes a site-specific approach for determining the probability of inadvertent human intrusion (IHI) for the intruder-drilling scenario at the Area 3 and 5 RWMSs through a process known as expert elicitation. Specifically, probabilities of drilling inadvertently into disposed waste were assessed by formally eliciting expert judgments from a panel of Subject Matter Experts (SMEs), relying on their combined training and experience. This project was conducted for two primary reasons:

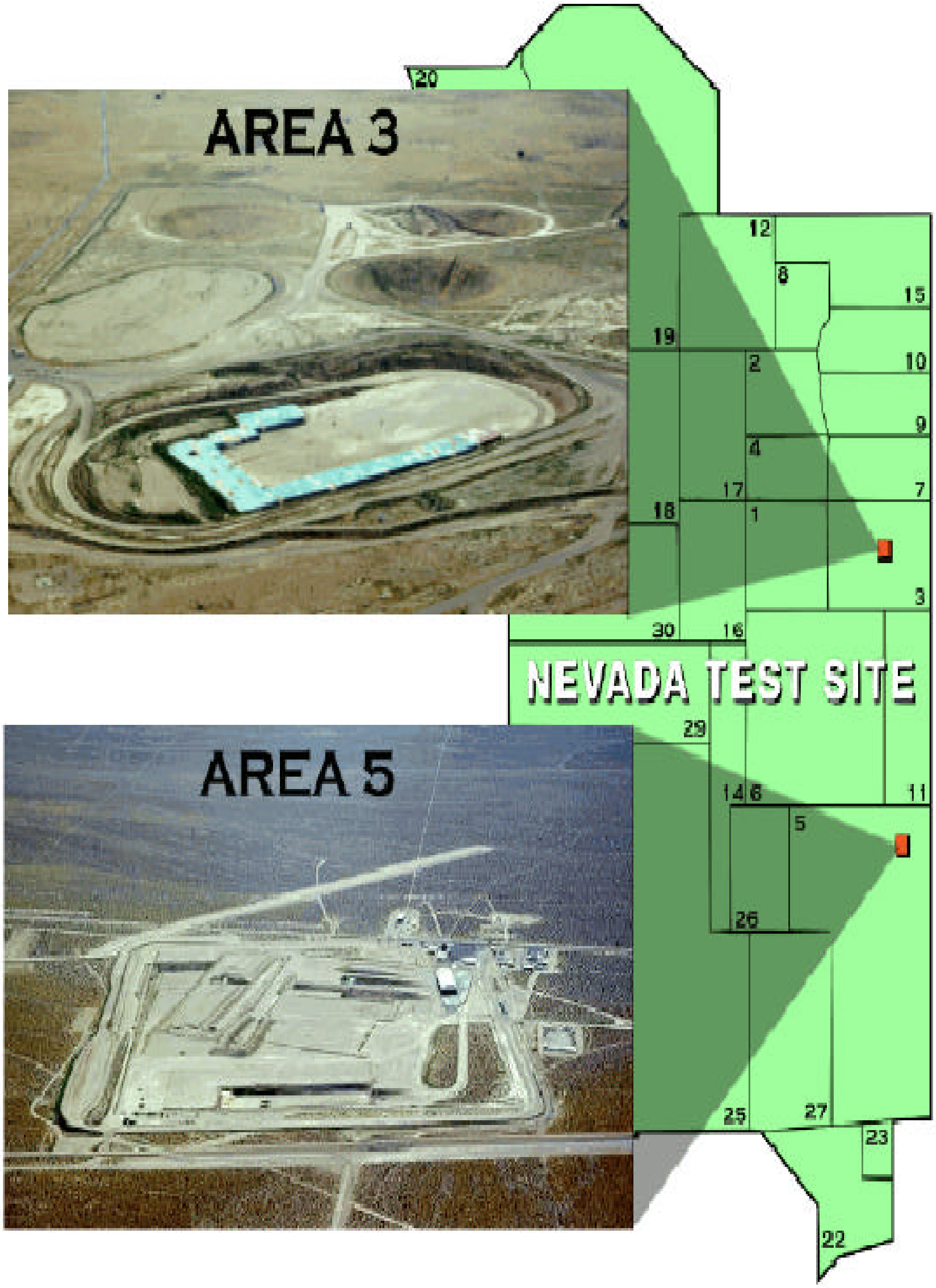

Figure 1 **Location of the Areas 3 and 5 Radioactive Waste Management Sites Within the Nevada Test Site.**

Figure 2 **Aerial Photograph of the Area 5 RWMS at the Nevada Test Site**

1. DOE Order 5820.2A and guidance provided by the DOE Performance Assessment Task Team (Wood et al., 1994) and Case and Otis (1988) recommend the development and use of site-specific, credible scenarios for dose exposure calculations based on an understanding of current conditions.

2. The evaluation of problematic waste streams under the PA (Brown et al., 1996), such as those characterized by high-specific activity, often requires a more thorough and rigorous approach, better handled by probabilistic methods than by standard deterministic analyses.

The organization of this paper is intended to provide the reader with pertinent background and scope to understand the base assumptions of the elicitation, the development of influence diagrams, the elicitation process and results, and conclusions of the study.

BACKGROUND AND SCOPE

The Area 5 RWMS PA followed established practice by using intruder scenarios similar to those used in previous PA studies for disposal of low-level radioactive waste (Shott et al., 1995). Three types of scenarios were considered:

1. The intruder-construction scenario assumes a homesteader builds a house over a waste disposal site and excavates a foundation into the buried waste.
2. The intruder-discovery scenario is identical to the intruder-construction scenario, but assumes the intruder recognizes the hazardous nature of the excavated waste.
3. The intruder-drilling scenario assumes a future settler drills for groundwater through a waste disposal site, and is exposed through various pathways to contaminated drill-cuttings.

The elicitation focuses on the intruder-drilling scenario, because the results were applied to a PA evaluating deep disposal options for a problematic waste stream (high-specific activity, low-level radioactive waste). For deep disposal configurations, the intruder-drilling mechanism is usually the limiting scenario for PA performance objectives. A preliminary PA often starts with screening calculations to evaluate the limiting scenario against the appropriate performance objectives. The probabilities derived in this study are limited to use in dose calculations for the intruder-drilling scenario. However, the scenarios developed by the SMEs and input obtained about the management controls options are directly applicable to PAs that evaluate shallow-land waste disposal, with necessary modifications.

The exposure scenario of interest in this study is the intruder-driller. This scenario considers an individual, the "homesteader," who unknowingly breaches containment of the waste by drilling to groundwater. The drilling process transports waste to the surface where the drill cuttings are mixed with soil in the homesteader's vegetable garden. Case and Otis (1988) indicate that the selection of post-institutional control scenarios can be a fairly subjective process, therefore justifying the use of the elicitation process for scenario development. Furthermore, Case and Otis indicate that "scenario construction should consider current patterns of activity in the area," in which case it is appropriate to consider scenarios that go beyond the default scenarios presented in Wood et al. (1994). While the default "homestead" scenario served as the starting point for this study, other scenarios are suggested and developed that account for potential "community" scenarios.

A traditional PA assumes that IHI *will* occur (a probability of one) during the course of the 10,000-year time frame to which the PA is applied. This deterministic approach may be reasonable for waste disposal sites near populated areas where the likelihood of human intrusion is increased. However, IHI is much less likely in the remote Mojave desert setting of the NTS. The RWMSs are situated in alluvial basins where the average annual rainfall is less than 10 centimeters, near-surface processes are dominated by evapotranspiration, permanent surface-water features are rare, and depths to groundwater exceed 250 meters (Figure 2; Shott et al., 1995; Winograd, 1981).

probabilistic study described in this paper was conducted in calendar year 1996. The study is reported in Black et al. (1996).

ELICITATION

Overview

Assessment of the probability of IHI was completed through an expert elicitation. Although this approach is justifiable technically, it is important that the process includes development of models and assumptions, and sharing of information among all participants to ensure that the results are credible. This process involves a number of components that are used to build a solid foundation prior to the SME elicitation sessions. Initial steps taken in the process focused on obtaining sufficient information to identify the areas of expertise needed to perform the assessment. Preliminary models were developed in the form of "influence diagrams." Influence diagrams show important factors or variables, and the relationships between those variables, at a simplified level that facilitates natural interpretation (Figure 3).

The elicitation was conducted using a three-step process:

1. Developing the logic of the pertinent variables affecting IHI through development of influence diagrams for the scenarios and the management controls
2. Holding open workshops involving participation of stakeholders, scientists, and the public to examine the logic and acceptability of the approach taken for the probabilistic study
3. Assessing the probabilities of intrusion into waste units by convening and formally eliciting expert judgments from a panel of SMEs

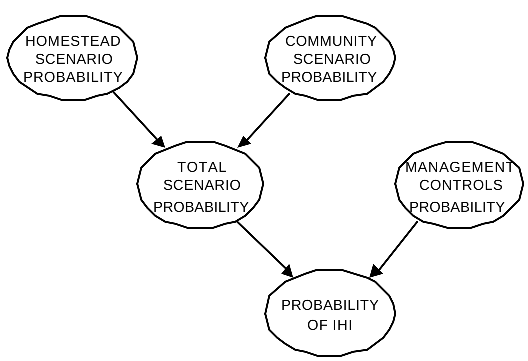

Figure 3. Influence diagram depicting the major components of the probability of inadvertent human intrusion assessment.

Booker, 1991; Keeney and Raiffa, 1993; Raiffa, 1968). These topics have significant uncertainty that commonly cannot be reduced by conventional means of data gathering. The issue of IHI for the RWMSs in Frenchman and Yucca Flats involves multiple factors with largely non-reducible uncertainty. There is uncertainty in the future missions and institutional control of the NTS, uncertainty in the viability, values and practices of future societies, and uncertainty in future hydrogeologic processes that make arid desert lands either more or less desirable to society.

The foundation of the approach taken in this study is summarized as follows:

- Specify assumptions and models
- Gain acceptance from relevant stakeholders that the assumptions and models are reasonable
- Obtain relevant input to fulfill the needs of the models
- Calculate the probability of IHI as a consequence of the assumptions and the model input

Base Assumptions

The initial steps in this probabilistic study involve developing a model of how IHI occurs. This analysis could become hopelessly complex if every mechanism of possible IHI were considered, given the uncertainty of future changes in society. Therefore, some basic conditions were established for the modeling process.

The current boundaries of the NTS are subject to institutional control. Open public access to waste disposal sites is prohibited. Future IHI can only occur if institutional control of the NTS ceases, and knowledge of the existence and location of waste disposal sites is not in the public domain. As long as institutional control of the NTS is actively maintained, it is reasonable to assume that all public development on the site will be precluded and that IHI will be avoided. Even after institutional control is lost, knowledge of the hazardous nature of the site may be maintained for some period of time and should continue to deter public incursion. Site knowledge could be enhanced by the presence of some form of permanent surface marker or warning sign. Two additional factors could deter drilling for groundwater, should institutional control and site knowledge become ineffective. Surface barriers can be built to restrict or prohibit access to the land immediately above a waste disposal site, and subsurface barriers can be constructed to prevent completion of a drilling operation. This set of conditions underlie the model and are collectively termed “Management Controls.”

An overview of the modeling process, including the scenario components and the management controls factors, is shown in Figure 3. The scenarios and the management controls factors are subject to evaluation through the elicitation process. The homestead and community scenarios are evaluated separately, and then are combined to provide a total scenario probability of IHI. This represents the probability of IHI, assuming all management controls factors are ineffective. If any of the management controls are effective, it is assumed that IHI cannot occur. The next step involves evaluation of the potential effectiveness of the management controls. The results for management controls are then combined with the conditional scenario results to provide an overall assessment of the probability of IHI. The management controls module acts as a probability modifier for the scenario probabilities.

A second assumption addresses prediction of future changes in society and technology. Past studies have shown that many aspects of science and technology, particularly social sciences that are more susceptible to human influence, are inherently unpredictable (Casti, 1990). At best, stochastic or probabilistic models of future events can be developed. Accurate prediction of most events is impossible (for example, population growth, technology development, societal patterns, climate change, etc.). Consequently, a working assumption for this probabilistic study of IHI is that forecasting of future patterns must be based on current technology and current societal practices. This presents a potential credibility problem for future PAs. To counteract this potential problem, a

The final assumption for the basic approach concerns the mechanisms by which an inadvertent intruder who gains access to NTS chooses to settle in a remote alluvial valley. A number of scenarios are possible, including both homestead and community scenarios, and a range of factors may affect the outcome of the probabilistic assessment of IHI for these scenarios. Examples of such factors include the suitability of the land surface for expected settlement activities and the hydrogeologic setting of the site, that is, future groundwater resource availability. The factors and the models developed by the SMEs for each scenario provided the necessary focus for the expert elicitation.

Elicitation Process

Preliminary influence diagrams include factors such as the number of homesteads, community lifetime, well density, well lifetime, depth to groundwater, and topographical features. An external review was conducted through a workshop including stakeholders, scientists, and public representatives. The workshop was a key element of the process that ensured that stakeholders understood and shared a basic agreement in the credibility of the probabilistic approach (Black et al., 1996). Useful outcomes of the stakeholder and public interactions were to focus on making the probabilistic assessments specific to Nevada, and to validate the logic used in the influence diagrams for the management controls module and the homestead and community scenarios. In particular, the workshop participants suggested that current population trends indicate that an urban scenario is plausible and should be considered for evaluation. Hence, the rationale for development of site-specific, credible community scenarios. The workshop participants fully endorsed "periodic review of intrusion," with an acknowledgment that such an approach will realize success only with assurances that sufficient funds are made available. A scientific review was also performed by convening a group consisting of leading scientists from government institutions and private companies. The peer review group provided critical input on details of the approach, and confirmed the general findings from the workshop.

The influence diagrams include factors that directly affect the potential for IHI to occur. The first step in selecting SMEs was to identify relevant disciplines to address these factors. Ten disciplines were chosen: agronomy, anthropology, demography, economic geology, geotechnical engineering, hydrogeology, hydrology, land-use planning, sociology, and drilling technology. Selection criteria for the disciplines included demonstration of classic training in the discipline, familiarity with the discipline application in the arid Southwest, and some familiarity with probability and statistics.

The selected SMEs were provided critical references and background materials prior to convening the first elicitation session to ensure a sufficient knowledge base for an effective session. The first elicitation session began with a field trip that familiarized the SMEs with the Area 3 and Area 5 RWMSs, Waste Management Program functions, topological features, hydrologic and geologic processes, and communities within the vicinity of NTS. The remainder of the first session was dedicated to structuring the influence diagrams. The SMEs were presented preliminary influence diagrams and were encouraged to debate the merits and deficiencies of the diagrams, then to modify them to reflect their consensus opinions. The SMEs' input resulted in the final structuring of the influence diagrams. The first session ended with general training on probabilistic concepts used in expert elicitations. The SMEs became familiar with methods for eliciting probability distributions and with potential sources of bias that can arise in the elicitation process.

The second session focused on formal elicitation of the probabilistic input required to fulfill the specifications of the influence diagrams. The elicitation involved assessment of quantile values from the SMEs using standard methods of expert judgment (Black et al., 1994; Keeney and Raiffa, 1993; Meyer and Booker, 1991; Raiffa, 1968). To ensure that inputs from the SMEs were recorded accurately, and for quality assurance purposes, the elicitation sessions were taped and several sets of written notes were archived. The SMEs were also provided a summary report that described their input. Each SME verified that their input was recorded accurately and was used appropriately. They were also asked to provide an evaluation of the elicitation process. This provided useful when management controls are considered ineffective. These results are then adjusted for the potential effectiveness of management controls to provide a final assessment of the probability of IHI.

Inadvertent Human Intruder Scenarios

Results of the elicitation for the homestead and community scenarios are discussed in this section. Elicitation was performed by forming sub-groups of SMEs with expertise pertinent to specific factors. Other members of the SME panel were given the opportunity to comment, ask questions, or disagree with the sub-group experts. A variety of elicitation methods were used that are described in Black et al. (1996).

A consensus step at the start of the elicitation was definition of the base assumptions by the SME panel. The SMEs agreed with the workshop findings--that using current knowledge of society is the only credible approach to a probabilistic assessment of IHI. Further, the SMEs agreed that a periodic review of intrusion every 25 years is necessary as the current knowledge base changes. Specifically, if societal or technological changes significantly affect the results. The SMEs also indicated that sufficient funds need to be established to ensure that periodic review will occur.

The SMEs were provided complete freedom to discuss and revise the scenarios as necessary. This process resulted in acceptance of the homestead scenario and refinement of the community scenario. Three separate community scenarios were identified:

1. A small community located in the alluvial basins of Frenchman or Yucca Flats (Base Community Scenario)
2. Urban expansion of Las Vegas north up the valley corridor and into the alluvial basins of NTS, including “commuting homesteaders” (Las Vegas Expansion Scenario)
3. A small community located in Jackass Flats, or in another area nearby Frenchman and Yucca Flats, including “commuting homesteaders” (Jackass Flats Scenario)

The SMEs defined “commuting homesteaders” as settlers who commute regularly from their homes located outside of the community or urban resource base. This was distinguished from the homestead scenario for which homesteaders were assumed to be isolated from any central community. The homestead scenario, combined with the three community scenarios, yield the four scenarios that the SMEs considered in this study.

The four scenarios follow a common basic model (Figure 4). The probability of IHI was evaluated separately for each scenario. Inputs obtained from the SMEs for each scenario provided information relevant to the top-level factors: the number of wells at a point in time (well density) and the well lifetime. Elicitation of these inputs depended on other factors specific to each scenario. The inputs were used to assess the total number of wells that are anticipated to be drilled in Frenchman and Yucca Flats during the evaluation period.

Area estimates of Frenchman and Yucca Flats were estimated with GIS and mapping techniques, and the area of the waste footprint is assumed to be two acres. The total number of wells and the ratio of area of the waste footprint to the area of the alluvial basins were required to a determine the probability that at least one well would intersect the waste footprint, causing an intrusion event.

A number of factors were included in the scenario-specific influence diagrams, all of which effect assessment of the number of wells that will be drilled during the evaluation period. For example, suitability of the land surface and hydrogeologic factors may influence the likelihood of establishing a settlement in the vicinity of the RWMSs. The suitability of the land surface may be influenced by the remoteness of the alluvial basins, playas (dry lakes) that are contained within these basins, and surface-collapse craters that were formed by underground testing (Figure 2). The SMEs attempted to establish a balance in the selection of factors included in the influence diagrams. This required a conscious effort to ensure that the number of variables were sufficient to document and defend the

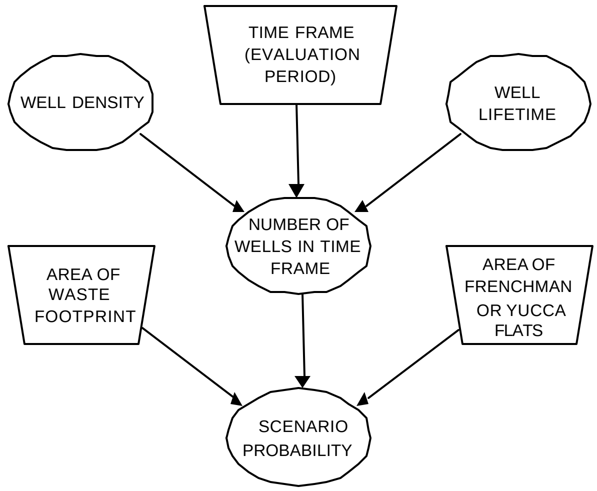

Figure 4 Influence diagram of factors in the basic scenario model.

~~Homestead Scenario:~~ The homestead scenario was further defined by the SMEs in terms of isolated and independent homesteads. Assumptions for the homestead scenario include:
1. The homesteads are isolated.
2. Each site will have one active water well within its area.
3. No resources will be shared between homesteads.

The SMEs' assumed that each homestead will have a single water well drilled into the deep aquifers of the NTS region. The drilling technology is consistent with that used at settlements in alluvial valleys of the southern Great Basin. The total number of wells drilled during the evaluation period for this scenario is influenced primarily by the potential for homesteading in these areas and the expected lifetime of a homestead.

The SME input indicated that independent homesteading is extremely unlikely to occur in Frenchman or Yucca Flats. The total number of wells anticipated over the course of the 10,000-year evaluation period is very small for this scenario (approximately 20), leading to a probability of IHI of around 0.03%. This probability estimate is founded on the assumption that management controls are ineffective, and the waste footprint size is two acres.

~~Base Community Scenario:~~ The Base Community Scenario consists of locating a community within Frenchman or Yucca Flats (Figure 1). Each alluvial basin area was evaluated separately for the community scenarios. Assumptions for this scenario include:

1) Only one community may exist in Frenchman or Yucca Flats at a given time.
2) Each community starts with four production wells.
3) Resources are shared within the community.

The types of future communities envisioned by the SMEs include a research park, prison facility, military base, religious group, or a casino. The probability of a community being located in Frenchman or Yucca Flats was considered by the SMEs to be very small because of the hostility of the environment, as well as the distance from a population center for infrastructure support services. The total number of wells drilled during the evaluation period was influenced by the potential for a community to settle in these areas, the expected lifetime of a community, and the expected lifetime of a production well. If one of the four production wells ceases to function, then a replacement well was assumed to maintain the community water supply. There may be several replacement wells drilled during the community lifetime that would be located within the boundaries of the community well field.

For all the community scenarios, the SMEs considered settlement in Frenchman Flat to be more likely than in Yucca Flat. They considered the heavily-cratered areas of Yucca Flat, where the Area 3 RWMS is located (Figure 2), much less likely to be settled than elsewhere in the basin. The SMEs indicated that the planned community considered for this scenario was extremely unlikely to occur. Given the expected lifetime of each community that may exist in these areas, and the expected lifetime of a production well, within the next 10,000 years the number of wells drilled in Frenchman Flat is less than 20. This small number of wells yielded a probability of IHI of approximately 0.03%. The number of drilled wells in the heavily-cratered area of Yucca Flat under this scenario was expected to be considerably less, resulting in an estimated probability of 0.003%.
Las Vegas Expansion Scenario: Given current population trends, the SMEs considered it reasonably likely that expansion of Las Vegas would exert population pressures on Frenchman and Yucca Flats. This scenario, and the Jackass Flats Scenario, represent hybrids between the Homestead and Base Community Scenarios because they assume that the spillover population operates as "commuting-homesteaders," who rely on the central community for a variety of resources. However, each of these commuting-homesteaders drill their own water well. The total number of wells drilled was influenced by the potential for Las Vegas to expand sufficiently that it places population pressures on Frenchman or Yucca Flats, the expected lifetime of Las Vegas, the expected number of homesteads that are settled in Frenchman and Yucca Flats, and the expected lifetime of a private well. If a private well ceases to function, then a replacement well is installed as before.

This type of scenario was more likely to occur than the Base Community Scenario. The number of wells drilled in Frenchman Flat in 10,000 years is approximately 300, including replacement wells. The resultant scenario probability of IHI is approximately 0.2%. The number of wells drilled in the heavily-cratered area of Yucca Flat was considerably less, resulting in a probability of 0.01%.

~~Jackass Flats Scenario:~~ This scenario consists of locating a community in an area near Frenchman and Yucca Flats. Jackass Flats is centrally located in the vicinity of the Flats of interest (Figure 1). The assumption is that there are many areas around NTS that would be more desirable than Frenchman or Yucca Flats for community settlement, but that such communities would place population pressure on these two areas. For example, a community that develops in Jackass Flats, or around the current infrastructure of Mercury (Figure 1), is considered large enough to spill population over into neighboring valleys.

The opinion of the SMEs was that this type of scenario is likely to occur, and that communities of this type can be expected to be present intermittently for approximately 5,000 years out of the evaluation period. The number of wells drilled in Frenchman Flat was thought to be approximately 5,000. The resultant scenario probability of IHI is approximately 10%. The number of wells drilled in the heavily-cratered area of Yucca Flat under this scenario was considerably less, resulting in an estimated probability of approximately 1%.

The Jackass Flats Scenario clearly dominates the total assessment of the probability of IHI. Therefore, the probabilities derived for this scenario represent the total probabilities of IHI for Frenchman and Yucca Flats. The likelihood of IHI occurring is small, even if management control factors are completely ineffective. The effectiveness of management controls modify this probability to reduce the occurrence of IHI.

Management Controls

The probability assessments for each scenario are derived separately from the management controls. If management controls are found to be effective, then the scenario probabilities are modified accordingly. Five management controls are considered to be pertinent (Figure 5): institutional control, site knowledge, placards and markers, surface barriers, and subsurface barriers. The underlying assumption is that if management controls are functional, IHI is *not possible*.

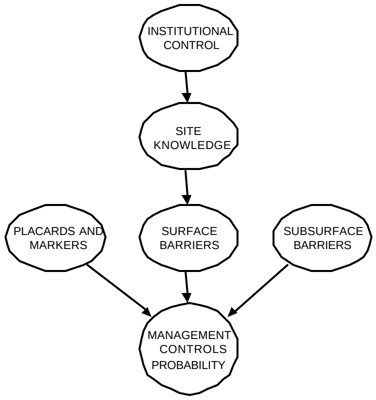
INSTITUTIONAL CONTROL
SITE KNOWLEDGE
PLACARDS AND MARKERS
SURFACE BARRIERS
SUBSURFACE BARRIERS
MANAGEMENT CONTROLS PROBABILITY

Figure 5. Influence diagram of factors in the management controls model.

The first factor included in Figure 5, institutional control, includes options ranging from current security-controlled access of the NTS, zoning restrictions, Federal or State ownership of designated lands, to periodic patrols of sensitive areas. Institutional controls are maintained to ensure that certain activities will not jeopardize the integrity of the waste disposal site. If institutional control of the NTS or the RWMSs is not maintained for the full evaluation period, then the other nodes of the management, homestead, and community modules become important.

The second factor of the management controls module concerns site knowledge of the waste sites (Figure 5). The SMEs' definition of site knowledge refers to written or oral communication, or societal memory, of the existence of the waste sites. This factor presumes that, if site knowledge is retained, IHI *will not* occur. The SMEs noted that persons settling in Frenchman or Yucca Flats will either have, or not have, knowledge of the past use of portions of the NTS as waste disposal areas. Consequently, there is the possibility that some individuals may be attracted to, or knowingly intrude into waste disposal areas (Black et al., 1996). However, by definition, these individuals cannot be considered *inadvertent* human intruders, and therefore are not included in the probabilistic assessment.

The SMEs decided that the potential for institutional control or site knowledge to last for 10,000 years was highly unlikely. Their opinion concurred with those of the workshop participants. Elicited input for the institutional control and site knowledge factors indicate less than 500 years of combined effectiveness. It was considered more likely that control would be lost gradually. The SMEs considered several mechanisms for gradual erosion of institutional control and loss of site knowledge: political change, economic constraints, or less concern by society for the importance of waste management issues.

The three remaining management controls (Figure 5) consist of physical deterrents:

1. Placards and markers are informational signs or symbols placed near, or above, the waste site that are designed to warn against intrusion into the underlying waste.
2. Surface barriers are engineered structures placed over the waste or closure cap that may prevent siting of the drill rig, or the drilling operation.
3. Subsurface barriers are engineered structures below the ground surface, but above the waste, that are constructed intentionally to deter intrusion. Barrier materials included concrete, rock, metal, rubber, and so on for SME evaluation.

The SMEs evaluated the potential effectiveness of these physical deterrents. They argued that placards and markers designed to current societal interpretations are unlikely to maintain their intended meaning in the future, unless their design is relatively simple. A simple warning sign was designed by the SMEs that depicts the waste buried at depth with upright and prone bodies symbolizing the concepts of life and death.

The panel concluded that a surface barrier can be designed and constructed that would effectively deter drilling. Effectiveness of the surface barrier was defined by the inability of the driller to locate and set-up a rig atop the waste site. They reviewed current designs and structures and judged them to be ineffective, so they developed their own barrier designs. The central design theme was a high (about 3 meters), steep-sided mound (or closure cap), armored or surrounded with large boulders that would make drill-rig siting difficult to impossible.

It was concluded that cost-effective subsurface barriers cannot be designed or constructed, because human curiosity or technology would eventually penetrate all barriers. However, the SMEs indicated that the subsurface barrier most likely to interfere or prevent drilling would consist of at least 1.5-meter-thick concrete with 2.54-centimeters-thick rebar reinforcement, spaced to no-greater-than 18-centis apart.

Assuming that the most favorable surface barrier described is effective at a probability of 95%, as suggested by the SMEs, this management control modifier can be applied to the scenario probabilities. If it is applied to the worst case Jackass Flats scenario, then based on the SME input, the overall probability of IHI at Frenchman Flat is less than 1%; for Yucca Flat, it is less than 0.1%. If this management control, or another equally
effective management control were implemented, then these probabilities reasonably reflect the overall probability of IHI for a footprint of two acres corresponding to waste buried in the Area 3 and 5 RWMSs at the NTS.

CONCLUSIONS

- Site-specific and credible scenarios for the intruder-driller were developed through workshop discussions involving stakeholders, scientists, and the public, as well as by the SME panel. Four intruder-drilling scenarios were derived: the standard Homestead Scenario, the Base Community Scenario, the Las Vegas Expansion Scenario, and the Jackass Flats Scenario. Of these four, the SMEs determined that the Jackass Flats Scenario is most likely, occurring for around 5,000 years of the 10,000-year evaluation period in either Frenchman or Yucca Flats. A community in Jackass Flats was considered large enough to spill population over into adjacent valleys, creating "commuting homesteaders." The probability of IHI for the Jackass Flats Scenario is about 10% for Frenchman Flat (the Area 5 RWMS location), and about 1% for Yucca Flat (the Area 3 RWMS location). The lower probability of IHI in Yucca Flat is attributed to the presence of surface-subsidence craters, created by underground testing, that effect the expected number of drilled wells.

- Of the five management control factors (institutional control, site knowledge, placards and markers, surface barriers, and subsurface barriers) assessed in the elicitation, surface barriers were found to be potentially the most effective in reducing the probability of IHI. The SMEs determined that a surface barrier designed to prevent the driller from setting up a drill rig atop the waste site would be 95% effective. The subsurface barriers and placards and markers were considered less likely to deter intrusion than a well-designed surface barrier. A simple warning sign, which the SMEs illustrated, may reasonably provide a 50% probability of effectiveness. Elicited input for the institutional control and site knowledge factors indicate less than 500 years of combined effectiveness over the 10,000-year evaluation period. It was considered more likely that control would be lost gradually. The SMEs considered several mechanisms for gradual erosion of institutional control and loss of site knowledge: political change, economic constraints, or less concern by society for the importance of waste management issues.

- Assuming that the surface barrier described by the SMEs is effective at a probability of 95%, the resultant Jackass Flats Scenario probabilities for Frenchman and Yucca Flats can be further modified by the effectiveness of the surface barrier to deter IHI. Applying the surface barrier

1. and provides a means of describing and quantifying management control options now, and into the future. On the other hand, the deterministic approach to PA assumes that IHI by drilling *will* occur at a probability of 100%. As demonstrated in this study, probabilistic PA results for the NTS are more realistic, and have proven successful in evaluating problematic waste streams (Brown et al., 1996) that require a more thorough and rigorous method of analysis.

2. Periodic review of intrusion is proposed by the SMEs, at an interval of 25 years, to reassess probabilistic estimates given that changes in society (political, economic, cultural, etc.) or technology will affect the results of the evaluation. Sufficient funds should be allocated now to ensure that periodic review of intrusion will occur.

3. A major conclusion and recommendation of this study is the need for further work regarding alternative options for implementation of management controls. The effectiveness of management controls are dependent on DOE policy decisions. The SMEs concluded in the elicitation that the absence of clear DOE policy regarding management controls increased the uncertainty of their estimates. Further work in this area can be conducted through decision analysis that incorporates factors such as cost, construction, and schedule to identify the most appropriate decision action to deter drilling associated with IHI.

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APPENDIX B

PROBABILITY OF INADVERTENT HUMAN INTRUSION CALCULATIONS: POSTDRILLING

B.1 INTRODUCTION

Inadvertent human intrusion (IHI) occurs if one or more persons, unaware that radioactive waste has been disposed at a site, become exposed to radioactivity by exhuming or otherwise coming into direct contact with the waste. U.S. Department of Energy (DOE) Order 5820.2A (1988) requires an assessment of dose to an intruder that might arise from waste disposed after September 26, 1988.

The assumption that intrusion occurs sometime within the compliance period is conservative. At a site capable of supporting agriculture, intrusion during the postinstitutional control period might be considered plausible. At such a site, the assumption that intrusion occurs might not be unreasonable. However, this assumption is less reasonable at an arid site such as Frenchman Flat (location of the Area 5 Radioactive Waste Management Site [RWMS]). Where occurrence of intrusion is unlikely, only assessments accounting for the site-specific probability of IHI avoid excessive conservatism.

There are at least two concepts of probability: relative frequency (frequentist) and reasoned belief (Bayesian). The relative frequency probability of an event is the number of times, in a great many trials, that the event occurs, divided by the number of trials. This is the definition generally applied to repeatable events (see, for example, Gnedenko [1962]). Examples of situations where relative frequency probability is commonly applied include coin tossing, games of chance, and meteorological events, where future conditions are forecast from the proportion of times a given weather event occurred following circumstances similar to those existing at the time of forecast.

The reasoned-belief probability of an event is the degree of belief a rational individual holds, given previous data or knowledge, in the event's occurrence (see, for example, Morgan and Henrion, 1995; or Raiffa, 1970). Examples of situations where reasoned belief probability might be applied include the outcome of a particular sporting event, the possible existence of life on Mars, or the possible occurrence of armed conflict in a certain time span in the future. No concept of probability, other than reasoned belief, can be meaningfully applied to one-time events, such as intrusion into the Area 5 RWMS during the compliance period.

Reasoned belief can differ among individuals because of differences in knowledge bases and cognitive biases. Scientific use of reasoned-belief probability requires elicit and quantify opinions of a panel of unbiased experts (Casti, 1990; Meyer and Booker, 1991).

This Appendix briefly describes the calculation of the probability of IHI at the Area 5 RWMS based on an expert elicitation study Black *et al.* (2000). This study used input from several subject matter experts (SMEs). The calculations presented are based on the models and inputs to those models provided by the SMEs. The purpose of this Appendix is to show how the SME inputs were used in calculations of the probability of IHI to support the generation of waste concentration limits in the main text. Assembling the panel of experts and eliciting their opinions involved the following steps:

- Preliminary intrusion scenarios and probability models were developed in the form of influence diagrams. These scenarios and models were subjected to extensive internal and external review, and were modified accordingly.

- The underlying ideas of the scenarios and models were presented to various stakeholders, who examined their logic and acceptability (Mathai *et al.*, 1996). Stakeholder groups represented were Citizen Alert, the Community Advisory Board, Community Radiation Monitoring Program, the Nevada Division of Environmental Protection, the Nevada Nuclear Waste Project Office, and the Nevada Nuclear Waste Task Force. Scenarios and models were modified to accommodate stakeholder concerns.

- A panel of ten SMEs was assembled. These SMEs represented the disciplines of agronomy, anthropology, demography, economic geology, geotechnical engineering, hydrogeology, land-use planning, sociology, and well drilling. SMEs were selected in a manner that minimized the possibility of SME personal bias (e.g., no connection with groups advocating or opposing disposal of radioactive waste; no current financial ties to DOE/Nevada Operations Office [NV], etc.). SMEs were trained in expressing beliefs as probabilities. After further refining scenarios and models, SMEs expressed their reasoned beliefs concerning model inputs. These input probability distributions were used to provide estimates of the probability of IHI.

A brief overview of the scenarios and models selected follows. Complete details appear in Black *et al*. (2000).

B.2 OVERVIEW OF APPROACH

Many factors strongly influence the calculated probability. Most were described by SME inputs. Two factors that are critical to the calculations were preset for the elicitation session:

- length of compliance period, and

The expert elicitation study was conducted with a 10,000-year compliance period. The length of the compliance period used in this analysis is 1,000 years. This change is due to guidance included in DOE (1996). Sufficient information was obtained during the elicitation to be able to reasonably evaluate the postdrilling intrusion scenarios for time frames shorter than 10,000 years.

The expert elicitation study was conducted with a waste footprint set at 0.8 hectares (ha) (2 acres [ac]) for the elicitation study. This condition was established to allow calculation of the probability of IHI. During the elicitation process, the expert panel chose to evaluate the potential for IHI by assessing the number of wells that might be drilled in Frenchman Flat during the compliance period. Consequently, the elicitation was performed essentially independent of waste footprint size.

The probability of IHI depends on the area of the waste footprint and the area of Frenchman Flat, which was estimated using a Geographic Information System to be 33,300 ha (86,000 ac). As the relative size of the waste footprint to the area of Frenchman Flat increases, the probability of IHI increases. The probability of IHI within the compliance period also increases as the length of the compliance period increases.

Calculations of the probability of IHI proceeded as follows:

1. SMEs provide inputs, usually in the form of distributions. The SMEs provided their opinions on quantiles of the distribution (e.g., the 10th, 25th, 50th, 75th, 90th percentiles).

2. Distributions were fitted to the quantile inputs obtained from the SMEs. The methods by which final cumulative distribution functions (CDFs) were established are not crucial to the overall results. Only gross deviations from the inputs are likely to have any serious consequence for conclusions (Raiffa, 1970).

3. Standard Monte Carlo simulation methods were used to propagate the fitted distributions through the influence diagram model (a model which reflects the relationships between the factors influencing IHI).

4. The distribution of the probability of IHI from the output was estimated from the simulated results. Under the reasoned-belief, or subjective (Bayesian) probability paradigm, anything that is unknown is random, and hence has a probability distribution (Wright and Ayton, 1994). This includes unknown probabilities such as the probability that IHI will occur during the compliance period.

Four scenarios were considered by the SMEs, including a homesteader scenario and three community scenarios. The initial calculations for each scenario lead to a conditional IHI scenario probability. The probability is termed conditional because of an assumption that there are no effective management controls, where management controls are factors which reduce the probability of intrusion, such as institutional control, placards and markers, or subsurface barriers. The SMEs considered several mechanisms by which management controls could effectively reduce the potential for IHI to occur. Of these controls, credit is taken in calculation of the waste concentration limits only for the period of institutional control. The final steps of the calculations in support of generation of the waste concentration limits process are to combine the conditional scenario probabilities from the four scenarios and to combine this result with the outcome of the institutional control factor. The final step effectively takes into account the degree of effectiveness of a period of institutional control.

The SMEs were generally asked for quantile input to distributions for the input parameters as opposed to single numbers, such as an expected value. Using the distributional information and a simulation approach ultimately allows calculation of distributions for the final probability of interest. However, it must be recognized that the final distributions of the probability of IHI are conditional on the process undertaken during the expert elicitation study. For example, the final products are conditional on:

- the SMEs' knowledge (including information provided to the SMEs throughout the project),
- the influence diagram models,
- the actual SME inputs (quantiles of distributions, etc.),
- the methods used to fit CDFs to the input quantiles provided by the SMEs, and
- constants that are used instead of distributions for some inputs.

Because of the conditions imposed, the final probability distributions might underestimate the overall uncertainty or variability of the results. However, the mean probability of IHI estimated through these methods is probably slightly underestimated because of some simplifications made in the calculations. Waste concentration limits are generated based only on the mean probability of IHI, in which case it is expected that the resultant waste concentration limits, when based on the postdrilling scenario, are conservative. A full discussion is provided in Black *et al*. (2000).

The four scenarios considered by the SMEs were termed the homesteader scenario, the base community scenario, the Las Vegas Expansion scenario, and the Jackass Flats scenario. Descriptions of these scenarios, SME inputs, and the calculations are provided in the following sections. Complete details can be found in Black *et al*. (2000).

- Homestead density (distribution of number of homesteads at a given time). The SMEs indicated that, at any point in time, the probability that no homesteads would exist in Frenchman Flat was 0.98 and, with probability 0.02, one or more homesteads would exist. Sufficient information was elicited to place a probability distribution on the number of homesteads present for those times that the number was positive.

- Homestead lifetime (number of years a homestead remains viable). The SMEs indicated that homestead lifetimes has a slightly positively skewed distribution, with a median of 12.5 years.

- Well lifetime (number of years a well remains viable). The SMEs indicated that well lifetime has a slightly skewed distribution, with a median of 35 years.

- Number of wells per homestead. The SMEs determined that one well per homestead was a reasonable approximation.

- Distance between replacement wells (wells drilled to replace an existing well when, for some reason, the existing well ceases to meet the homesteader's needs). Distance between replacement wells had little impact on the probability of intrusion. Well lifetimes were, on average, about three times longer than homestead lifetimes. Hence, few homesteads have replacement wells.

The distributions that were fit from the SME input, and the influence diagram models, provided the basis for the simulations. For each simulation run, a series of random numbers was drawn from the distribution of homestead lifetime until they summed to at least 200 years (the total length of time for which the SMEs thought that at least one homestead might be present corresponding to 98 percent of the time that there would be zero homesteads). The floor of 200 years in this calculation introduced slight conservatism in results. For each homestead lifetime, a random number was drawn from the homestead density fitted distribution, and the total number of homesteads was summed. This is the same as the number of wells for this scenario because of the assumption of one well per homestead.

The SMEs hence provided sufficient input to estimate a distribution for the number of primary wells that would be drilled in Frenchman Flat during the compliance period. Each simulation resulted in a single realization of the total number of primary wells. The next step was to incorporate this information in calculations of the probability that a well would intersect the waste footprint. For each simulation, the primary wells were randomly located in Frenchman Flat. A number of replacement wells was also drawn at random, and replacement wells were placed near the primary well. Replacement wells occurred infrequently for this scenario. This process was repeated effectively 1,000,000 times for each of the 10,000 simulations. For most repetitions, no wells intersected the waste footprint, but occasionally a repetition had at least one well that simulations allowed a distribution of the probability of IHI to be generated. The average of these simulated probabilities was 0.00026, with minimum and maximum simulated values of approximately 0.0001 and 0.0005, respectively

B.4 BASE COMMUNITY SCENARIO

For the base community scenario, the SMEs provided inputs for the following factors:

- Effective number of years that a base community might exist in Frenchman Flat. This was assessed as 50 to 100 years. Quantiles were not explicitly elicited for the distributions of these factors because the effect of using any value within this range would not have any significant impact on the results, and because the probability of IHI for this scenario is clearly very small, given the SME input.

- Community lifetime. Given the existence of a base community in Frenchman Flat, this is the number of years that it might exist. The SME input is summarized in Table B-1.

Table B-1 Community Lifetime and Associated Cumulative Probabilities

Community Lifetime	Cumulative Probability
10	*0.1*
35	0.25
50	0.5
65	0.75
100	*0.90*

Based on the SME quantile inputs, a continuous cdf was fit to this factor and was used as the basis for simulation.

- Community well lifetime. The SME input is summarized in Table B-2. Based on these inputs, a continuous cdf was fit to this factor and was used as the basis for simulation. Only community water system supply wells were included in this scenario.

Table B-2 Community Well Lifetime and Associated Cumulative Probabilities

Well Lifetime	Cumulative Probability
10	0.1
35	0.5
50	0.9

Given these input variables, distributions were estimated for the total number of communities and number of wells existing in Frenchman Flat during the compliance period. The number of communities was determined by drawing from the community lifetime distribution until values drawn summed to at least the minimum number of years that communities might exist (50 years).

To simplify calculations, it was assumed that communities could be sited anywhere in Frenchman Flat. There was no requirement that the communities should be sited in the same place, nor were they prohibited from being sited in the same place. As multiple communities rarely occurred, this simplification had little impact on the estimated probability.

A community was assigned four initial, or primary, water supply wells. The SMEs indicated tat this was probably conservative for the types of community envisioned. They did not choose to refine this input because they felt that this scenario was unlikely to occur, and hence did not warrant further consideration. Replacement wells were also considered, based on a comparison of community lifetime and community well lifetime distributions. Each well was considered separately, and random draws from the well lifetime distribution were made to determine when replacement wells were needed. Well lifetimes were drawn for each well until the total lifetime met or exceeded the lifetime of the community. The algorithm used was otherwise similar to the one used for the homesteader scenario. The spatial placement of the primary wells was constrained per input from the SMEs so that the four primary wells were evenly placed in a square on one-half-mile centers. The process was repeated effectively 1,000,000 times for each of the 10,000 simulations to provide a distribution for the probability of IHI for this scenario.

The overall probability was calculated to be approximately 0.00017, with minimum and maximum simulated values of approximately 0.00005 and 0.00006, respectively. These probabilities are very small and, like the Homestead scenario, are dwarfed by the probability of IHI for the Jackass Flats scenario.

B.5 JACKASS FLATS COMMUNITY SCENARIO

This scenario was suggested by the SMEs as a hybrid of the homesteader and base community scenarios. That is, it was assumed that a community might exist near Frenchman Flat, but that some members associated with that community might prefer to live in a more remote setting such as Frenchman Flat, but that these “commuting homesteaders” would still benefit from the infrastructure of the community. The SMEs provided the following inputs:

- Effective number of years that base communities might exist in the vicinity of Frenchman Flat. The SMEs determined that a community in some area near but not in Frenchman Flat would place population pressure on Frenchman Flat due to the presence of “commuting homesteaders” (those who want to live near

- Community lifetime. The distribution of community lifetimes for this scenario is the same as for the base community scenario, and is presented in *Table B-1*. Also, the SMEs indicated that commuter homesteads can be assumed to last the same length of time as the corresponding communities. Consequently, the distribution for homestead lifetimes for this scenario is also the same as that for the community lifetime provided in *Table B-1*.

- Number of commuter homesteads. Table B-3 provides a brief summary of the SME input for the distribution of number of homesteads per community. A continuous cdf was fit to these inputs and was used as the basis for the simulations.

- Well lifetime. The SMEs decided that well lifetime should be the same for this scenario as for the homestead scenario. A continuous cdf was fit to these inputs and was used as the basis for the simulations.

Table B-3 Summary of SME Input for Number of Commuter Homesteads per Community for Frenchman Flat

Number of Homesteads	Cumulative Probability
1	*0.1*
50	0.5
100	0.95
200	*0.99*

The simulations and calculations for this scenario were very similar to those performed for the homesteader scenario.

Each simulation involved random draws from the interval 2,500 to 7,500 to determine the base number of years that the communities might exist as required. The number of communities was determined by successive random draws from the distribution of community lifetimes. These random draws were repeated until the sum of community lifetimes was closest to the randomly drawn target base number of years. The communities were treated as independent, both in time and in space. Once the number of communities was established for a single simulation run, the number of homesteads for each of those communities was drawn at random from the corresponding cdf.

Replacement wells were determined in the same way as for the Homesteader scenario. Each simulation resulted in a single realization of the total number of primary wells expected to be drilled in the evaluation period. These primary wells were located at random in Frenchman Flat, and determinations were made concerning intersection with the waste footprint. The process was repeated 10,000 times for each of the 10,000 simulations.

For the Frenchman Flat scenario, the overall mean conditional scenario probability was estimated to be approximately 0.11. Minimum and maximum conditional scenario probabilities based on the simulated distribution are approximately 0.03 and 0.21, respectively.

B.6 LAS VEGAS EXPANSION SCENARIO

This scenario, again defined by the SMEs, was a similar hybrid scenario. In this case, however, the central community that might occur was an expanded city of Las Vegas. Again, it was assumed that some commuter homesteaders might prefer to live outside the city in a more remote setting, such as Frenchman Flat. The SMEs provided the following inputs:

- Probability of Las Vegas expanding. The SMEs suggested that a population of approximately 3,000,000, about three times the current population of Las Vegas, would be required before Frenchman Flat might be impacted by population pressure. The SMEs believed that the greatest population Las Vegas could reasonably achieve is 5,000,000. The SMEs indicated that the probability that Las Vegas might expand sufficiently to put population pressure on Frenchman Flat ranged from 0.10 to 0.60, with a “most likely” value of 0.20.

- Lifetime of Las Vegas. Obviously, this scenario can only occur during the time that Las Vegas is a viable city. The SMEs indicated that the probability that Las Vegas will survive at least 500 years is 0.90, the probability that Las Vegas will survive at least 1,000 years is 0.50, the probability that Las Vegas will survive at least 1,500 years is 0.10, and the probability that Las Vegas will survive 2,000 years is 0.01.

- Number of homesteads. The SMEs indicated that, during the period in which Las Vegas is large enough to put population pressure on Frenchman Flat, Frenchman Flat would contain one or more homesteads 90 percent of the time, more than 30 homesteads 50 percent of the time, and more than 75 homesteads 10 percent of the time.

- Homestead lifetime. Identical to the discussion in Section B.3.

- Well lifetime. Identical to the discussion in Section B.3.

- Distance between replacement wells. Identical to the discussion in Section B.3.