DOE/NV-593-Vol. I

Assessing the Probability of Inadvertent Human Intrusion at the Nevada Test Site Radioactive Waste Management Sites

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Prepared by

Argonne National Laboratory

Paul Black, Kelly Black, Lisa Stahl, Mark Hooten, Tom Stockton, and Dean Neptune
of
Neptune and Company, Inc.

Prepared for

the U.S. Department of Energy
Nevada Operations Office
under Argonne National Laboratory Contract Number
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EXECUTIVE SUMMARY

The United States Department of Energy (DOE) Order 5820.2A (DOE 1988) requires each site disposing of low-level radioactive waste (LLW) to prepare and maintain a site-specific performance assessment (PA). The goal of the PA is to determine potential risks to the public and the environment that are posed by waste management systems, and to compare those risks to established performance objectives. One of the performance objectives concerns the potential risks caused by inadvertent human intrusion (IHI) into buried waste. An inadvertent human intruder is an individual who unintentionally breaches buried waste during the regulatory compliance period that occurs after site closure.

Several intrusion mechanisms are considered in a PA, including a construction scenario, a discovery scenario, and a well drilling scenario. The objective of this study is to generate an assessment of the probability of IHI into deep or intermediate-depth buried radioactive waste in the Area 3 and Area 5 Radioactive Waste Management Sites (RWMSs) at the Nevada Test Site (NTS). Consequently, the intrusion mechanism of concern is well drilling.

A traditional PA under DOE Order 5820.2A 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, and evaluates the risk associated with such an intrusion. This deterministic approach may be reasonable for waste disposal sites near populated areas. However, IHI might be much less likely in the remote Mojave/Great Basin desert setting of the NTS. The RWMSs are situated in alluvial basins where the average annual rainfall is less than 10 cm (4 in.); near-surface hydrologic processes are dominated by evapotranspiration; permanent, natural, surface water features are rare; and the depth to groundwater generally exceed 235 m (770 ft.). This study takes into account site-specific factors to develop a more realistic probabilistic evaluation of IHI.

One of the standard assumptions of a deterministic PA is that IHI will occur. The desire to determine if problematic high-specific activity LLW can be accepted for disposal at the NTS, by determining if this assumption is reasonable in this remote and environmentally hostile setting, is the basis for assessing the probability of IHI and evaluating the expected human health radiation risk. The basic premise of the probabilistic approach to assessing IHI during the compliance period, is that the only viable assessment method is subjective elicitation. Through this assessment, these remote areas at the NTS might be shown to exhibit favorable conditions for the disposal of DOE-titled LLW for which the intruder-drilling scenario is limiting. If it can be demonstrated that these NTS RWMSs can accept different classes of LLW, then radiation exposure to the public and the accessible environment could be significantly reduced. Another benefit is the potential for the subjective elicitation methods used, if they proved to be successful, to be employed within DOE and other Government agencies to address challenging policy issues associated with radioactive waste disposal and environmental stewardship.

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 less desirable to society. The significant uncertainty associated with these topics cannot be appreciably reduced by conventional means of data gathering. Consequently, assessment of the probability of IHI was performed through an expert elicitation.

Expert judgment has proven to be a particularly useful tool for evaluating probabilistic estimates for rare or poorly understood phenomena and for forecasting future events. This approach is technically sound. An important ingredient of the process is the development of models and assumptions, and sharing of information among all participants to ensure that the results are credible. A number of components were used to build a solid foundation before expert opinion was sought through subject matter expert (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, and developing preliminary models in the form of "influence diagrams" that show the important factors or variables and the relationships among them at a simple, intuitively appealing, level.

A stakeholder workshop was convened early in the project to involve the public in the development of the project. Participants included representatives from the Community Radiation Monitoring Program, Community Advisory Board, the University of Nevada Las Vegas, Citizen Alert, and Nevada Nuclear Waste Task Force. State groups included the Nevada Division of Environmental Protection and the Nevada Nuclear Waste Project Office. The stakeholders confirmed that site-specific community scenarios should be considered in addition to the default homesteader scenario. They verified that appropriate variables had been identified for consideration in the intrusion scenarios, and they strongly endorsed the probabilistic process and underlying assumptions.

An SME panel was then convened to provide needed expertise to finalize the models and provide quantitative input to specify distributions for the factors included in the models. The disciplines that were identified as having a direct bearing on the influence diagrams included agronomy/soil science, anthropology/archaeology, demography, hydrogeology, geotechnical engineering, economic geology/resource use, rural and urban land-use planning, water-well drilling, and sociology.

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

The main assumption addresses prediction of future changes in society and technology. The stakeholders and SMEs recognized that accurate prediction of most events (for example, population growth, technology development, societal patterns, or climate change) is very unlikely. Consequently, a working assumption for this probabilistic study of IHI is that forecasting of future patterns must be based on knowledge of current technology and current societal practices.

The stakeholders and SMEs further realized the need to periodically revisit the probabilistic estimates if changes occur in society or technology that could significantly affect the results of the evaluation. Periodic review at intervals of no more than 25 years was proposed as an alternative to dealing with the largely unbounded uncertainties of predicting the future. They emphasized the need to establish some form of trust fund to guarantee that the assessment would be revisited periodically. They also recognized that establishing a periodic review process could have a dual benefit of helping to ensure continued institutional control as well as re-evaluation of the probability of IHI.

The models consist of two primary components: intrusion scenarios and management controls. Management controls consist of five factors that, if effective, are assumed to eliminate the possibility of IHI: institutional control, site knowledge, placards and markers, surface barriers, and subsurface barriers. 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 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 inadvertent public incursion. Site knowledge could be enhanced by the presence of some form of permanent surface markers or warning signs. Two additional factors could deter drilling for groundwater, should institutional control and site knowledge become ineffective: 1) surface barriers can be built to restrict or prohibit access to the land immediately above a waste disposal site, and 2) subsurface barriers can be constructed to prevent completion of a drilling operation.

A number of possible site-specific intrusion scenarios were identified by the SMEs and in the workshop discussions involving stakeholders, scientists, and the public. The standard homesteader scenario was accepted by the SMEs for evaluation, along with three different community scenarios that were judged by the SMEs to be equally or more plausible in this arid desert setting. Four scenarios were evaluated in this study:

1. The Homesteader scenario; the standard homesteader scenario in which independent homesteads are located in Frenchman Flat or Yucca Flat

2. The Base Community scenario, in which a small community is located in the alluvial basins of Frenchman Flat or Yucca Flat

3. The Jackass Flats scenario, in which a small community is located in Jackass Flats, Mercury, or some other area near Frenchman Flat and Yucca Flat, allowing for "commuter homesteaders" living in Frenchman Flat or Yucca Flat

4. The Las Vegas Expansion scenario, in which urban expansion of Las Vegas north up the valley corridor and into the alluvial basins of NTS, allows for "commuter homesteaders" in Frenchman Flat or Yucca Flat

The SMEs identified several factors that might affect the outcome of the probabilistic assessment of IHI for these scenarios (for example, the suitability of the land surface for expected settlement activities, and future groundwater resource availability). The factors and models developed by the SMEs for each scenario provided the necessary focus for the expert elicitation. The homestead and community scenarios were evaluated separately, and then combined to provide a total scenario probability of IHI, conditional on all management controls factors being ineffective. If any of the management controls are completely effective, it is assumed that IHI cannot occur. Therefore, the potential effectiveness of management controls must be evaluated and the results combined with the scenario results to provide a final assessment of the probability of IHI.

The basic model requires calculation of a probability of IHI for each of the four scenarios. In each case the final step in the calculations was based on the total number of wells expected to be drilled in Frenchman Flat or Yucca Flat during the compliance period. This number was used in a probabilistic calculation that assessed the chance that at least one of these wells would intersect the waste footprint (the surface area of the waste disposal unit, assumed to be two acres), causing IHI to occur. The manner in which the number of wells was determined differs for each scenario, depending on the factors the SMEs identified as important in each case. The elicited input obtained from the SMEs was in a form that lent itself to estimation of probability distributions for each factor. The probability distributions were propagated through the models, using simulation techniques, to calculate scenario and management controls probabilities. These techniques were used to completely reflect the SME inputs and to account for the variability or uncertainty they expressed.

Of the four scenarios considered, 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 Flat or Yucca Flat. When the scenarios are combined in a simple additive manner, the probability of IHI is about 11% for Frenchman Flat (the Area 5 RWMS location), and less than 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 affect its desirability for settlement and, hence, the number of wells expected to be drilled. The Area 3 RWMS is located in the heavily cratered area within Yucca Flat.

It should be noted that all the results depend on the assumptions and conditions of the study. The assessed probability of IHI is dependent on the SMEs and their current knowledge of technology and society, their inputs both to the structure of the model and specification of input distributions, and some aspects of the elicitation process and the mathematical modeling performed. The results also depend heavily on the choice of areal size of the waste footprint, and must be adjusted if a different size is considered.

The scenario probabilities of 11% for Frenchman Flat and 1% for Yucca Flat are also dependent on the absence of management controls, which could be implemented to prevent IHI. DOE/NV has considered the need for long-term management controls for the Area 3 and Area 5 RWMSs, but has not established policy for their implementation. Assessment of management controls factors, therefore, should be regarded as preliminary and exploratory. Of the five management control factors assessed (i.e., institutional control, site knowledge, placards and markers, surface barriers, and subsurface barriers), surface barriers were considered potentially the most effective for reducing the probability of IHI. The SMEs determined that a surface barrier designed to prevent the driller from setting up a drill rig above the waste site could be 95% effective. Subsurface barriers and placards and markers were considered less likely to deter intrusion than a well-designed surface barrier. The SMEs suggest that a simple warning sign, which the SMEs illustrated, may reasonably provide a 50% probability of effectiveness.

The SMEs considered it more likely that institutional control would be lost gradually than suddenly through a catastrophic event. Several mechanisms for gradual erosion of institutional control and loss of site knowledge were considered, including political change, economic constraints, or lessened societal concern over waste management issues. Elicited inputs for the institutional control and site knowledge factors indicate less than 500 years of combined effectiveness over the 10,000-year evaluation period.

The scenario probabilities can be modified by considering the potential effectiveness of management controls. Assuming that the surface barrier described by the SMEs as most effective (with a probability of 90%) is implemented, the worst-case Jackass Flats scenario probabilities decrease: the overall probability of IHI in Frenchman Flat becomes approximately 1%, and the probability of IHI in Yucca Flat becomes less than 0.1%. Yucca Flat is a better choice for locating a waste site to reduce the probability of IHI, given the intruder-drilling mechanism.

The probabilistic approach to assessing the intruder-driller for NTS PAs results in more site-specific, credible scenarios; yields significantly lower probabilities (the highest is approximately 11%) for Frenchman Flat and Yucca Flat; and provides a means of describing and quantifying management controls options now and into the future. On the other hand, the deterministic approach to NTS PAs assumes that IHI by drilling will occur with 100% certainty. It should be realized that the reported probabilities depend on the waste footprint size of two acres. The input provided is equally valid for estimating the probability of IHI for other waste footprint sizes. The probability increases with area of the waste footprint. The input can also be applied to shallow buried waste, although other intrusion mechanisms (intruder-construction, intruder-discovery) should also be evaluated for these cases, and some awareness of the assumptions made to make this transition is needed (for example, some of the inputs provided by the SMEs were not further refined because of the assumption of a 10,000 year evaluation period).

As demonstrated in this study, a probabilistic approach to assessing IHI using expert opinions is more realistic than a deterministic approach. Probabilistic PA results have proven successful in evaluating problematic waste streams that require a more thorough and rigorous method of analysis (Brown et al. 1997, Shott et al. 1997, Shott et al. 1998, Barker et al. 1998).

Another conclusion and recommendation of this study is the need for further work regarding alternative options for implementing management controls. The effectiveness of management controls is 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 for deterring drilling associated with IHI.

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Alan Thomas	Bechtel Nevada
Theresa Brown	Sandia National Laboratories
John Cochran	Sandia National Laboratories
David Gallegos	Sandia National Laboratories

The Peer Review Group provided a thorough review for each technical stage of the project, including review of preliminary models and basic approach to elicitation, elicitation sessions, and the drafts of the final report.

Bruce Crowe	Los Alamos National Laboratory
Charles Davis	Envirostat
Doug Duncan	U.S. Department of Energy/Nevada Operations Office
William Roberd	Golder Associates, Inc.

Argonne National Laboratory and the Yucca Mountain Project also provided review comments on drafts of the final report.

Jack Ditmars	U.S. Department of Energy/Argonne National Laboratory
Jeff Keisler	U.S. Department of Energy/Argonne National Laboratory
Ron Whitfield	U.S. Department of Energy/Argonne National Laboratory

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Juana Blackburn	Desert Research Institute

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The U.S. Department of Energy/Nevada Operations Office Project Manager for Performance Assessments at the low-level RWMSs in Frenchman and Yucca Flats was Beth Moore. The Project Manager for Neptune and Company's efforts on this project is Paul Black. For further information regarding this project, contact:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

The U.S. Department of Energy, Nevada Operations Office (DOE/NV) operates, oversees, and has responsibility for future closure of low-level Radioactive Waste Management Sites (RWMSs) located in Frenchman Flat and Yucca Flat at the Nevada Test Site (NTS) (Figure 1-1). The DOE/NV Waste Management Program provides low-level radioactive waste (LLW) 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.

Regulations under U.S. Department of Energy (DOE) Order 5820.2A (DOE 1988), which pertain to waste disposal after 1988, specify that each radioactive waste disposal site shall prepare and maintain a site-specific radiological Performance Assessment (PA). A PA is a series of analyses conducted to determine potential risks posed to the public and the environment by waste management systems, and to compare these risks to established performance objectives (e.g., 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 conditionally approved for the post-1988 disposal units in the Area 5 RWMS, located in northern Frenchman Flat (Figures 1-2 and 1-3) (Shott et al. 1998, Barker et al. 1998). A PA for the Area 3 RWMS, located in southern Yucca Flat (Figures 1-2 and 1-3) has also been conducted and conditionally approved (Shott et al. 1997). Each PA must evaluate facility operation based on four performance objectives, 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 mrem/yr.

3. Assure that an effective dose equivalent received by an individual who inadvertently intrudes into the waste after loss of institutional control (usually assumed to occur at 100 years) will not exceed 100 mrem/yr for continuous exposure and 500 mrem/yr for a single acute exposure.

4. Protect groundwater resources consistent with federal, state, and local regulations.

The third performance objective listed above is used to evaluate the potential for disposed radioactive waste to adversely impact an inadvertent human intruder after loss of institutional control and reduced effectiveness of other management controls (such as barriers or markers). 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.

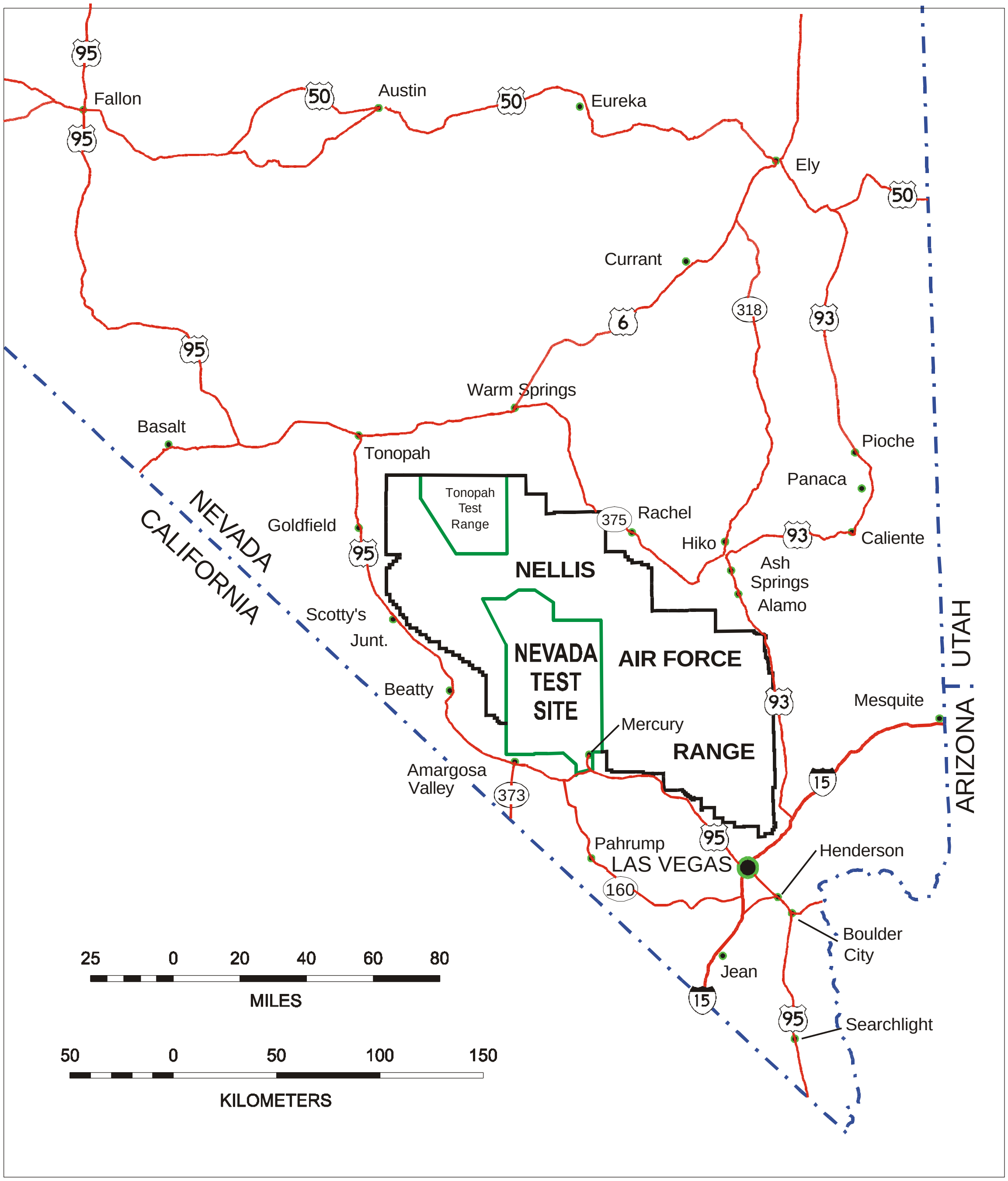

Figure 1-1 Location of the Nevada Test Site in southern Nevada

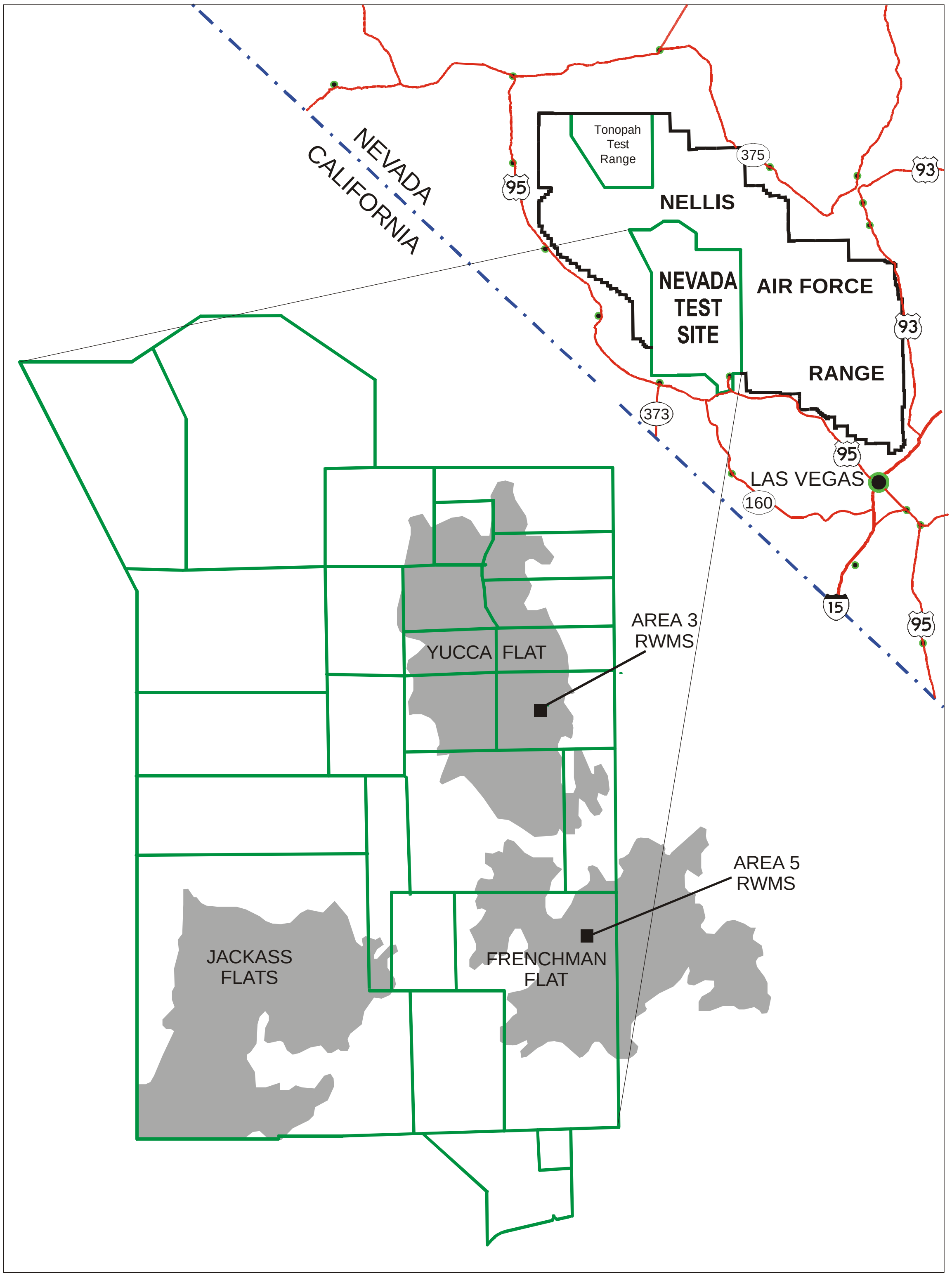

Figure 1-2 Locations of the Area 3 and Area 5 Radioactive Waste Management Sites at the Nevada Test Site

Figure 1-3 Oblique aerial photographs of the Area 3 Radioactive Waste Management Site (above) and the Area 5 Radioactive Waste Management Site (below) at the Nevada Test Site from 7 July 1998

The PA process as defined in Wood et al. 1994 (cf. Cochran 1995) recommends that three standardized exposure scenarios be used to assess the potential consequences of inadvertent human intrusion (IHI) into buried waste:

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, except that it 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.

Performance assessments have traditionally been performed using a deterministic approach to IHI. That is, risk or dose consequences are evaluated assuming IHI will occur. Under the standard deterministic exposure scenarios for the inadvertent human intruder, some waste forms that could be considered for burial at the NTS under DOE Order 5820.2A (DOE 1988) present unacceptable risk from radiation exposure. If shallow burial of waste forms is not adequately protective under the assumption that IHI will occur, then the waste forms are assumed to be buried at intermediate or greater depths. Deeper burial of the waste minimizes both the potential for IHI and the potential for radiation exposure through other pathways.

The intruder-drilling scenario is often the dominant scenario for waste proposed for burial at the NTS RWMSs. This is particularly true for more deeply buried waste. For this exposure scenario, an individual (the "homesteader") 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. Contaminated soil and vegetables form the basis for contaminant fate and transport to other pathways and the exposure assessment.

One of the assumptions of a deterministic PA is that IHI will occur. The desire to determine if high-specific activity LLW could be accepted for disposal at the NTS, by determining if this assumption is reasonable in the remote and environmentally hostile setting of the NTS, is the basis for assessing the probability of IHI and evaluating the expected human health radiation risk. The basic premise of this alternate approach to assessing the probability of IHI during the compliance period, is that the only viable assessment method is subjective elicitation.

Through this assessment, remote areas at the NTS, where the RWMSs are situated, might be shown to exhibit favorable conditions for the disposal of DOE-titled low-level radioactive waste for which the intruder-drilling scenario is limiting. If it can be demonstrated that these NTS RWMSs can accept different classes of low-level radioactive waste, then radiation exposure to the public and the accessible environment could be significantly reduced. Another benefit is the potential for the subjective elicitation methods used, if they proved to be successful, to be employed within DOE and other Government agencies to address challenging policy issues associated with radioactive waste disposal and environmental stewardship in general.

The intruder-drilling scenario is the main focus of this study, because the intent is to apply the results to the prospective burial of problematic high-specific activity LLW. The results can, however, be applied to shallow buried waste, so long as it is understood that for shallow buried waste, well drilling might not be the dominating intrusion mechanism and that other intrusion mechanisms should also be evaluated.

The standard intrusion scenarios define the exposure mechanisms, but do not similarly prescribe the human habitation scenarios underlying transport of the waste from the subsurface to the surface. Case and Otis (1988) indicate that "scenario construction should consider current patterns of activity in the area." They further note that the selection of post-institutional control scenarios can be a fairly subjective process, in which case it is appropriate to consider scenarios that go beyond the default scenarios. While the default "homestead" scenario served as the starting point for this study, "community" scenarios were also suggested and developed.

The specific objective of a probabilistic approach to this problem is to assess the potential for IHI to occur, as opposed to assuming that it will occur. The deterministic assumption that IHI will occur over the course of a 10,000 year time frame (the evaluation period used in this study) is very conservative and can reasonably be questioned for sites as remote as the Area 3 and Area 5 RWMSs (Figure 1-3). While the deterministic approach may be reasonable for waste disposal sites near populated areas, where the probability of human intrusion is greater, IHI is much less likely in the remote, Mojave/Great Basin desert setting of the NTS. The RWMSs are situated in alluvial basins where the average annual rainfall is less than 10 cm (4 in); near-surface hydrologic processes are dominated by evapotranspiration; permanent, natural surface water features are rare; and depths to groundwater exceed 235 m (770 ft) (Shott et al. 1998, Winograd 1981).

This report describes a site-specific approach for assessing the probability of IHI for the intruder-drilling exposure scenario at the Area 3 and Area 5 RWMSs. A process known as expert elicitation is used in this project because some of the parameters that might affect the probability of IHI are difficult or impossible to measure directly, but may fall within the knowledge domains of experts. Specifically, probabilities of inadvertently drilling into disposed waste are assessed by formally eliciting judgments about a number of related variables from a panel of subject matter experts (SMEs). This approach relies on the combined training and experience of the SMEs to arrive at a credible and defensible assessment of the probability of IHI. Once an assessed probability is obtained through the elicitation process, the probability may be applied in a calculation of expected radiation risk (or dose) to provide relevant information for waste management decisions at the NTS RWMSs.

The remainder of this document first provides a brief discussion of the regulatory background for IHI, and follows by providing a description of the steps taken and the main events that shaped the final product. The following sections describe:

- regulatory background for IHI;
- pre-elicitation steps, including initial model development;
- involvement of stakeholders in the development stages;
- the procedures used to identify the technical disciplines and subject matter experts;
- the first elicitation session, in which the model structures were finalized;
- the second elicitation session, in which quantitative inputs were sought to fulfill the specifications of the final models; and,
- the results and findings that were generated regarding probabilistic assessment of the potential for IHI during the compliance period.

Two facets, stakeholder involvement and quality assurance, were integrated into each stage of the project to the extent practical. Both of these aspects were implemented to help ensure that the end product of this project (i.e., an assessment of the probability of IHI) will provide input that has real utility to waste management programs at the NTS. The roles of the stakeholders, peer review groups, and quality assurance programs are also explained in the following sections.

This document is also supported by a series of Appendices that are contained in a separate Volume (Black et al. 2001). The Appendices provide detailed information on:

- Preliminary activities (such as the stakeholder workshop, contracting the SMEs, development of preliminary influence diagrams, and distribution of information to the SMEs prior to the elicitation sessions);
- The quality assurance process used in this project (including overhead presentations to the SMEs, information on the training workshops, and the SME certification that their input was captured appropriately);
- The elicitation sessions (including transcripts and summaries of the SMEs inputs, and a more thorough technical description of the approach taken to elicitation in this study); and,
- The technical approach taken to modeling the SME input and generating the probability of IHI (including mathematical modeling and sensitivity analyses)

The Appendices that comprise Volume II of this report contain text that provides further detail of the activities undertaken in this project, and attachments that are copies of documents that are directly relevant to this main report and the results presented. Other documents that were used to support this project are contained in the project archives and are available on request (a complete listing of available documents is provided in Appendix G of Volume II).

2.0 REGULATORY BACKGROUND

Interpretations of DOE Order 5820.2A (DOE 1988) are provided in Case and Otis (1988) and Wood, et al. (1994). These interpretations provide guidance on how this DOE order might be applied to radioactive waste disposal sites. In particular, Case and Otis (1988) indicate that PAs should include site-specific factors that might help distinguish some potential waste disposal sites as more desirable than others.

The U.S. Nuclear Regulatory Commission (NRC) and the U.S. Environmental Protection Agency (EPA) also have published guidance on radioactive waste disposal. In particular, NRC's 10 CFR 61 (NRC 1982) governs commercial low-level waste, and EPA's 40 CFR 191 (EPA 1985) sets requirements for the disposal of transuranic wastes, high-level waste, and spent nuclear fuel. However, the DOE order is used to govern disposal of low-level waste at all DOE facilities. Cochran (1995) provides a comparison between DOE Order 5820.2A (DOE 1988) and other regulatory documents pertaining to radioactive waste disposal.

Comparison among regulatory documents is also available in a DOE draft interim policy document on basic assumptions for compliance with inadvertent human intruder performance objectives (DOE 1995). This document makes it clear that the DOE (through DOE Order 5820.2A) and the NRC (through 10 CFR 61) both have mandated protection of an inadvertent human intruder in their requirements for low-level waste disposal. However, these agencies have implemented intruder protection in different ways because they have different objectives. DOE classifies waste on a site-specific basis, whereas NRC uses a generic classification system for its low-level waste regulation. What is clear in the DOE draft interim policy document (DOE 1995) is that the likelihood of intrusion should be considered based on design factors (e.g., barriers, warning signs, depth of burial) and length of institutional control. Furthermore, this document goes on to suggest that the most important factor for determining the reasonableness of the results of an intruder analysis is the credibility of the assumed scenario, which should take into account social customs and environmental conditions at the site.

The DOE draft interim policy document (DOE 1995) and Case and Otis (1988) clearly pave the way for a probabilistic, as opposed to a deterministic, approach to assessing the potential for IHI into a low-level waste disposal site. However, documents from other agencies provide mixed messages on the need for a probabilistic approach. DOE and NRC regulations pertaining to low-level waste disposal do not address methodology issues for conducting PAs. Until recently, documents from NRC more specifically addressed the exposure scenario. Since this elicitation was performed, two relevant NRC documents have appeared. The first is a draft NRC Branch Technical Position (BTP) on the use of expert judgment (Kotra et al. 1996), an outgrowth of NRC assessment of use of expert judgment by the Yucca Mountain Project. This BTP provides a clear validation of the elicitation processes used in this study. The second recent NRC document is a draft BTP, "Performance Assessment Methodology for Low-Level Waste Site Licensing," (Performance Assessment Working Group 1997). This NRC document endorses application of a probabilistic approach to performance assessment but provides inconsistent guidance on a probabilistic approach to scenario assessment.

The National Academy of Sciences (NAS) also recently produced a report on Yucca Mountain standards (NAS 1995). The relevant section of the NAS recommendations is contained in Chapter 4, "Human Intrusion and Institutional Controls." The NAS recommendations broadly agree with the results of this study, with one difference concerning the ability to probabilistically assess the length of institutional control. This study and the NAS recommendations agree that historical evidence shows human institutions are transient. However, the NAS document concludes that probabilistic assessment is not possible, while this study demonstrates that available anthropological and historical evidence can be used to make probabilistic assessments.

From a regulatory standpoint, it should be recognized that NRC regulations do not apply to DOE sites at this time. Under current guidelines, the NRC does not require consideration of IHI (Performance Assessment Working Group 1997). Thus the NRC regulations are less restrictive with respect to waste acceptance criteria than DOE Order 5820.2A (DOE 1988). In addition, it should be recognized that the NAS recommendations apply to disposal of high-level waste rather than low-level waste, perhaps explaining the difference in regulatory perspectives towards IHI.

The approach used in this study extends the direction provided in existing interpretations of relevant regulatory documents. Performance assessment related documents from DOE, NRC, and EPA are largely silent on the specific subject of probabilistic assessment of IHI. However, Case and Otis (1988) and DOE (1995) provide sufficient material to suggest that a probabilistic approach is not only reasonable, but necessary; and the NRC and NAS documents at least indicate that scenario selection is important and must be based on some subjective factors. NRC documents have also fully endorsed expert elicitation as an appropriate approach when hard (objective) data is difficult or impossible to collect.

A probabilistic approach handles uncertainty logically, and provides management with the tools needed to make defensible decisions in the face of uncertainty. Further, the probabilistic approach is necessary to be able to answer important questions for which data collection is difficult or too costly. A probabilistic approach considers the unique local setting of low-level waste disposal sites on the NTS, including the arid climate, remote location, and scarcity of surface water or shallow groundwater. Without such an approach it would not be possible to provide the same level of justification or defensibility for any conclusions drawn or decisions made.

3.0 BASIC APPROACH

Expert judgment has proven a particularly useful tool for evaluating probabilistic estimates for rare or poorly understood phenomena and for forecasting future events (Kotra et al. 1996, Morgan and Henrion 1995, Meyer and Booker 1991, Keeney and Raiffa 1993, Raiffa 1970). Problems that have significant uncertainty not readily reducible by conventional means of data gathering are often best addressed by application of expert judgment. The issue of IHI for the RWMSs in Frenchman and Yucca Flats involves multiple factors with largely non-reducible uncertainty. For example, uncertainty exists in the future missions and institutional control of the NTS; the viability, values and practices of future societies, and, in hydrogeologic processes that may make arid desert lands either more or less desirable to society in the future. Due to the large amount of uncertainty involved in determining the probability of IHI and the difficulty or impossibility of collecting data to estimate this probability, expert judgment is appropriate for this application, and was applied to this assessment.

To help ensure that the results of an expert elicitation process are credible, it is important that information be shared among all participants and stakeholders (e.g., DOE/NV, the State of Nevada, the public) and that a quality assurance program be implemented. Although the focus of the elicitation approach involves obtaining input from the selected SMEs, a number of components are required to build a solid foundation before conducting the elicitation. The elicitation approach is based on logical or rational constructs consistent with decision analysis, social choice theory, and probability theory. Initial steps in this project focused on developing preliminary models; gaining input and acceptance from stakeholders that the approach, including assumptions and models, is reasonable; identifying the areas of expertise needed to perform the assessment; and sharing pertinent background information with the selected SMEs before conducting the formal elicitation sessions. The elicitation can be summarized as a four-step process (details of the approach are presented in Neptune et al. 1996):

1. Developing a preliminary list of factors affecting IHI and the relationships among them through preliminary intruder scenario models.

2. Convening a workshop involving participation of various local stakeholders to examine the logic and acceptability of the approach to be used for this probabilistic study, and using this input to modify the list of factors and relationships as necessary.

3. Convening a panel of SMEs to also examine the logic and acceptability of the approach, and to finalize the list of important factors and structure the relationships among the factors .

4. Formally eliciting expert judgments from the panel of SMEs on the list of factors that they established.

Once the probabilistic inputs are obtained from the SMEs, then the model structure implied by the relationships between the important factors is used to generate the probability of IHI. The remainder of this section provides a description of the assumptions underlying the approach, steps taken prior to conducting the elicitation sessions, the process of elicitation used to obtain input from the SMEs, and the quality assurance process implemented throughout the project. These components of the project help ensure that the final assessment of the probability of IHI represents a reasonable and credible evaluation that can be used to enhance waste management decisions at the NTS RWMSs. Detailed discussions of the quality assurance program, the stakeholder workshop and related activities, identification of SMEs, and the elicitation sessions are found in Appendices A through D (Black et al. 2001[1]).

3.1 Assumptions

The initial steps in this probabilistic study involved developing a model of how IHI might credibly occur at the remote RWMSs in Frenchman and Yucca Flats. This analysis could have become hopelessly complex if every mechanism of possible IHI were considered, given the uncertainty of future changes in society. Therefore, some basic assumptions or conditions were established for the modeling process.

3.1.1 Inadvertent Human Intrusion Scenarios

The assessment of the probability of IHI is dependent upon the way in which a potential inadvertent human intruder chooses to settle in a remote alluvial valley. The SMEs identified a number of possible credible scenarios besides the standard Homesteader scenario. Consequently, the assessment included both the default independent Homesteader scenario and community scenarios. Community scenarios considered include development of community settlements in Frenchman Flat or Yucca Flat, and the development or growth of nearby communities that cause Frenchman Flat or Yucca Flat to be settled by "commuter homesteaders" without development of an actual community base within either Flat. In general, the Homesteader scenario assumes independent homesteading with no shared resources and at least one well per household. A community in Frenchman Flat or Yucca Flat, by contrast, assumes a settlement in which an infrastructure exists to facilitate sharing of resources, and water is supplied through a community production well system. The remaining scenarios are hybrids, assuming "commuter homesteading" in Frenchman Flat and Yucca Flat associated with nearby communities or Las Vegas. These community scenarios were expected to be driven by current population trends, which indicate population expansion in Las Vegas and surrounding areas.

[1] All appendices to the document are compiled in Volume II of this report (Black et al. 2000).

Evaluation of the intrusion scenarios is driven primarily by considering the number of wells that might be drilled during the time frame under consideration. Drilling for water was the only intrusion method directly assessed. The standard intruder-construction and intruder-discovery scenarios were ruled out because of the assumed depth of disposal of the Fernald waste that provided the impetus for this study (see Chapter 1). Other possible forms of intrusion by drilling, including deep mining or exploratory drilling for other natural resources, were considered extremely unlikely and insignificant in comparison to the potential for water well drilling because of the lack of natural resources in the subsurface of these NTS alluvial basins.

The time frame applied in this project, or the evaluation period, was set at 10,000 years consistent with the compliance period established in DOE Order 5820.2A[2]. The area that overlies buried waste (the waste footprint), and the areas of Frenchman and Yucca Flats, along with different factors for each scenario, also influence the probability of IHI. For the purpose of this report, the area of the waste footprint was set at two acres based on the expected volume and dimensions of disposal of the Fernald waste described in Chapter 1. This factor did not impact the elicitation of information from the SMEs, but was used in the algorithms from which the probability of IHI was calculated. The areas of Frenchman Flat and Yucca Flat were estimated using geographical information system (GIS) techniques at approximately 86,000 acres and 70,500 acres, respectively. The GIS estimates were based on differentiating the relatively steep slopes of the surrounding mountains from the relatively shallow slopes of Frenchman Flat and Yucca Flat. The study objective was to estimate the probability that one or more wells might intersect the two-acre waste footprint given the number of wells expected to be drilled in Frenchman Flat and Yucca Flat in the next 10,000 years.

The IHI scenarios were initially evaluated assuming that access to the site was completely uninhibited. Methods of restricting access to the site (management controls) were then evaluated for their effectiveness and used to modify the IHI scenario probabilities to arrive at an overall probability of IHI.

3.1.2 Management Controls

The boundaries of the NTS are currently subject to institutional control. Public access to waste disposal sites is physically prevented by the use of fences, placards, and on-site management. The first basic assumption is that IHI can only occur if institutional control of the NTS ceases, and if 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 no public development will occur on the site

[2] At the time of this study, the relevant compliance period, as defined in DOE Order 5820.2A (DOE 1988), was 10,000 years. Soon after this study was concluded, DOE Order 435.1 (DOE 1999) became effective. The compliance period defined in the newer DOE Order is 1,000 years. Consideration of the potential impact of this change on the probability of IHI is investigated in Appendix F.

and IHI will be avoided. Deterministic PAs assume that institutional control will be maintained for some fixed amount of time, usually 100 years; however, the probabilistic approach taken in this project allows the period of institutional control to be evaluated by the SMEs. Even after institutional control is lost, knowledge of the hazardous nature of the site might be maintained for some time, and such knowledge should continue to deter public incursion. Site knowledge could be enhanced by the presence of some form of permanent surface marker or warning sign. Should institutional control and site knowledge become ineffective, two additional factors could deter IHI through drilling for groundwater: 1) surface barriers can be built to restrict or prohibit access to the land immediately above a waste disposal site, and 2) subsurface barriers can be constructed to prevent completion of a drilling operation.

The five conditions described above (institutional control, site knowledge, placards and markers, surface barriers, and subsurface barriers) were identified by the SMEs as important factors that can reduce the potential for IHI to occur. These factors underlie the model used in this project, and are collectively termed "management controls." If any of the management controls are effective, then it is assumed that IHI cannot occur. While the management controls factors are not expected to be completely effective, their combined degree of effectiveness is expected to limit the chance of IHI occurring.

The evaluation of the IHI scenarios was the main objective of the elicitation. Evaluation of Management Controls was performed to provide DOE/NV with some insights into their potential effectiveness. The inputs for some of the Management Controls factors should, therefore, be regarded as preliminary, representing examples that DOE/NV might want to consider further.

3.1.3 Periodic Review of Inadvertent Human Intrusion

The potential for future changes in society and technology must be addressed to proceed with this approach to assessing the probability of IHI. Studies have shown that many aspects of science and technology are inherently unpredictable (Casti 1990). At best, stochastic or probabilistic models of future events can be developed and used to support decision-making. However, accurate prediction of most future events is very difficult (e.g., technology development, societal patterns, or climate change). Consequently, a working assumption for this probabilistic study of IHI is that forecasting of future patterns must be based on current knowledge, including current technology and current societal practices. The results are, therefore, conditional on the SMEs' current knowledge base, which includes knowledge of current trends that are in common use for planning purposes (e.g., population expansion), but does not include speculation on the future of technology or changes in the habits or customs of current society that might influence the potential for IHI. Given the reliance on current knowledge, it is a legitimate concern that the results may not be applicable if changes in pertinent technologies or societal practices occur. To counteract this potential difficulty, a further element of this approach is to require periodic revisiting of the IHI models.

While institutional controls are active, evaluation of the potential for an inadvertent human intruder will be revisited periodically, or as necessary. Revisiting would be considered necessary if changes are seen in waste site conditions, waste management technology, or viable exposure scenarios that might significantly affect the potential for IHI to occur. The following factors should be considered periodically: changes in the state of waste management technology (i.e., more efficient and effective methods become available for dealing with radioactive waste); changes in the local population tendencies and characteristics (e.g., building of earth-sheltered houses, or heat sinks); and changes in site conditions (e.g., natural disasters, increased precipitation, climate change).

Under this system of periodic re-assessment, each new assessment of IHI is projected out for the full compliance period based on then-current knowledge. Futuristic scenarios are avoided in each periodic reassessment so that significant changes are accounted for only when they have occurred. This approach is similar in intent to those described in EPA guidance for disposal of high-level radioactive waste (40 CFR 191), and in DOE Order 5820.2A, which requires that a maintenance program be established to update a PA on a periodic basis.

The inclusion of only currently known conditions and plausible scenarios was important for achieving technical and non-technical stakeholder acceptance of this elicitation and PA process. Conditioning on current knowledge avoided the potential for speculation on the future, and tied the assessment, instead, to more tangible information based on present technology and knowledge of historical and current societal practices. The stakeholder groups and the SMEs fully endorsed this approach to assessment of IHI along with periodic review. It is important to note, however, that all the stakeholders and the SMEs agreed that funding must be guaranteed now (through a trust fund or other form of appropriation) to accommodate future periodic review of the potential for IHI, and to support any actions that must be taken as a result of future re-assessments.

3.1.4 Basic Approach to Model Development

The NRC BTP (Kotra et al. 1996), which appeared after this study was performed, provides substantial support for this approach to assessing the probability of IHI. This approach is also fully consistent with the Bayesian decision theoretic approach to problem solving (c.f., Raiffa 1970, Morgan and Henrion 1995, DeGroot 1970, Berger 1985). The initial objective is to ensure that all parties agree on assumptions, including the model structure and the model components. Once this is achieved the results are simply consequences of the assumptions and the data or information collected. The only possible challenges to the conclusions are challenges to the agreed-upon assumptions, or challenges to the expert opinions if the information supplied was subjective.

The approach is perhaps best illustrated by the way in which it handles future events. Both NRC and DOE have indicated that expert elicitation cannot be applied to speculative future events because the future is unknowable. In this study, evaluation of purely speculative future events was avoided by establishing conditions. The intent of the conditioning was to focus the SMEs on present and past knowledge, and to use their knowledge bases to consider the future. This avoided pure speculation of potential technological and societal changes and, instead, allowed a focus on prediction conditioned on current knowledge. A fundamental component of a (Bayesian) probabilistic analysis is that conditions are established, and findings and results depend on these conditions. If the conditions are changed, then the results probably change and a re-evaluation might be necessary. The “periodic review” approach described in the previous section provides such a re-evaluation, and is fully consistent with the Bayesian approach to probability analysis that requires updating based on new information.

One difficult issue must be recognized. Based in part upon the results of this study, a decision could be made in the present to dispose of a quantity of low-level waste. It is possible that in the future the probability of IHI will be different (based on changes in conditions), and a different decision might be reached because the conditions of the problem have changed. If the best decision today is to bury the waste, then the decision problem or question tomorrow is whether to exhume the waste, leave it in place as is, or leave it in place with more stringent closure mechanisms active. The probabilistic question of whether IHI will occur does not change, but the decision endpoints do change. It must be accepted that the future is unknowable and any decision made today might change under different conditions (such as those gained by gathering more information over time). It is then a matter of balancing tradeoffs through a cost-benefit (decision) analysis to determine if the decision should be postponed pending collection of more information. If sufficient information is available, then a decision can be made based on current conditions.

Figure 3-1 provides a summary of the approach taken to assessing the probability of IHI. This flow chart highlights the major components of the approach, including specification of assumptions and conditions, gaining stakeholder input and acceptance; calculating the probability as a consequence of the assumptions and conditions and the input obtained (from the SMEs); and re-evaluating the process periodically or as conditions change. The first step involves developing a sufficient understanding of the problem that an approach and preliminary models can be developed based on a set of assumptions and conditions. The second stage involves finalizing these models, including gaining input and agreement from stakeholders on the approach, the models, and the assumptions and conditions. The first and second steps often require some iteration before final agreement is possible. The third step involves collecting input from the SMEs and using it to produce results (in this case the probability of IHI). The results are based solely on the agreed-upon approach, models, assumptions and conditions, and the SME input. Finally, it must be recognized that the probability of IHI might be affected by changes in assumptions or conditions. A decision analytic approach should then be used to determine if re-evaluation is necessary.

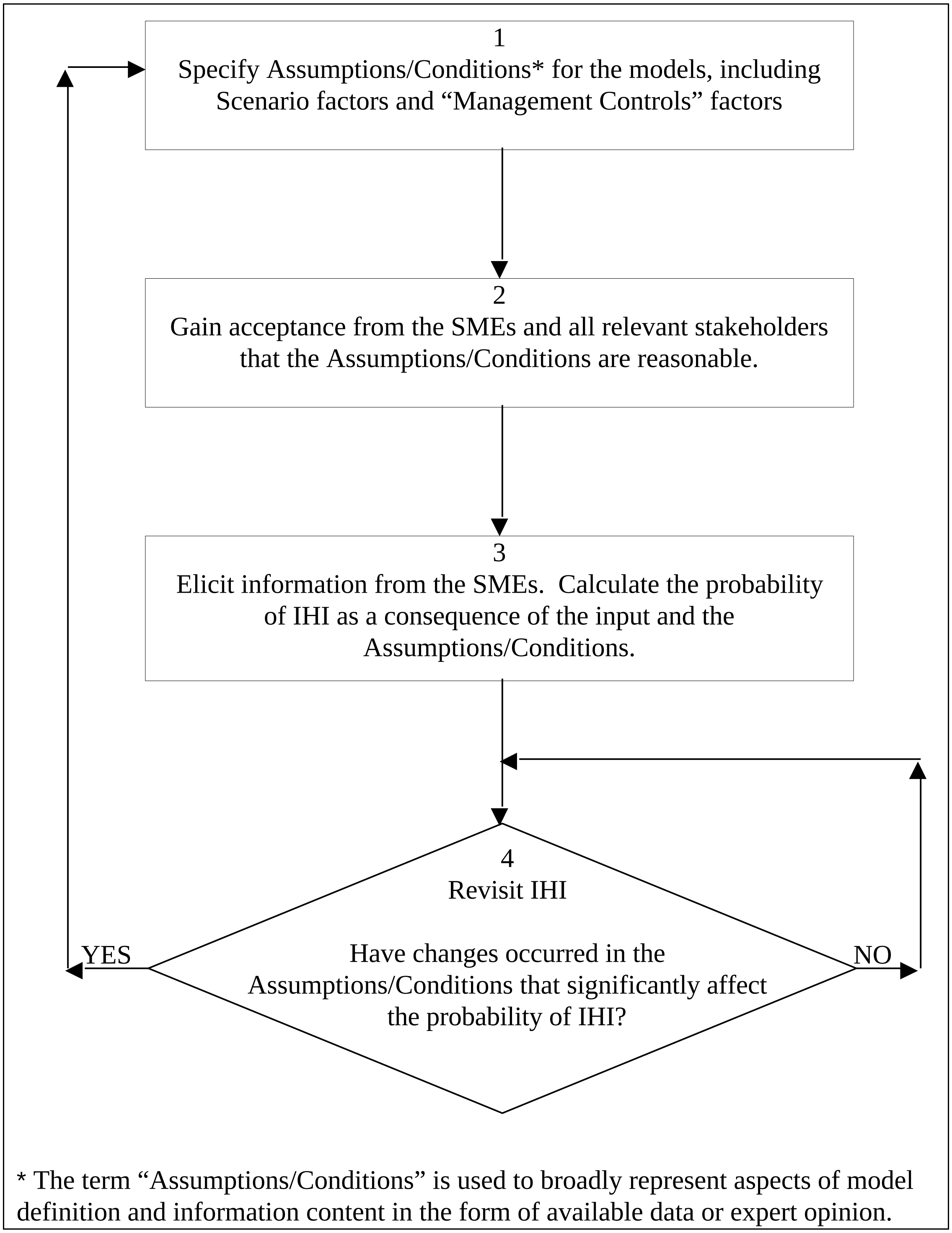

Figure 3-1 Summary of the basic approach to assessing the probability of inadvertent human intrusion.

3.2 Pre-Elicitation and Quality Assurance Activities

Several activities were completed before interactions with the SME panel began: initial model development, interactions with various stakeholder groups, subsequent model modifications or refinements, identification of suitable SMEs, and measures to ensure process quality assurance and control.

Quality assurance activities are regarded as fundamentally important for the ultimate success and acceptability of this project's findings because of the subjective nature of the input used to generate an assessment of the potential for IHI to occur. Some of the underlying reasons for addressing quality assurance in this project were to gain credibility with technical and non-technical stakeholders, and to be able to provide project defensibility. Several mechanisms were employed to ensure that the final product is defensible to stakeholder audiences, including peer review of the project, training of SMEs in probability and elicitation concepts, and SME acceptance and validation of their own inputs. Details of the quality assurance program for this project can be found in Neptune et al. (1996) and in Appendix A.

Another key component is the quality control process, which included thorough documentation of all project stages. Quality control was considered crucial because of the subjective elements in this project. Thorough documentation provides the means by which all of the project components, inputs, reports, rationale, and decisions can be made available following the culmination of this project. All written and taped products associated with this project are available in the Attachments to the Appendices in Volume II of this report (Black et al. 2001) or in an archival file at DOE/NV (see Appendix G).

The archived materials include all interim reports referenced in this document, written and taped records of the elicitation sessions, written communications with the SMEs (pre-screening, information packets, evaluation questionnaires, certifications that their input has been properly used), computer programs used to generate calculations of the probability of IHI based on the elicited SME input, copies of further information requested by the SMEs, copies of presentation materials used throughout the project, and lists and qualifications of the SMEs, and copies of all internal review comments and responses. Appendix G provides more details of the actual contents of the archival files.

3.2.1 Initial Model Development Using Influence Diagrams

Models were developed in the early stages of the project for the homestead and community scenarios, and for the management controls modifying factor. Development of these models was facilitated by using a form of influence diagram that graphically portrays the important factors and their inter-relationships. Influence diagrams have been commonly used in decision analysis, policy analysis, and probabilistic assessment for about 20 years (Howard and Matheson 1981, Analytica 1996).

An influence diagram shows the essential qualitative structure of a model, unobscured by details of the underlying mathematical formulas. It provides a representation of a model that portrays explicitly the influences among the model variables, using an intuitive graphical view of the model structure portrayed as nodes connected by arrows. Each node depicts a variable of interest, and each arrow depicts a relationship, or an influence, between a pair of nodes. An influence arrow from one variable to another means that the value of the first variable directly affects the value of the second variable. Several nodes may affect another node, depending on the modeled relationships among nodes.

Figure 3-2 shows the essential features common to each of the intrusion scenario models. The objectives are to obtain information about the number of wells that are expected to be drilled throughout the compliance period and to calculate a scenario probability using the areas of the waste footprint and of Frenchman and Yucca Flats. These scenario probabilities reflect the chance of IHI based on the conditions and assumptions of this study, including SME knowledge and their input to the assessment. In addition, these scenario probabilities assume that access to the site is uninhibited (i.e., that all management controls are ineffective). The probabilities of IHI for each scenario can be combined to produce an overall estimate of the probability of IHI during the compliance period.

The management controls factors are evaluated. These factors may be use to modify the scenario probabilities. This modification leads to an estimate of the probability of IHI based on selected management controls options. Figure 3-3 is a simple influence diagram that shows how the scenario models and management controls factors are brought together. Probabilistic details are provided in Appendix E, and preliminary influence diagrams are found in Black et al. (1996).

3.2.2 Project Review

The influence diagram models presented in Figures 3-2 and 3-3 provided the foundation for assessing the probability of IHI. These models were subject to several levels of review to assure the quality of the approach. The first review group was the PA team, which consists of personnel from DOE/NV, Bechtel Nevada, Sandia National Laboratories, and Desert Research Institute (an independent research institute sponsored by the University of Nevada System). This team provided review comments throughout the project.

The second group that provided review consisted of a wide variety of public stakeholder groups, including representatives from Community Radiation Monitoring Program, Community Advisory Board, the University of Nevada Las Vegas, Citizen Alert, and Nevada Nuclear Waste Task Force. State groups included the Nevada Division of Environmental Protection and the Nevada Nuclear Waste Project Office.

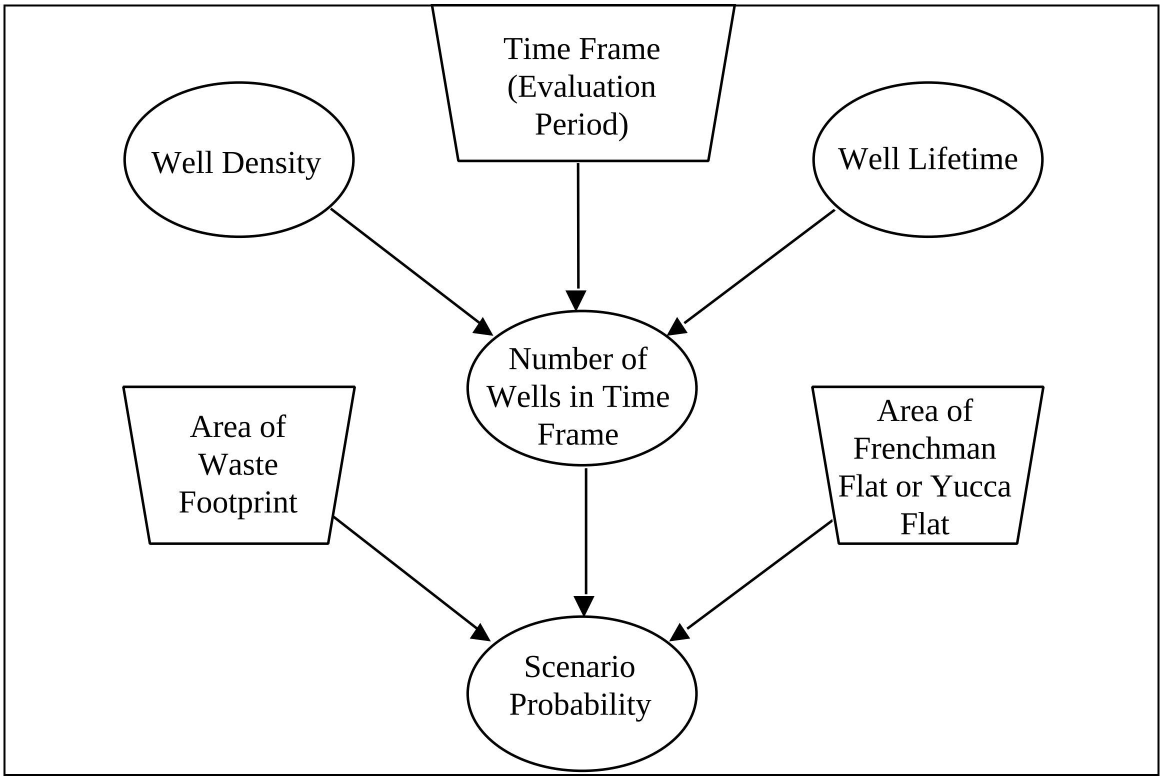

Figure 3-2 Basic common form of each scenario influence diagram models

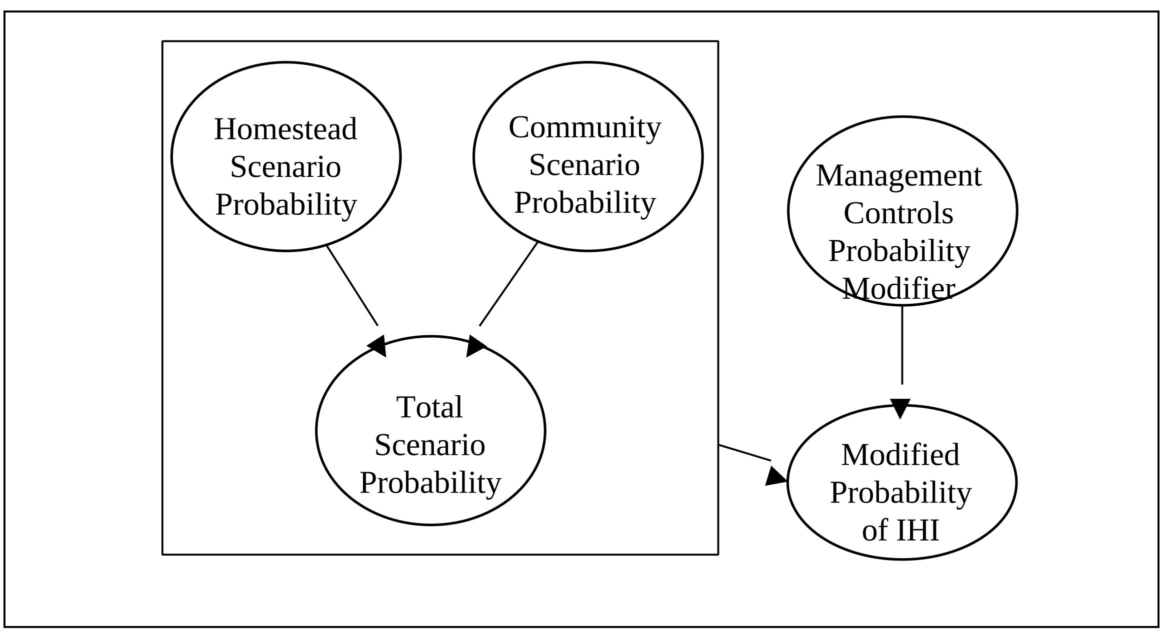

Figure 3-3 Top-level influence diagram for the probability of inadvertent human intrusion into buried waste at the Nevada Test Site Radioactive Waste Management Sites

A third group was convened for the purpose of providing peer review capabilities for the initial model development effort, preparation for the SME panel elicitation sessions, and reviews of draft reports. This peer review group (PRG) consisted of four people selected from government and industry for their knowledge, expertise, and experience in similar efforts (see Appendix A).

Stakeholder interactions served several purposes in this project. The first was to engage stakeholders in the process to foster understanding, input, and agreement that the basic approach is credible. If the basic approach did not seem reasonable to these broad groups, then suggestions would have been sought on how assessment of the potential for IHI could otherwise be performed. A second purpose was to obtain suggestions on how the basic models could be improved. A third purpose was to engage stakeholders early in the project so that the final product would address their concerns.

Throughout the model development stages of the project the PA team played an integral role reviewing and providing comments on the influence diagrams and the rationale behind their development. The influence diagrams were first presented to the PA team, which provided an internal consistency check that the objectives of the project were being realized.

During later stages of model development, the PRG was convened. Because the PRG had not been initially involved in the project, they provided a fresh perspective on the modeling process. The PRG was also convened to perform as surrogate SMEs for “dry runs” of the elicitation sessions, so that problems could be anticipated and resolved prior to conducting the SME elicitation sessions. Interactions with the PRG were recorded in written summaries with responses from the project team. The credentials of the SMEs are presented in Appendix C (Black et al., 2001), and documentation of the PRG interactions is available in the project archives. Finally, the Nevada Risk Assessment/Management Program provided an external substantive technical review of this project.

3.2.3 Stakeholder Workshop

Proactive and continued interaction with stakeholders is viewed as critical to the success of the project (cf., Mathai and Black 1995). To involve stakeholders in the DOE/NV Waste Management Division PA Process in an active and informed manner, a public workshop was conducted. The stakeholder groups represented were from the PA team and public stakeholder groups described above. Local Native American groups were also identified as having valuable perspectives that should be included; however, no Native American representatives were able to attend the workshop. The representatives from the PA team served a dual purpose: 1) to hear the concerns and issues from the stakeholders themselves, and 2) to participate in a facilitated discussion with other stakeholders so that an open exchange of information could occur.

Opening the workshop with an overview of the Waste Management Program and its regulatory basis provided the impetus and context for evaluating the probability of IHI and reinforced the information package sent to the participants prior to the workshop. Presentation of the management controls module, the Homesteader scenario, and the community scenario followed.

After these presentations were made, the group divided into two discussion groups to provide everyone with an opportunity to participate in the discussion. Dialogue was focused around questions designed to guide the groups through topics needed for the next steps in the project. The strategy was to engage interested parties in discussion of the proposed process for assessing the probability of IHI, and the assumptions underlying the proposed elicitation, such that the final answer should merely be a consequence of the process and assumptions.

This workshop assisted the PA process by providing stakeholders and DOE/NV staff with the opportunity to meet on a common plane and exchange ideas. The results of this workshop provided valuable perspectives for modifying aspects of this study, and ensured that the approach to evaluating the potential for IHI addressed the concerns of each group. In particular, many suggestions for amending the preliminary influence diagram models were provided by the workshop participants. Clarification was obtained regarding the importance of including both homestead and community scenarios to accommodate site-specific habitation patterns in the PA process.

Stakeholders at the workshop provided validation that the approach and models were reasonable. In addition, they unanimously emphasized that periodic reviews of the process are essential. This interaction with stakeholders led to greater confidence that the methodology being employed was appropriate. Discussions from this workshop also helped to solidify the methods of analysis for the probabilistic approach. A more detailed discussion of the results of this stakeholder workshop is contained in Appendix B.

3.2.4 Selection of Subject Matter Experts

In order to ensure that the appropriate SMEs would be brought together for the elicitation session, it was necessary to identify the types of subject matter expertise required to fulfill the specifications of the influence diagram model. In accordance with the preliminary influence diagrams, nine disciplines were identified to be included on the SME panel: agronomy/soil science, anthropology/archaeology, demography, economic geology/resource use, geotechnical engineering, hydrogeology, land-use planning, sociology, and water-well drilling. Some disciplines were expected to have overlapping areas of expertise (e.g., hydrogeology and water-well drilling; anthropology and sociology; demography and land use planning), but each SME was expected to provide unique insights into different facets of the influence diagram models.

Experts from each of the disciplines were expected to provide input to common factors in the models. The disciplines of demography, sociology, and anthropology were anticipated to provide input on current population patterns as they might pertain to both the homestead and community scenarios. Similarly, an anthropologist was needed to provide input on historical settlement patterns. Anthropology and sociology expertise were also expected to bear on issues of how long institutional control and site knowledge might be maintained, and how effective placards and markers or other surface features might be in deterring drilling at the waste site. A geotechnical engineer was sought to provide input on the potential effectiveness of surface and subsurface barriers, and well drilling expertise was sought to counter arguments for such barriers. Intrusion scenario influence diagrams required expertise in hydrogeology, water-well drilling, and current practices regarding the number of wells for various population densities. The services of a natural resources specialist or economic geologist, as well as a soil scientist or agronomist, were needed to define similar desert areas that could be used to increase understanding of the area of interest. Finally, a land-use planner was needed to provide information on community designs, particularly as related to population size and community water supply systems.

Based on the disciplines expected to be needed, a short list of potential candidates was identified and final selections were made using specific selection criteria. The selection criteria were geared toward finding SMEs that were familiar with the desert southwest area within their disciplines, and reasonably familiar with probabilistic concepts. Administrative criteria as well as technical criteria were used to ensure to the extent possible that unexpected biasing would not enter the elicitation process.

The SMEs were required to not have any actual, potential, or perceived conflict of interest in the performance of related U.S. government or state government work. Related DOE work was considered to be any work performed as a current employee of the DOE or prime contractor to the DOE. SMEs were also required to have had no formal or informal association with groups advocating or opposing the disposal of radionuclide wastes at this time or any previous time at any location. The objective of the search was to find SMEs with both the requisite technical knowledge and the ability to provide objective, unbiased inputs regarding a topic with the potential to become politically charged.

Upon review of the candidates' credentials, it was determined that two hydrogeologists were needed; one who was particularly familiar with rural settings and needs, and one who was more familiar with urban requirements. Hence, 10 SMEs were selected. The selection procedure is described in detail in Appendix C. Candidate qualifications, along with the activities in which the SMEs were expected to engage, were detailed in the request for proposals. The required activities included reading background materials, taking a site tour, participating objectively in the elicitation process, and reviewing and certifying their inputs.

3.3 Elicitation Process

Once identified, the SMEs were convened for two elicitation sessions during which the necessary inputs to fully specify, or complete, the defined models were obtained. The selected SMEs were provided with background materials to review before the first SME panel session was convened. The first session was conducted the week of 9 July 1996; the second session was conducted the week of 5 August 1996. The purpose of the first SME panel session was to train the SMEs in elicitation techniques, to indicate expectations of their participation, to identify the SMEs' additional data needs, and to finalize the influence diagram models.

The purpose of the second SME panel session was to complete training of the SMEs in the quantitative elicitation process and to obtain elicited quantitative input from the SMEs. The time between the two sessions was to be used by the SMEs to gather and review further information they had requested, and for the project team to implement modifications or refinements to the influence diagram models as suggested by the SMEs during the first session.

Training sessions for the SMEs in elicitation methods provided a form of quality assurance to further ensure defensibility of the end product (see Appendix D). These sessions were conducted to indicate to the SMEs potential pitfalls associated with elicitation methods, and to train the SMEs in elements of probability theory that are relevant to this type of elicitation. In particular, descriptions of cognitive and management biases that can adversely affect elicited subjective input were presented. The awareness gained from the training exercises and presentations was expected to mitigate the potential for unexpected biasing during the elicitation process.

Another crosschecking mechanism used as a quality assurance mechanism required SME review and acceptance of their inputs from the elicitation. Each SME completed an evaluation of the elicitation session. This evaluation provided useful feedback on the practical adequacy of the elicitation approach, the validity of the model and inputs to the model, and the performance of the facilitation team. The SME panel was also required to formally agree to the inputs they provided during the elicitation session by certifying that the inputs properly reflect, or represent, their responses during the elicitation sessions. This quality assurance measure was considered critical because it provides a "stamp of approval" for the elicitation inputs.

The pre-elicitation activities provided the preliminary influence diagram models and an approach to assessing the probability of IHI. These had gained acceptance as an initial conceptual model among peer reviewers and stakeholder groups. The next step in the process was to convene the SME panel to obtain expert opinions on the models, and to elicit inputs to those models. Interactions with the SMEs consisted of three main phases: conditioning, structuring, and elicitation. Details are provided in Appendix D.

3.3.1 Conditioning

The conditioning phase consisted primarily of providing the SMEs with sufficient information to enable them to participate effectively in the elicitation sessions. During this phase information about conditions and practices at Areas 3 and 5 was presented, along with information on the methods that would be used to obtain their expert opinions. While the experts were identified based on their knowledge of particular subjects important for assessing the probability of IHI, they were not expected to have extensive site-specific knowledge. Moreover, under the conditions of their contracts, the SMEs were not allowed to be working on DOE/NV-related projects (Section 3.2.4). Therefore, they were not expected to have specific, advance knowledge of the problem they were convened to study. Consequently, background information about the site had to be provided to the SMEs during the conditioning phase in order for them to be able to apply their specific discipline expertise to the problem of assessing the probability of IHI. This information is available in Appendix C (Black et al, 2001), or in the project archives. Information provided during the conditioning phase included:

- information packets containing general NTS information, information specific to waste disposal practices at Areas 3 and 5, and current and historical DOE waste management practices;
- a field trip to the NTS with emphasis on Areas 3 and 5;
- presentations on issues such as geology, hydrology, socioeconomic conditions of the surrounding areas, regulatory requirements for PAs, the closure program at NTS, and how PAs are performed; and,
- any additional information the SMEs requested throughout the SME panel sessions.

Training workshops were conducted on probability and elicitation techniques to enhance the SMEs' ability to quantify their expert judgments in probabilistic terms. These training workshops focused on probabilistic concepts that would be important to the elicitation, elicitation methods that would be used, a discussion of elicitation biases that are common and that might be exhibited during the elicitation, and methods by which these biases might be mitigated or at least recognized. Biases fall into two main categories: motivational and cognitive.

Motivational biases include management bias and peer pressure bias. The SMEs' individual, objective opinions were being sought, and these opinions were not to be muddied by perceptions of DOE management or elicitor opinions (management bias), or perceptions of conclusions that other experts have reached in other similar studies such as Yucca Mountain expert panel elicitation sessions (peer pressure bias). The SMEs were instructed not to err on the "safe" side with any of the inputs because the statistics underlying the process take care of uncertainty directly. Further, the SMEs were told that it was acceptable for one or more of them to disagree on an input. While the ideal situation would be for the relevant experts for a given question to come to agreement, differing views would be represented in the final analysis if agreement was not possible. The SMEs were also instructed not to provide responses to serve their own best interests.

The existence of cognitive biases with respect to probabilistic elicitation is well-documented (cf., Kahneman et al. 1982). Cognitive biases possible in probabilistic elicitation include anchoring on starting values (insufficient adjustment), relying too heavily on availability of easily recalled information, relying on how representative an instance is of stereotypes, ignoring base rates (i.e., actual rates of occurrence of related phenomena), overestimation of small probabilities, and insufficient accounting for the effect of conjunctive events. The idea of convening a panel of SMEs is, in part, to mitigate the tendency for some of these biases to emerge. For example, the availability and representative biases should be mitigated because the SMEs should have a broad knowledge of their field of expertise. However, if such biases were suspected during the elicitation, further discussion was encouraged to broaden the base of knowledge or the perspectives from which responses were provided. Similarly, these biases could be overcome, in part, by providing sufficient background information. Overcoming cognitive biases was one of the primary purposes of providing such a broad extent of background information to the SMEs, and of augmenting that information as needed.

Elicitation methods were also used to mitigate some of these biases. For example, information was first elicited about extreme values from distributions. By eliciting from both extremes, and working towards the center, appropriate adjustment of the elicited values occurs. The potential for biases was also countered by asking for the same information in different ways (e.g., asking for quantile values given probabilities, asking for probabilities given quantile values, and validating the elicited distributions by indicating some further consequences of the elicited input).

3.3.2 Structuring

The next step in the process was for the SMEs to finalize the structure of the influence diagram models, and to assess the basic assumptions of the approach. The preliminary influence diagrams served as the starting point for the structuring stage of the process. Several structuring steps were required: defining base assumptions, establishing the need for periodic re-evaluation of the potential for IHI, defining the distinction between the homestead and community scenarios, specifying the influence diagrams for the homestead and the community scenarios, specifying the management controls module, and specifying conditional independence assumptions or correlations between influence diagrams. The final influence diagram models were defined by the SMEs through this structuring step. It should be noted that the development of influence diagrams is often an iterative process between the structuring and elicitation phases. In this study intermediate influence diagrams were often developed and modified as a result of further discussion. The influence diagrams presented in Chapter 4 reflect the final thoughts of the SMEs.

Structuring took place predominantly in the first SME session, although it did continue into the beginning of the second session. Also, the SMEs provided preliminary thoughts during the structuring sessions on the probabilities associated with the factors to be elicited (see Appendix D). This quantitative input was not included in the final assessment of IHI. Rather, the quantitative information elicited formally in the second session was used as input to the models because it was based on all of the background and structuring information that was made available to the SMEs.

3.3.3 Elicitation

After conditioning and structuring were completed, the third and final phase of direct interactions with the SME panel consisted of eliciting inputs to the finalized models. This elicitation was the main focus of the second SME panel session. During this session, input to the management controls module and the homestead and community scenario models was obtained. This elicitation session started with a training workshop on elicitation methods, familiarizing the SMEs with the elicitation techniques that are available and identifying the elicitation methods with which they were most comfortable.

A variety of elicitation methods were discussed with the SMEs. These methods included variations on both indirect and direct probability assessment. All approaches essentially require one of two assessments: (1) an assessment of a probability, or quantile, for a given value of the parameter of interest (e.g., asking for the probability that institutional control of the waste site will be lost within the next 500 years), or (2) an assessment of a value of the parameter of interest given a probability (e.g., asking for the value, in years, at which there is an equal chance that institutional control will be lost before or maintained after). Most of the methods used in the SME elicitation were a mixture of the two approaches as the SMEs became more familiar with the elicitation requirements.

When values were elicited for quantiles of a distribution, the main method used to more fully define a probability distribution was to continually halve the quantile of interest until no further useful information could reasonably be obtained. The process worked by first asking about some extreme values, then asking about a middle ground (i.e., the median). Median assessment methods as described in Raiffa (1970) are used to assess the 25% quantile value, then the 12.5% quantile value, and so forth; and also to ask for the 75% quantile value, then the 87.5% quantile value, and so forth. Through this method, questions could always be posed in terms of “which is more likely?” Alternative approaches, such as asking if one set of possibilities is twice as likely or five times as likely as another set of possibilities, often are difficult to administer because of the sensitivity of larger ratios. As the session progressed, the SMEs required less assistance with specification of a distribution; they became more prepared to offer their own valuations on a distribution directly.

The final elicitation technique used was to present to the SMEs the distributions they had produced, and to read off “consequences” implied for other quantiles or values. This mechanism was used to verify or validate their initial input, and to allow adjustments as they deemed necessary. This mechanism was used twice (for the management controls factors of "institutional control" and "site knowledge"), after which point the SMEs expressed felt that sufficient validation had been performed and that this was no longer a necessary component of the quantitative elicitation session. Appendix D contains a more complete description of the elicitation process.

3.4 Summary of Quantitative Methods

The influence diagrams provide a qualitative description of the underlying models that were finalized by the SMEs. Elicited inputs to the models were provided by the SMEs once the models had been defined. The purpose of this section is to provide a brief description of the quantitative methods used to propagate the SME input through the influence diagram models to generate distributions for the probability of IHI. Details of the technical approach are presented in Appendix E.

3.4.1 Probabilistic Basis and Constraints

The SMEs were asked to provide quantiles as input to distributions to specify the distributions, as opposed to single numbers such as an expected value. Elicitation of several quantiles permitted estimation of probability distributions for each of the input variables. This distributional information was included directly in the calculations. A simulation approach was taken to propagate the distributions through the influence diagram structure. This approach ultimately generates simulated distributions of the probabilities of interest (e.g., scenario-specific probability distributions of IHI). The final results presented as distributions provide some indication of the uncertainty, or variability, associated with the probability of IHI, but they do not deal with all possible sources of uncertainty or variability because of the assumptions and conditions imposed. If some of the assumptions or conditions could be relaxed then the reported spread would probably be greater. This might be most obvious considering the assumption of current knowledge. Clearly, if this assumption were relaxed then considerably more variability in the results would be expected.

Conditions and assumptions relate to the models, base assumptions, and the group of SMEs. For example, a different set of SMEs would have a different knowledge base and may provide different probability inputs and develop different influence diagram models. However, the primary purpose of using the overall approach to this study is to ensure that the conclusions are sound. A different group of SMEs (or the same group at a different time) might have different specific inputs, but, given no substantive change in assumptions, the end results can be expected to be numerically similar and to qualitatively generate the same conclusions. Appendix E provides a more complete discussion of the assumptions, conditions or constraints upon which the results presented are based.

3.4.2 Overview of Simulation Approach

All of the SME inputs were used to fit probability distributions in the forms of cumulative distribution functions (cdfs) to each input factor, and to propagate this information through the influence diagram models using a Monte Carlo simulation technique. This section provides an overview of the algorithms used to generate a distribution of the probability of IHI for each scenario. The schematic in Figure 3-4 shows the important steps for assessing these probabilities. The first steps in the calculation process were to transform the SME input in the form of quantiles into cdfs, or probability distributions for the elicited factors. Fitting techniques were used to establish cdfs, which were then used as the basis for the simulation algorithms. The simulations were performed by drawing random numbers from the fitted cdfs, and propagating them through the influence diagram models.

Each simulation involved drawing at random from the fitted cdfs and propagating these realizations through the influence diagram. This process was repeated 10,000 times, resulting in simulated distributions for the final probabilities of interest (e.g., scenario probability of IHI), and for all intermediate factors (e.g., number of wells drilled in the 10,000 year period). Through the simulation process, numerical representations of the scenario-specific influence diagram models were used to establish simulated probability distributions for the scenario probabilities.

The initial step of the propagation for each of the scenario-specific influence diagram models was to take the total number of wells drilled in Frenchman Flat or Yucca Flat during the compliance period and calculate the probability that at least one well would intersect the waste footprint. This calculation was based on assumptions of the areal size of the flats and the waste footprint. This step was complicated by the role of replacement wells and the impact of the cratered sub-area of Yucca Flat. The outcome of each realization of the simulations was a simulated scenario-specific probability of IHI, and the final outcome of all realizations was a distribution on this probability. These final distributions represent the variability or uncertainty found in randomly sampling from the SME inputs after distributions (cdfs) were fitted to their input, but conditional on the constraints indicated in Section 3.4.1.

The intrusion scenarios were combined to produce a distribution of the overall probability of IHI. For reasons that will become clear during the presentation of the results, the method by which these intrusion scenarios were combined does not significantly affect this distribution. Although under different circumstances adding the intrusion scenario probabilities together might be conservative, this simple additive approach was adequate for assessing the total probability of IHI for this project. In addition, the modifying management controls factor was then applied to the scenario-specific distributions to obtain an overall probability of IHI for each scenario (i.e., the condition on ineffective management controls was removed). However, it should be recognized that the management controls factors were not as well defined as the intrusion scenario factors. Consequently, these analyses should be regarded as preliminary and exploratory.

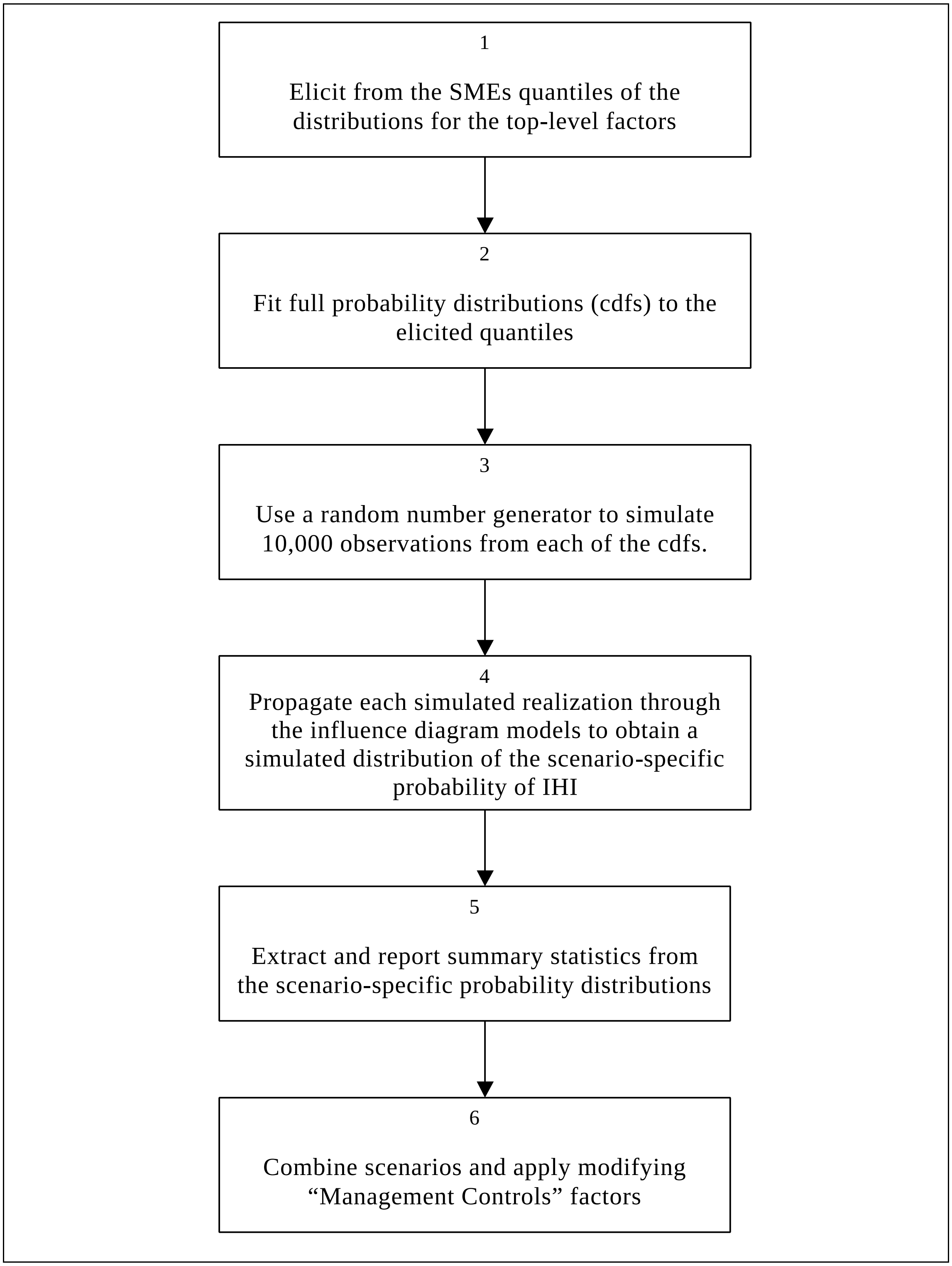

Figure 3-4 Computational steps for generating the probability of inadvertent human intrusion

4.0 ELICITATION AND RESULTS

With the model structures finalized by the SMEs in the form of influence diagrams, quantitative elicitation of the inputs needed to specify the mode parameters was conducted. The quantitative elicitation was performed by forming subgroups 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 subgroup experts. Appendix D describes this elicitation process as it was implemented, and identifies the SMEs that were considered key people for each factor. The responses elicited through this process, along with the underlying model specifications, made it possible to calculate the probabilities of IHI for each intrusion scenario.

A consensus step at the start of the elicitation concerned definition of the base assumptions by the SME panel. The SMEs agreed with the stakeholder workshop findings that using current knowledge of society is the only credible approach to a probabilistic assessment of IHI. Further, the SMEs agreed with the workshop participants that a periodic review of intrusion at least every 25 years is desirable as the current knowledge base changes, and specifically, if societal or technological changes occur. 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 standard Homesteader scenario and refinement of the preliminary community scenario. Three separate community scenarios were identified by the SMEs:

1. A small community located in the alluvial basins of Frenchman Flat or Yucca Flat (Base Community Scenario)

2. Urban expansion of Las Vegas north up the valley corridor and into the alluvial basins of NTS, including "commuting homesteaders" in Frenchman Flat and Yucca Flat (Las Vegas Expansion Scenario)

3. A small community located in Mercury, Jackass Flats, or in another area near Frenchman Flat and Yucca Flat, including "commuting homesteaders" in Frenchman Flat and Yucca Flat (Jackass Flats Scenario)

The SMEs defined commuting homesteaders as settlers who commute regularly from their homes outside the community or urban resource base. The commuting homesteaders case is distinct from the Homesteader scenario, in which homesteaders were assumed to be isolated from any central community. The Homesteader scenario, combined with the three community scenarios, yields the four scenarios that the SMEs considered in this study.

Each of the four intrusion scenarios is discussed in turn in this chapter, with the following information is provided in each case:

1. A presentation of the influence diagram models for the intrusion scenarios and the management controls module, which were finalized by the SMEs

2. A description of the input elicited from the SMEs

3. The resulting probabilities of IHI derived from the propagation of the SME inputs through the influence diagram models

In addition, this chapter contains a discussion of how and under what conditions the separate results can be combined. A presentation of the input received from the SMEs on Management Controls follows the discussion of the four intrusion scenarios. Details of the technical approach to propagation of SME input and combination of scenario results are presented in Appendix E. Some sensitivity analyses conducted to determine the impact of each of the factors included in the influence diagram models on the outcome probability of IHI are presented in Appendix F.

It is worth noting that the level of SME input varies from factor to factor. Some factors were clearly very important to the model, and were tangible enough that reasonable input could be obtained. Other factors, while important, provided qualitative information that supported factors included explicitly in the model. For example, suitability of the land surface and hydrogeologic factors that may influence the probability of establishing a settlement in the vicinity of the RWMSs were treated as implicit factors that provided qualitative information for explicit factors such as the number of homesteads expected in the vicinity of the RWMSs. The SMEs attempted to establish a balance in the selection of factors included in the influence diagrams. Establishing this balance required a conscious effort to ensure that the model was sufficiently comprehensive that all the main factors were included, but not so complex that the model might become intractable. The SMEs made careful distinctions between factors explicitly included and those that were implicit. Savage (1972) provides a useful rationale for marginalizing and conditioning models to provide a balance.

Some constants were used in the calculations. These were for the areal sizes of Frenchman Flat, Yucca Flat, the cratered area of Yucca Flat and the waste footprint. The waste footprint was established as two acres based on the Fernald waste as described in Chapter 1. This has no effect on the elicitation process because the distribution of the number of wells that might be drilled is the controlling elicitation endpoint. The waste footprint can be changed, for example to reflect other potential waste streams, without having any effect on the elicitation. The effect is on the probability of IHI. If a larger waste footprint is considered then the probability of IHI will be greater. A discussion of the impact of changing the waste footprint size can be found in Appendix F.

As noted, GIS techniques were used to estimate the other areas of interest. These are described more fully in Appendix E. The size of Frenchman Flat, excluding the Frenchman Lake (the playa in Frenchman Flat), was estimated at approximately 86,000 acres. The size of Yucca Flat, excluding the playa and excluding moderately and heavily cratered area, was estimated at approximately 70,500 acres, and the size of the cratered areas in Yucca Flat was estimated at approximately 24,000 acres. These inputs are important to the algorithms that are used to generate the probability of IHI.

4.1 Homesteader scenario

The first action taken by the SMEs for the Homesteader intrusion scenario was to provide a sufficient definition of homesteading in the remote alluvial basins of Frenchman Flat and Yucca Flat. The SMEs recognized the difficulty of completely separating homesteading from community settlements because of the possibility that a community could arise from many homesteads located close to one another. However, because the SMEs did not expect independent homesteading to occur with any great frequency, they chose to simplify matters and distinguish between the two possibilities. The Homesteader scenario was defined by the SMEs in terms of isolated and independent homesteads. Three specific assumptions were made for the Homesteader scenario:

1. The homesteads are isolated.

2. Each homestead 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 Frenchman Flat or Yucca Flat. The drilling technology was assumed to be consistent with that used at settlements in comparable alluvial valleys. The SMEs determined that the influence diagram model should include factors relating to number of homesteads, homestead lifetime (the number of years that a homestead remains viable), and number of wells and well lifetimes. Other parameters that must be included in the model to complete the probabilistic calculation are areal size of Frenchman Flat and Yucca Flat, or sub-areas thereof, and areal size of the waste footprint.

The SMEs also considered distance between replacement wells to be potentially important. Replacement wells became a consideration because well lifetimes could, occasionally, be shorter than homestead lifetimes. If a well collapses or becomes unusable for any other reason, then a replacement well is assumed to be drilled. Replacement wells are assumed to be in close proximity to the original well location because homesteaders would want to use existing water supply lines as much as possible.

For this scenario, the types of potential homesteaders were defined by the SMEs to include artists, telecommuters, writers, and others whose income comes from a source independent of their location. The SMEs discussed the possibilities of ranching, mining, or raising cash crops such as grapes, but dismissed them as very unlikely. Mining was dismissed by the economic geologist SME because of the minimal mineral resources in the area, and that, with current technology, it was not economically feasible to mine the mineral resources that exist in Frenchman Flat and Yucca Flat. Irrigation farming was dismissed because it also was not believed to be economically feasible. Given the water needs of the type of homesteader envisioned, the possibility of more than one original well per homestead was essentially dismissed as having such a small probability that it would have a negligible effect on the outcome

Prior to the quantitative elicitation, the SMEs expressed their views strongly that the type of independent homesteading envisioned for this scenario was extremely unlikely to occur. Consequently, the SMEs decided to evaluate Frenchman Flat and Yucca Flat together, and to ignore distinctions between the cratered and non-cratered areas of Yucca Flat that they deemed important for the community scenarios. For example, their input on the number of homesteads that might occupy this area applied to the combined areas of Frenchman Flat and Yucca Flat, including the cratered areas. Hence, the influence diagram presented in Figure 4-1 reflects an assessment of Frenchman Flat and Yucca Flat combined.

4.1.1 Inputs

The influence diagram begins with homestead density and homestead lifetime, factors that were elicited from the SMEs. These are defined as the distribution of the number of homesteads across time, and the expected length of time that a homestead might exist. When combined with the length of time being considered (the compliance period of 10,000 years), these variables generate a distribution of the total number of homesteads expected in Frenchman Flat and Yucca Flat combined over the time frame of interest (node 4). The well lifetime factor, which was also elicited from the SMEs, is then used to count the number of wells that will be drilled in Frenchman and Yucca Flats. A distribution of the total number of wells (node 6) is the critical factor for generation of the final probability of interest (node 10, the scenario-specific probability of IHI). Each of the influence diagrams follows the same basic structure, leading to estimation of the total number of wells that will be drilled as the basis for the final probabilistic calculation. Information pertaining to the areal sizes of Frenchman Flat, Yucca Flat, and the waste footprint, and to the expected distance between replacement wells is needed to generate the scenario-specific probability of IHI.

It should be emphasized that this Homesteader scenario was applied only to independent homesteading. That is, these homesteads are not linked in any way to a community settlement. The reason for this clarification should become clearer as the community scenarios are explained in the next section.

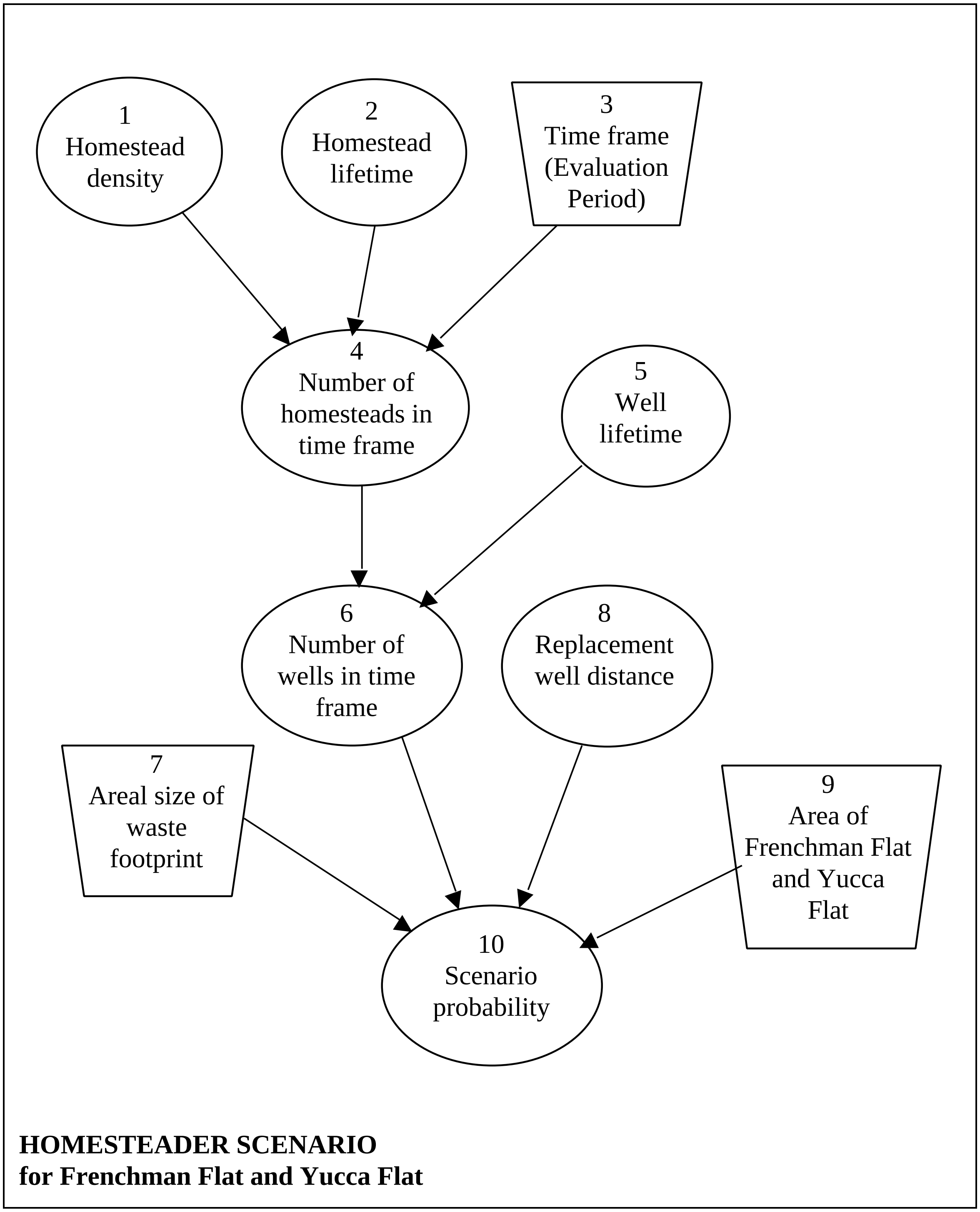

Figure 4-1 Homesteader scenario influence diagram

4.1.1.1 Homestead density (Node 1)

The SMEs felt that the number of homesteads would be sufficiently small that grouping Frenchman Flat and Yucca Flat made sense for this scenario. They agreed that no one would settle on the playas that are the collection, or low, points of Frenchman Flat and Yucca Flat, because of the inhospitable environment (essentially no vegetation exists in the playas). The probabilities of siting a homestead in the washes or the cratered area of Yucca Flat were thought to be very small, but the SMEs chose to ignore this stratification because the overall number of homesteads was also expected to be small.

Homesteader density, either in terms of homesteads per square mile, or of homesteads per year, was difficult to discuss directly. The SMEs preferred to refine this node to the percentage of the compliance period during which they would expect that there would be at least one homestead in either Frenchman Flat or Yucca Flat. In addition, the SMEs felt comfortable discussing how many homesteads they would expect to see when there was homesteading at the site.

The SMEs recognized that the area being considered is desolate, with minimal natural resources. The depth to groundwater is relatively great, and subsistence farming is not considered economically viable. Given these conditions, it is not surprising that the SMEs expect to see very few independent homesteaders in these areas during the compliance period. In response to queries on the number of homesteads likely to be present in Frenchman Flat or Yucca Flat in the next 10,000 years, the SMEs provided the following input:

- The probability of there being zero homesteads in the Frenchman Flat and Yucca Flat combined area at any given point in time was assessed as 0.98.

- The probability of exactly one homestead existing at any given time was estimated to be about twice the probability of two homesteads existing simultaneously.

- The probability of exactly one homestead existing at any given time was estimated to be 100 times greater than the probability of five homesteads existing simultaneously.

- The probability of more than five homesteads existing at any given time was considered to be zero.

Further details of the rationale for these, and all the other, SME inputs is provided in Appendix D. Appendix E provides summaries of the elicited input and shows how the elicited information was used in the modeling calculations. For many elicited factors the SMEs expressed a distribution that represented their uncertainty about their inputs. For this factor the SMEs chose not to worry about this level of detail because they felt that this scenario would have minimal impact on the overall results. They believed that the hybrid community scenarios (the Jackass Flats and Las Vegas Expansion scenarios) were far more likely to result in settlement of Frenchman Flat and Yucca Flat.

4.1.1.2 Homestead lifetime (Node 2)

The duration of individual homesteads was also elicited from the appropriate SMEs. The SMEs recognized that the homesteaders would have a monetary outlay for a well, and some physical or emotional investment that may encourage them to remain at the site for a number of years. On the other hand, it was reasoned that because of the inhospitable environment, few homesteaders would want to live in Frenchman Flat or Yucca Flat for long. The following responses were elicited on the issue of homestead lifetimes:

- The SMEs indicated that they thought it equally likely that a homestead would fold within 12.5 years or that a homestead would last for longer than 12.5 years. This value defines the median of the homestead lifetime distribution.

- The SMEs stated that they would expect 25% of the homesteads to fold within 6.25 years. This defines the lower quartile of the distribution.

- The SMEs felt that only 5% of the homesteads would last longer than 25 years, and only 1% would last beyond 40–50 years.

In a few cases, the SMEs provided ranges for their input. For example above, the SMEs felt that only 1% of homesteads would last beyond 40-50 years. The SMEs did not see the need to refine this range to a single point, again because of their perception of the unimportance of this scenario. When the SMEs supplied a range, the conservative end of the range with respect to its impact on the probability of IHI was used in the calculations. In the case of this scenario, the SMEs' perception that further refinement was not important was borne out by the results.

4.1.1.3 Well lifetime (Node 5)

Knowledge of local well traits dominated the discussion of well lifetimes for future homesteaders in Yucca Flat or Frenchman Flat. It was projected by the SMEs that polyvinyl chloride (PVC) pipe will be in common use for these private wells. The SMEs cited many potential difficulties that could bring an end to a well's useful lifetime, including the pipe breaking as the pump is dropped down, breakdown of the casing, encrustation, sand, cave-ins, and earthquakes. The input for this variable was elicited directly as the following:

- The median well lifetime is expected to be 35 years.

- 25% of the wells are expected to fail within 15–20 years.

- Only 5% of the wells are expected to fail within 10 years.

- Similarly, only 5% of the wells are expected to last longer than 50–70 years.

4.1.1.4 Replacement well distance (Node 8)

The SMEs indicated that when a well fails, a replacement well will be necessary for the homestead to remain viable. The SMEs were asked how far from the original well a replacement well might be sited. Distance between an original well and its replacement was important because wells that are close to one another by design may not have the same opportunity to intersect the waste footprint as wells that are randomly sited throughout Frenchman Flat or Yucca Flat. The following inputs were obtained:

- Half of all replacement wells are expected to be less than 30 ft from their corresponding original well, and half more than 30 ft away. That is, the median distance between the original well and the replacement well was assessed as 30 ft.

- 10% of the replacement wells are expected to be less than 10 ft from their corresponding original well.

- 10% of the replacement wells are expected to be more than 50 ft from their corresponding original well.

4.1.2 Results for the Homesteader scenario

With these elicited values, and the structure of the Homesteader intrusion scenario model (Figure 4-1), sufficient information is available to calculate the probability of IHI. In order to perform the calculations for this scenario, the potential homesteads were allocated randomly across the whole area of Frenchman Flat and Yucca Flat. The combined area of Frenchman Flat and Yucca Flat is approximately five orders of magnitude greater than the expected area of the waste footprint. With a small number of wells (approximately 25) allocated across the two areas for this scenario, the probability of one or more intersecting the waste footprint is extremely small.

The simulation proceeded, as indicated in Figure 3-4, by fitting cdfs to the input distributions for homestead lifetime and well lifetime. The number of homesteads was drawn at random (a number in the range 1 to 6, see Section 4.1.1.1), and a homestead lifetime was applied to these homesteads. This process was repeated so that repeated combinations of number of homesteads and homestead lifetimes were drawn until the sum of the homestead lifetimes reached at least 200 years. The number 200 was used because the SMEs indicated that for 98% of the time frame of the evaluation period of 10,000 years they expect there to be zero homesteads on Frenchman Flat and Yucca Flat. Note that only one waste footprint is allowed in these calculations across Frenchman Flat and Yucca Flat. Practically this make no difference because the probability of IHI is so small for this scenario. Conceptually, the reason for doing this is because the SMEs provided input based on a combination of the two areas. Further details are provided in Appendix E.

For each homestead, the homestead lifetime was compared to random draws from the well lifetime distribution to determine if replacement wells were necessary. Replacement wells occurred relatively infrequently, and some experimentation with the simulations indicated that the effect of so few replacement wells on the results was negligible. The reason this small number of replacement wells had so little impact can be thought of in terms of the number of original, or primary, wells, and the relative areas of Frenchman Flat and Yucca Flat (about 180,000 acres) and the waste footprint (two acres). The number of primary wells is small (an average of about 26), and the chance of a primary well intersecting the waste footprint by random spatial allocation of the wells is, therefore, very small. A replacement well is located relatively close to a primary well, therefore, if a primary well did not intersect the waste footprint, then it is very unlikely that its replacement well(s) would intersect the waste footprint. Details of the algorithms used are presented in Appendix E.

Table 4-1 provides the result for the Homesteader scenario probability. This table provides summary statistics for the propagated distributions, both for the intermediate factor of “number of wells” and for the probability of IHI. The results presented are summaries of the simulated output data. The minimum, maximum, and average simulated number of primary and replacement wells are shown. Several quantiles of the simulated distribution are also shown. These can be interpreted as the values that are greater than the associated percent of results. For example, 5% of the simulations resulted in less than 17 primary wells, and 75% of the simulations resulted in less than 27 primary wells. Figure 4-2 is a graphical representation of the simulated distribution of the Homesteader scenario results. This Figure shows a histogram of the output data overlaid with a smoothed histogram of the simulated data. Details of the algorithms and simulation results are presented in Appendix E.

Table 4-1 Summary statistics for the propagated probability distributions of the total number of wells and the probability of inadvertent human intrusion for the Homesteader scenario

Summary Statistic	Total Number of Wells		Probability of IHI
	Primary	Replacement	
Minimum	10	0	0.000098
5%	17	1	0.00018
25%	21	2	0.00022
Median	24	3	0.00026
Average	**24**	**3**	**0.00026**
75%	27	4	0.00030
95%	33	6	0.00036
Maximum	46	12	0.00050

The results portray a distribution for the number of wells and the probability of IHI. It should be remembered, however, that the spread of these distributions might be underestimated given the constraints discussed in Section 3.4.1. The output distributions are dependent on the SMEs and their current knowledge of technology and society, their inputs both to the structure of the model and specification of input distributions, and some impacts of the cdf fitting procedures and the mathematical modeling performed. In addition, the elicitation procedures were controlled to the extent possible to avoid motivational and cognitive biases, but it is well known in cognitive psychology that tail probabilities are often over-estimated in elicitation. Further discussion is provided in Appendix E. For this scenario, however, given the low scenario probabilities observed in the simulated results, lack of definition in the spread of the results has an insignificant impact on the conclusions. That is, the results for this scenario confirm the SMEs' opinions that independent homesteading is very unlikely to result in IHI into waste buried at the NTS Area 3 or Area 5 RWMSs.

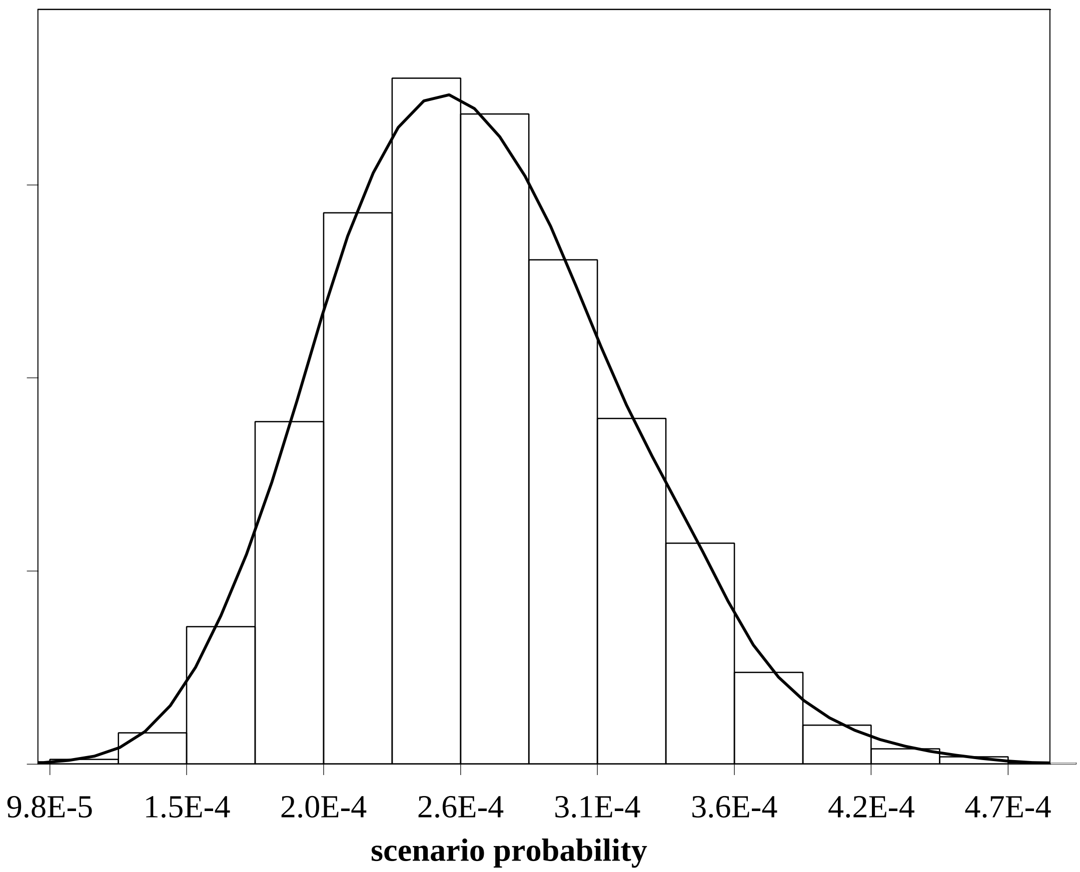

Figure 4-2. Distribution of the probability of inadvertent human intrusion for the Homesteader scenario

4.2 Community Scenarios

The SMEs raised a serious concern that the two scenarios (homesteader and community) as originally envisioned did not adequately account for the possible ways in which settlement in Frenchman Flat or Yucca Flat could occur. Whereas the difference between independent homesteading and basing a community in Frenchman Flat or Yucca Flat was clear, the SMEs felt that other hybrid scenarios were equally realistic and probably more likely to occur. After discussion of the possible mechanisms for settlement of Frenchman or Yucca Flat, the SMEs suggested three alternate community scenarios.

1. The "Base Community scenario," corresponded to the original notion of evaluating the potential for siting a community in Frenchman Flat or Yucca Flat, regardless of motivating factors. This is the only scenario for which the settlements in Frenchman Flat and Yucca Flat are envisioned as communities.

2. The "Jackass Flats scenario," involved siting a community in an area neighboring Yucca Flat and Frenchman Flat. The term Jackass Flats was used by the SMEs because they considered Jackass Flats, with its relative accessibility through the northwest corridor from Las Vegas to Tonopah, a reasonably likely area for a community settlement compared with other areas that neighbor Frenchman and Yucca Flats. Other sites were mentioned, particularly the existing, limited-access town of Mercury (which exists solely to support NTS activities). In addition, the concept more generally included any area that could be said to neighbor Frenchman Flat and Yucca Flat (e.g., Pahrump, Amaragosa, Indian Springs, or an old mining site to the northwest end of Yucca Flat).

   In summary, the name "Jackass Flats scenario" was chosen by the SMEs to represent the concept of increased settlement of Frenchman and Yucca Flats in the form of "commuter homesteaders" associated with the location of a nearby community. The SMEs indicated that some portion of the population of this type of community can be expected to live outside the main community center, in Frenchman Flat or Yucca Flat. Jackass Flats, in particular, was suggested as a more desirable candidate than Frenchman Flat or Yucca Flat because of more favorable living conditions such as more surface water, shorter distance to groundwater, and proximity to the existing major highway to Las Vegas. Mercury was suggested as more desirable because of the existing infrastructure as well as the direct route to Las Vegas.

   The SMEs indicated that Jackass Flats, Mercury, and other nearby sites with potential to support a community, appeared to be close enough to both of these areas that population pressure seemed reasonable to evaluate. This scenario was distinguished from the independent Homesteader scenario, in which a direct link to a community was not envisioned, and from the Base Community Scenario in which a community sited in Frenchman Flat or Yucca Flat was the focus.

3. The "Las Vegas Expansion scenario," involved similar population pressure on Frenchman Flat and Yucca Flat, but this time caused by an expansion of the city of Las Vegas. The SMEs did not envision Las Vegas expanding to encompass Frenchman Flat or Yucca Flat. They did imagine, however, Las Vegas expanding far enough to cause population pressure on these outlying areas from people who desire to live outside the city and have access both to relatively rural surroundings and the infrastructure of a large city.

In view of the SMEs' desire to consider three different community scenarios, this section addresses each separately. For each of the three models, the number of original (or primary) wells expected to be drilled during the compliance period was calculated through explicit elicitation of the model-specific factors. The SMEs also considered distance apart of replacement wells potentially important. Other parameters included in each model are area of concern (i.e., Frenchman Flat, Yucca Flat, or sub-areas thereof) and areal size of the waste footprint (specified by DOE/NV based on anticipated waste volumes). These factors were all necessary to complete the probabilistic calculation of IHI for each scenario.

It should be noted that other factors were considered implicitly. In particular there was considerable discussion about factors that might impact the siting of a community in Frenchman Flat or Yucca Flat. For example, the impact of depth to groundwater, slope, cratered area, playas, flood plains, were raised. The SMEs decided to handle most of these factors implicitly, although they set explicit constraints on two factors:

1. The probability of inhabitation of the playas in Frenchman Flat and Yucca Flat is zero. That is, the SMEs agreed that these areas will not be inhabited under any circumstances.

2. The heavily cratered areas in Yucca Flat were much less likely to be inhabited than the remainder of Yucca Flat. Specifically, the SMEs stated that the probability of settling in the non-cratered area of Yucca Flat would be 10 times as likely as settling in the cratered area if the areas were of equal size. Given the actual ratio of the sizes of the cratered and non-cratered areas, this statement equates to a statement that settlement in the non-cratered area of Yucca Flat is about 30 times more likely than in the cratered area.

4.2.1 Base Community Scenario

The influence diagram model for this scenario includes factors relating to the number of communities, community lifetime (the number of years that a community might be expected to exist in this area), number of wells supporting a community water supply, and well lifetimes. The SMEs made an assumption that there would not be more than one community located in either of the two areas at any one time. Therefore, the "number of communities" factor corresponds to a count of the number of temporally unique communities that might appear during the course of the 10,000-year evaluation period. That is, the types of community under consideration are assumed to rise and fall, eventually becoming ghost towns.

Community types that were discussed included communities based on a research industry such as nuclear or solar energy, mining communities, communities based on military or prison bases, religious communities, and Native American communities. Although the SMEs included many types of communities implicitly, the evaluation of this community scenario in terms of wells drilled was performed for a standard planned community with the water supply fully supported by a community water supply system. Consequently, private wells were not considered for this scenario.

The community under consideration for this scenario was assumed by the SMEs to be relatively independent of Las Vegas. That is, this scenario involved an independent, self-sustaining community in Frenchman Flat or Yucca Flat. Unlike the model for the independent Homesteader scenario described in the previous section, the SMEs decided to address Frenchman Flat and Yucca Flat separately for the community scenarios. Consequently, the influence diagram presented in Figure 4-3 applies equally to either area, and the model is used separately for each area.

4.2.1.1 Inputs

The influence diagram for the Base Community scenario begins with factors pertaining to the number of communities that might exist in Frenchman Flat or Yucca Flat during the next 10,000 years. The proportion of time a community might exist in these areas and the life span of such a community were elicited from the SMEs. From this information, a distribution of the total number of expected communities is generated (node 4). Information about the number of wells that might be needed to support a community and the lifetime of these wells then defines a distribution for the total number of wells expected to be drilled (node 7). For all of the community scenarios, the calculation of the scenario probabilities is performed separately for Frenchman Flat and Yucca Flat. The final step in the calculation of the probability of IHI combines the distribution of the total number of wells with information pertaining to the areal sizes of Frenchman Flat, Yucca Flat, the waste footprint, and the expected distance between replacement wells (node 12).

4.2.1.1.1 Proportion of time community may exist (Node 1)

This Base Community scenario considers the probability of a community being sited directly in Frenchman Flat or Yucca Flat. The kinds of communities the SMEs could imagine in this scenario include a research park, prison, military base, religious group, or a casino. The probability of such a community being located in these areas was considered very unlikely because of the hostility of the environment, lack of available infrastructure, as well as the distance to a major population center for support services.

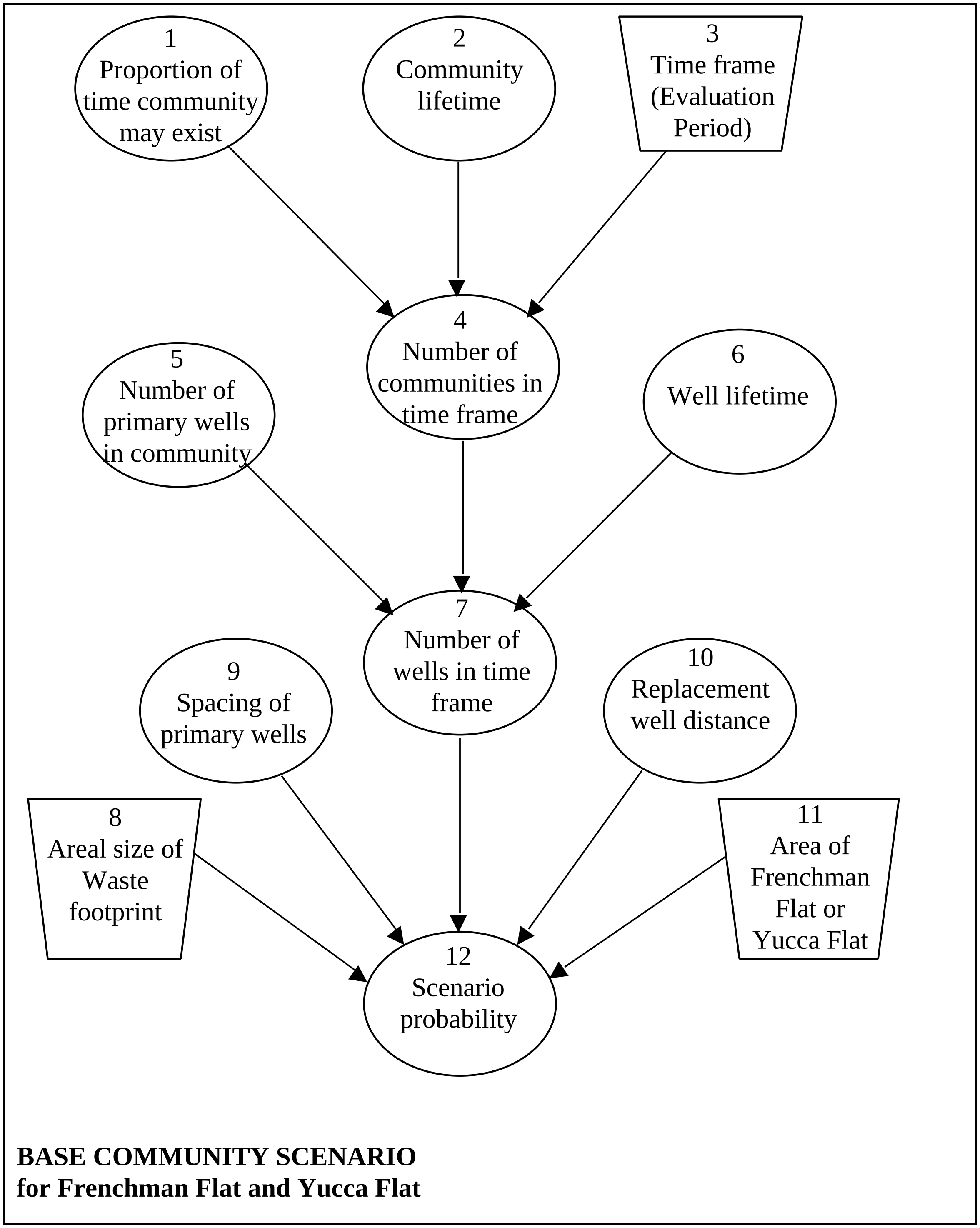

Figure 4-3 Base Community scenario influence diagram

The SMEs found it easiest to first consider the probability that a community would be located in Frenchman Flat, and then use comparative information to extrapolate the probabilities to Yucca Flat. Specifically, the SMEs indicated that the probability of communities being located in Yucca Flat would be half the corresponding probability for Frenchman Flat. The reasons for this difference included the greater distance of Yucca Flat from the population center of Las Vegas, and the subsidence cratering that occupies a large sub-area of Yucca Flat. In response to questions on the length of time during which the SMEs imagine Frenchman Flat will be the site of a community, the SMEs gave the following opinion:

- The proportion of the 10,000-year evaluation period for which the SMEs expect that there might be a community in Frenchman Flat is between 0.5% and 1%.

Consequently, the proportion of the 10,000-year evaluation period for which the SMEs expect that there might be a community in Yucca Flat is between 0.25% and 0.5%. The SMEs did not feel that there was a need to refine these ranges any further, primarily because they expected the probability of IHI for this scenario to be very small. The SMEs also indicated that the type of community envisioned was unlikely to support more than 5,000 people, and was likely to occupy an area of no more than 1 square mile.

4.2.1.1.2 Community lifetime (Node 2)

The types of communities the SMEs considered possible at Frenchman Flat are all single purpose as described above. Discussion of both the historical trends of small, single-purpose communities and the personal experiences of the SMEs led to agreement that the lifetime of the communities would be quite short. The SMEs' input on this issue follows:

- 10% of the communities are expected to collapse within 10 years.
- 25% of the communities are expected to collapse within 35 years.
- 50% of the communities are expected to collapse within 50 years.
- 75% of the communities are expected to collapse within 65 years.
- Less than 10% of the communities are expected to last longer than 100 years.

4.2.1.1.3 Number and spacing of primary wells (Nodes 5 and 9)

The SMEs agreed that one community production water supply well may be sufficient for the type of planned community envisioned, but two is possible. Assuming that each of these wells has a backup well, four wells was considered a realistic upper estimate of the number of wells for this type of planned community. The estimate of four wells was expected to be conservative, but the SMEs indicated that this scenario is so unlikely to occur that this limited conservatism will have negligible effect on the combined outcome for the three community scenarios. For spatial simplicity, the four wells were expected to be drilled in a square pattern on one-half mile centers, and hence would be contained within the 1 square mile area of the community suggested by the SMEs. The SMEs expected the wells to be at least this far apart to avoid the potential for localized draw down of the aquifer.

4.2.1.1.4 Well lifetime (Node 6)

A distribution of the expected well lifetimes was elicited from the pertinent SMEs. The types of wells under consideration for this scenario are community production wells. By contrast, the types of wells considered for the other intrusion scenarios are private wells. However, the SMEs provided the following input for the expected lifetime of a production well, which is not very different than the input provided for private wells (see Section 4.1.1.3):

- 10% of the wells are expected to fail within 10 years.
- 50% of the wells are expected to last at least 35 years.
- About 10% of the wells are expected to last longer than 50 years.

4.2.1.1.5 Replacement well distance (Node 10)

The SMEs determined that in the case of a replacement well being necessary, it would most likely be drilled within 100 ft of the well it is replacing. Because the SMEs considered this intrusion scenario very unlikely to occur, no further distributional clarification of this issue was elicited.

4.2.1.2 Results for the Base Community Scenario

The SMEs strongly indicated that the probability of a community being located in either Frenchman Flat or Yucca Flat was very low. This had an effect on both the elicitation and the calculations. For example, the SMEs did not want to refine the areal size of the community, the distance between the primary wells, or the separation distance for replacement wells. Some simplifications were also made in the calculations, introducing a small positive bias in the distribution of the probability of IHI.

The probability of siting a community over the waste footprint is very small because of the relative areal sizes of Frenchman Flat, or Yucca Flat, and the waste footprint, and the infrequency with which communities were expected to develop in these areas. Nearly all the simulations involve siting a single community at random in Frenchman Flat or Yucca Flat, and siting the four primary wells and the replacement wells according to the spatial information provided by the SMEs. The SMEs expected small communities for this scenario. In most simulations the community was not sited close to the waste footprint. In a few of the simulations, the community was close enough to the waste footprint that intersection with a well was possible, however, the small number of wells still made it unlikely that a well intersected the two-acre waste footprint. Each simulation provided an estimate of the probability that at least one well intersects the waste footprint. The 10,000 simulations provide a distribution of this probability. Details of the algorithms are provided in Appendix E. Tables 4-2 and 4-3 provide a summary of the results.

Table 4-2 Summary statistics for the propagated probability distributions of the total number of wells and the probability of inadvertent human intrusion for the Base Community scenario: Frenchman Flat

FRENCHMAN FLAT			
	Number of Wells		
Summary Statistic	Primary	Replacement	Probability of IHI
Minimum	4	0	0.000052
5%	4	3	0.000086
25%	4	5	0.00011
Median	8	7	0.00015
Average	**4**	**8**	**0.00017**
75%	8	10	0.00021
95%	12	18	0.00030
Maximum	20	52	0.00058

Table 4-3 Summary statistics for the propagated probability distributions of the total number of wells and the probability of inadvertent human intrusion for the Base Community scenario: Yucca Flat

YUCCA FLAT			
	Total Number of Wells		
Summary Statistic	Primary	Replacement	Probability of IHI
Minimum	4	0	0.0000060
5%	4	3	0.000010
25%	4	5	0.000013
Median	8	7	0.000018
Average	**4**	**8**	**0.000020**
75%	8	10	0.000025
95%	12	18	0.000036
Maximum	24	49	0.000076

The probabilities of IHI as assessed through the Base Community scenario are depicted graphically in Figures 4-4 (Frenchman Flat) and Figure 4-5 (Yucca Flat). These figures show a smoothed histogram, or density estimate, that overlays a histogram of the simulated output data. The results for Frenchman Flat are considerably greater than those for Yucca Flat because, according to the SMEs, settling in Yucca Flat is less likely than settling in Frenchman Flat, and settling in the cratered area of Yucca Flat is even less likely. Because the Area 3 RWMS is located in the cratered area, the probability of inadvertently intruding into the waste is reduced by the small probability of a community being located in this sub-area.

The very small probabilities of IHI seem consistent with the SMEs' beliefs that a community settlement in Frenchman Flat is very unlikely, and a community settlement in Yucca Flat is even less likely. As discussed in Section 3.4.1, the methods used in this assessment may have led to underestimating the spread of the output distributions. Given the low scenario probabilities observed in the simulated results, it is unlikely that the spread of the results would have a significant impact on the conclusions.

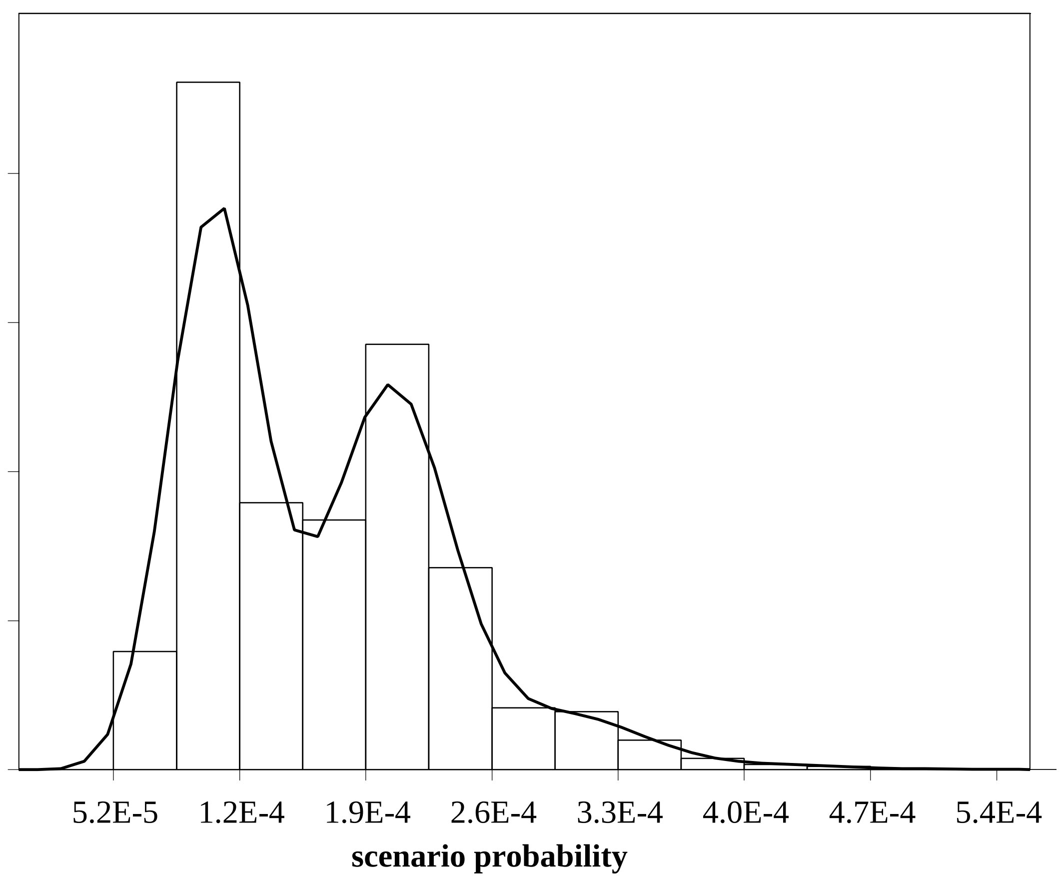

Figure 4-4 Distribution of the probability of inadvertent human intrusion for the Base Community scenario: Frenchman Flat

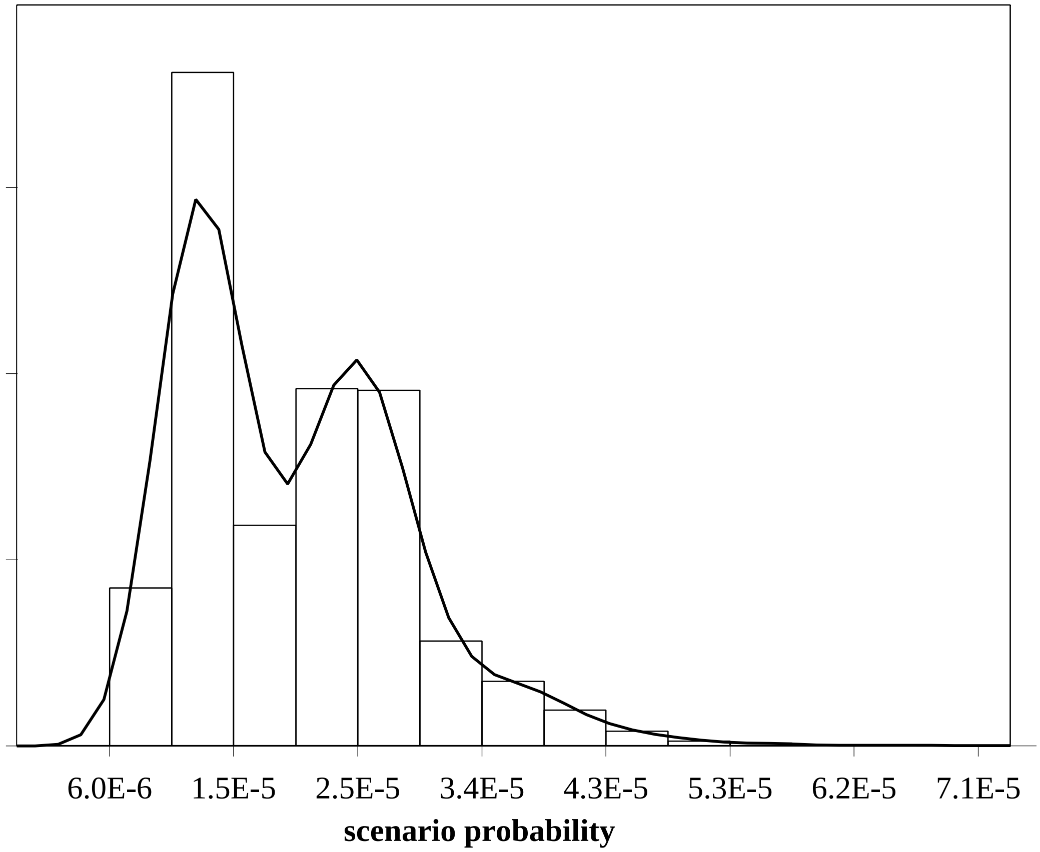

Figure 4-5 Distribution of the probability of inadvertent human intrusion for the Base Community scenario: Yucca Flat

4.2.2 Jackass Flats Scenario

The Jackass Flats scenario was described by the SMEs as an intrusion scenario in which a community is located near, but not directly in Frenchman Flat and Yucca Flat. Homesteading is expected to increase in the areas of interest because of the proximity of a settlement that could provide necessary services to homesteaders. The type of homesteading expected was termed by the SMEs "commuter homesteading" (i.e., settlers who desire to live in a more rural area, but who also wish to have the infrastructure of a community settlement immediately available).

4.2.2.1 Inputs

The SMEs considered the same types of communities for this scenario as for the Base Community scenario. It was expected, however, that the likelihood of a community being sited near Frenchman Flat or Yucca Flat would be considerably higher than the likelihood of a community being sited in these areas. Many factors influenced this greater likelihood, the most important being anticipated population expansion in southern Nevada and proximity to existing infrastructure. For example, the SMEs felt that because Jackass Flats is nearer to the main thoroughfare northbound out of Las Vegas, it would be easier to access, and therefore more likely to be settled than either Frenchman Flat or Yucca Flat. The SMEs also indicated that the existing infrastructure at the NTS support town of Mercury might make that a reasonable target for future community settlement.

This scenario is distinguishable from the Base Community scenario because the community itself is not located in Frenchman Flat or Yucca Flat. It is also distinguishable from the Homesteader scenario, for which a supporting community is not assumed. The influence diagram model for this intrusion scenario (Figure 4-6) begins with factors relating to community lifetime and the proportion of time that communities may exist in proximity to Frenchman Flat and Yucca Flat. These factors are used to determine the number of new communities that might develop during the 10,000-year evaluation period. Other factors in the model include number of commuter homesteads attached to the community, homestead lifetime (the number of years that a homestead might be expected to remain viable in this area), and well lifetime.

This scenario is essentially a hybrid of community and homestead settlement, and has components of each one represented in the development of the probability of IHI. Similar to the Base Community scenario, the number of communities that may exist during the compliance period is calculated first (node 4), and then is combined with the number of homesteads expected to be associated with each community. This provides estimates of the number of homesteads expected in Frenchman Flat and Yucca Flat, separately, over the period of interest (node 6). The total number of wells is calculated from the number of homesteads and the number of wells per homestead. This leads to estimation of the number of wells expected to be drilled during the compliance period (node 10), which is used directly to calculate the probability of IHI for this scenario.

4.2.2.1.1 Proportion of time community may exist (Node 1)

The first issue to be addressed by the SMEs for this scenario concerned the potential for a community to be located in Jackass Flats or some other area in the vicinity of Frenchman Flat or Yucca Flat (such as Mercury, Indian Spring, or Pahrump Valley) that would put population pressure in the form of commuter homesteading in the two areas of interest. That is, the number of years (out of the next 10,000 years) a community might exist in the vicinity of Frenchman Flat or Yucca Flat would, again, provide a limit on the time frame for which IHI could occur for this scenario. The SMEs provided the following responses:

- There will be communities for no less than 25% of the time.
- There will most likely be communities for about half of the time.
- There will not be communities for more than 75% of the time.

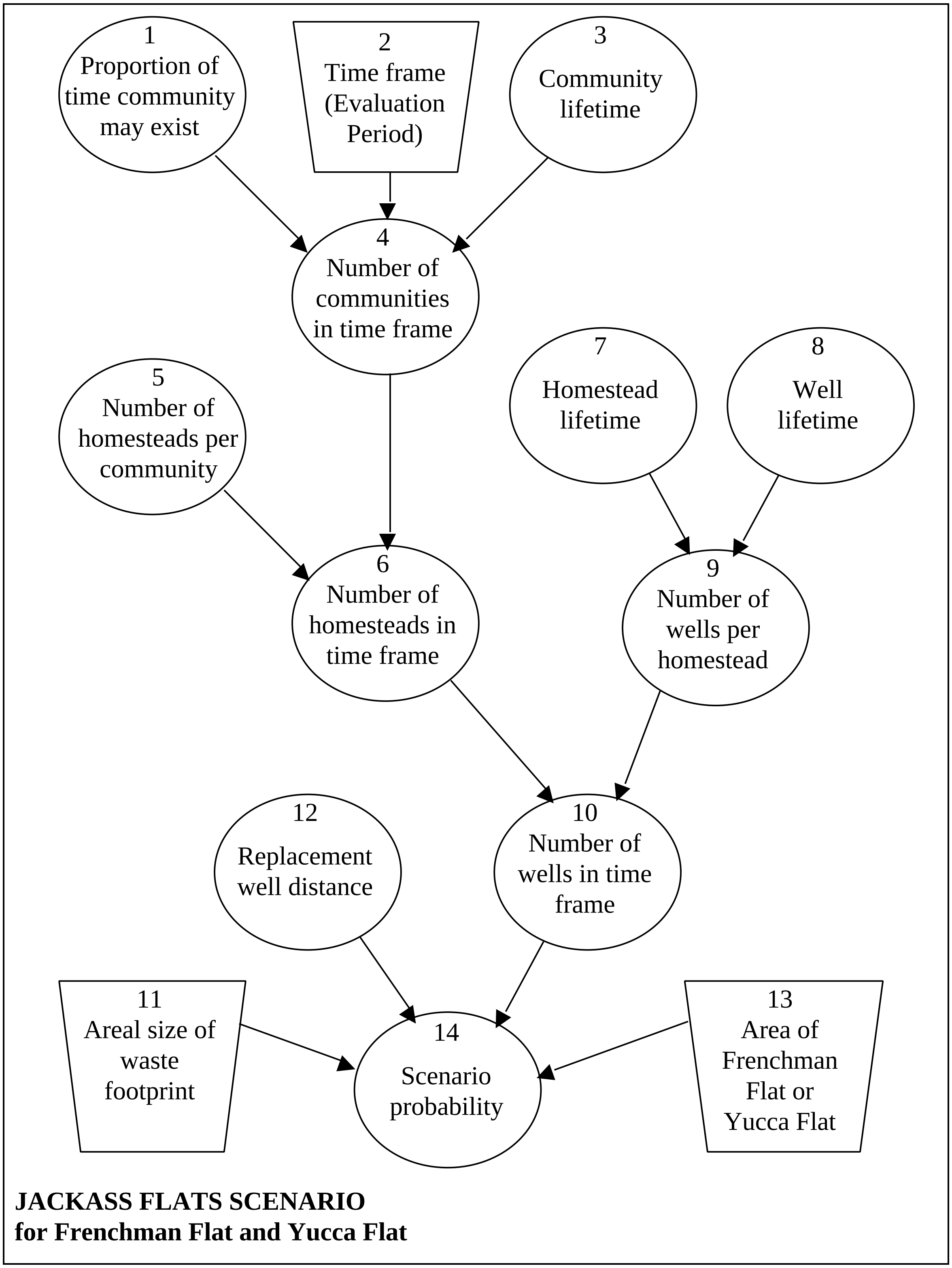

Figure 4-6 Jackass Flats scenario influence diagram

4.2.2.1.2 Community and homestead lifetimes (Nodes 3 and 7)

According to the SMEs, the community lifetime distribution for this scenario is the same as for the Base Community scenario (see Section 4.2.1.1.2) since the same types of communities are being considered. The SMEs based this assessment on historical knowledge of the difficulties faced by small towns in harsh desert environments (see Appendix D).

The SMEs also indicated that homesteads that occur as a result of nearby communities are expected to have the same lifetime as the corresponding community. The SMEs recognized that this might be a somewhat conservative assumption, because it is unlikely that all homesteads would exist from the onset of a community, and some might perish prior to the final demise of a community. Nevertheless, this was the input provided. A sensitivity analysis of the impact of replacement wells for this scenario is provided in Appendix F.

4.2.2.1.3 Number of homesteads per community (Node 5)

Once the possibility of such a community coming into existence was recognized, the next step was to assess the number of commuter homesteads that might be located in Frenchman Flat or Yucca Flat. When there is a community nearby, the SMEs indicate that they would expect:

- One or more homesteads in Frenchman Flat 95% of the time.
- More than 50 homesteads in Frenchman Flat 50% of the time.
- More than 100 homesteads in Frenchman Flat 5% of the time.
- More than 200 homesteads in Frenchman Flat 1% of the time.

Similar to the Base Community scenario, the SMEs expected Yucca Flat to have approximately half the number of homesteaders that Frenchman Flat would have.

4.2.2.1.4 Well lifetime and replacement well distance (Nodes 8 and 12)

The SMEs agreed on an assumption of one primary well per homestead, similar to the Homesteader scenario. Furthermore, they agreed that the well lifetimes and distance between replacement wells would be identical to those elicited for the Homesteader scenario (see Sections 4.1.1.3 and 4.1.1.4).

4.2.2.2 Results for the Jackass Flats Scenario

Assessment of the probability of IHI for this scenario proceeds by determining the number of original, or primary, wells to be drilled in the 10,000-year evaluation period under consideration, and determining the probability that one of these wells would intersect the waste site (assumed to be two acres) considering the total area available for siting homesteads and wells. Replacement wells are then considered by constraining their distance from the primary wells. The SMEs clearly indicated that the Jackass Flats scenario was the most likely scenario by which IHI could occur. The SME panel indicated that the probability would be between 0.25 and 0.75 that, at any given point in time, a community that included commuter homesteaders would be established in the vicinity of Frenchman Flat or Yucca Flat. This corresponds to a period of time (not necessarily consecutive years) of between 2,500 and 7,500 of the next 10,000 years. Because of the long time frame involved, the number of primary wells drilled under this scenario is comparatively large (approximately 4,600 primary wells are expected to be drilled in Frenchman Flat). The number of wells expected to be drilled in the cratered area of Yucca Flat is much lower (less than 100) because this area is much smaller and is considered much less desirable.

The calculation for this scenario is performed in the same way as for the Homesteader scenario, only the number of wells differs substantially, and the two areas of interest are considered separately. The resultant probabilities of IHI are presented in Tables 4-4 and 4-5, and reflected in Figures 4-7 and 4-8, which are probability density estimates that are overlaid on a histogram of the simulated output data (see Appendix E).

The Jackass Flats scenario provides by far the greatest probability assessment of the scenarios considered. The average simulated probability of IHI for Frenchman Flat is approximately 0.11. The simulated data suggest that the probability could be as high as 0.21 or as low as 0.03. For Yucca Flat, the average simulated probability is approximately 0.006. The spread of the Yucca Flat distribution suggests that this probability could be as low as 0.0013, or as high as 0.013. The distributions are clearly dominated by the uniform distribution input provided by the SMEs for the amount of time in the next 10,000 years that an extant community might place population pressure on Frenchman Flat or Yucca Flat. Given the importance of this scenario to the overall results, further work to refine this parameter might be worthwhile to better understand the mechanisms by which commuter homesteading might occur. For example, the SMEs indicated during the elicitation that most commuter homesteaders would probably settle nearer the edge of Frenchman Flat or Yucca Flat in areas that provide shade from the high summer temperatures. This margin of the model was not considered further by the SMEs, but could be explored if it becomes important to the decision making process.

It should be noted, again, that the results depend on all of the conditions and assumptions made during the study, and that the results should be interpreted accordingly. Also, the conditions and assumptions used in this assessment may have led to underestimating the spread of the results. Further details are provided in Appendix E.

Table 4-4 Summary statistics for the propagated probability distributions of the total number of wells and the probability of inadvertent human intrusion for the Jackass Flats scenario: Frenchman Flat

FRENCHMAN FLAT			
	Total Number of Wells		
Summary Statistic	**Primary**	**Replacement**	**Probability of IHI**
Minimum	1500	1800	0.031
5%	2500	3000	0.058
25%	3400	4200	0.082
Median	4600	5600	0.11
Average	**4600**	**5600**	**0.11**
75%	5700	7000	0.13
95%	6800	8300	0.16
Maximum	8500	10000	0.21

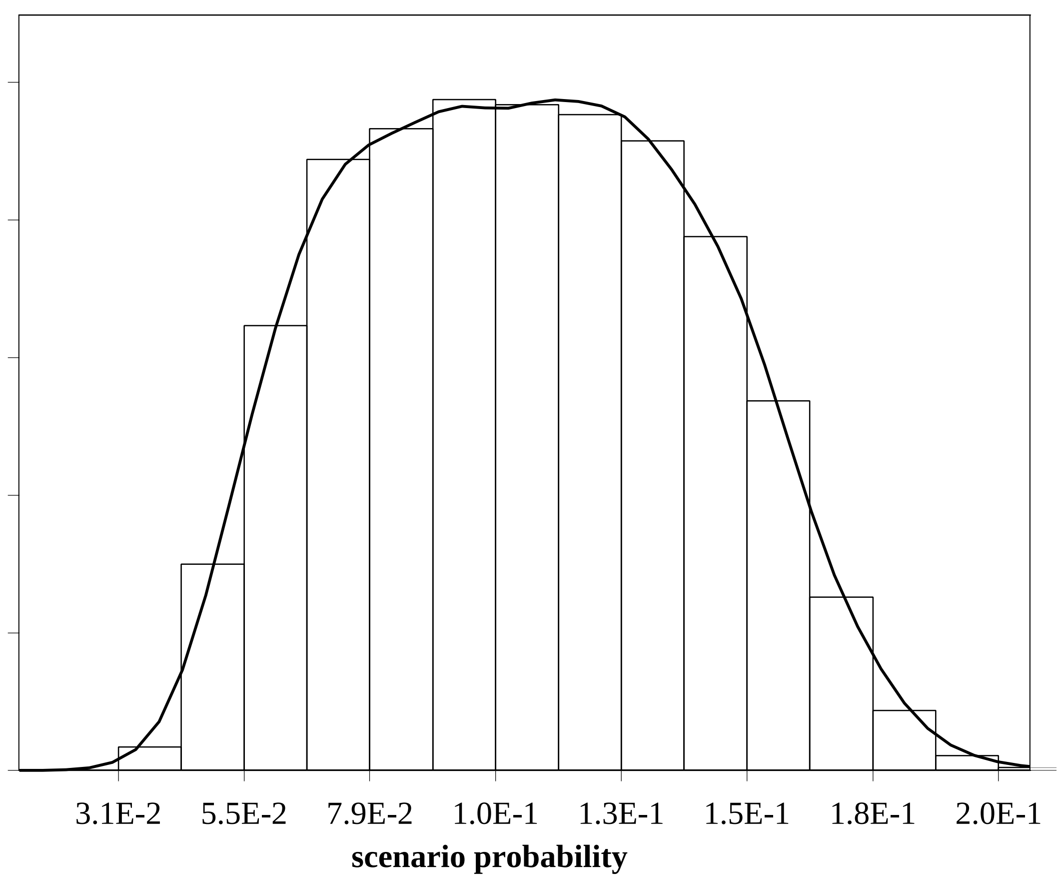

Figure 4-7 Distribution of the probability of inadvertent human intrusion for the Jackass Flats scenario: Frenchman Flat

Table 4-5 Summary statistics for the propagated probability distributions of the total number of wells and the probability of inadvertent human intrusion for the Jackass Flats scenario: Yucca Flat

YUCCA FLAT			
	Total Number of Wells		
Summary Statistic	**Primary**	**Replacement**	**Probability of IHI**
Minimum	800	1100	0.0010
5%	1200	1500	0.0034
25%	1700	2100	0.0048
Median	2200	2700	0.0063
Average	**2300**	**2800**	**0.0065**
75%	2800	3400	0.0080
95%	3400	4100	0.010
Maximum	4400	5000	0.013

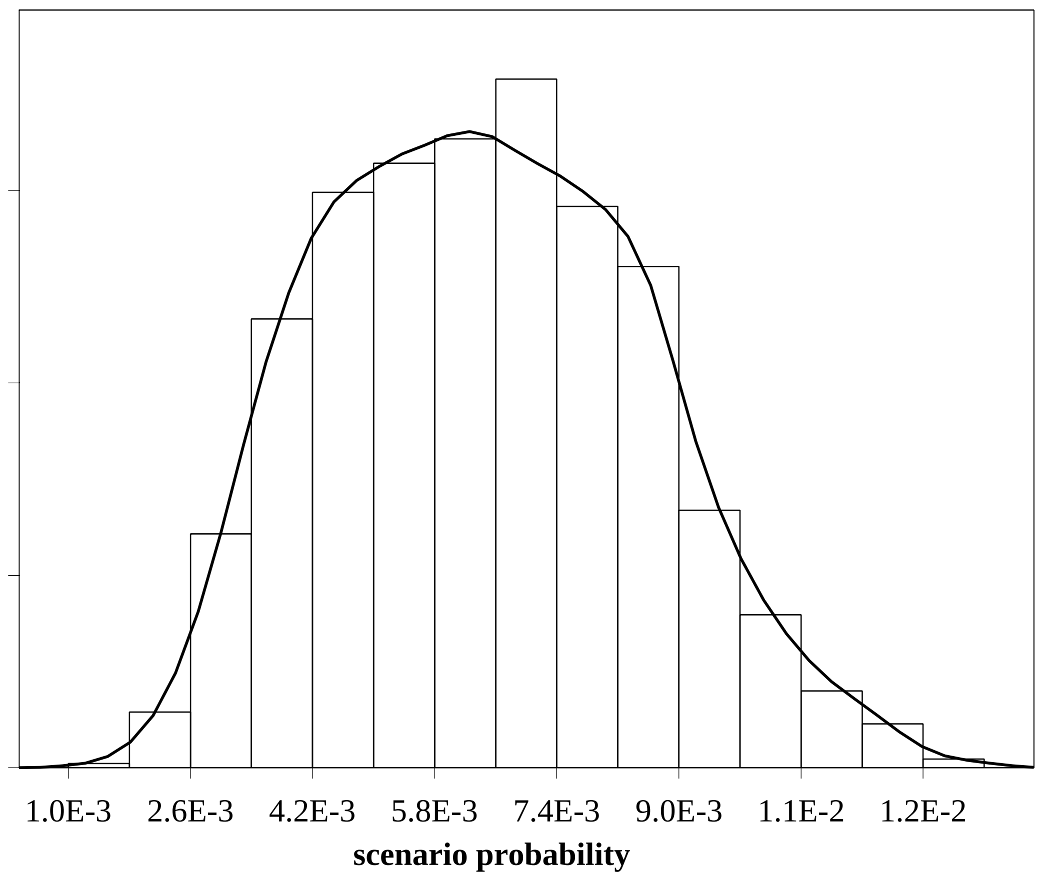

Figure 4-8 Distribution of the probability of inadvertent human intrusion for the Jackass Flats scenario: Yucca Flat

4.2.3 Las Vegas Expansion Scenario

This scenario involves sufficient expansion of Las Vegas that population pressure would be placed on the two areas of interest, primarily in the form of commuter homesteading. The city of Las Vegas is approximately 80 miles from Frenchman Flat and Yucca Flat. The SMEs recognized that considerable expansion of Las Vegas would be necessary before any population pressure might result in settlement of such currently remote areas. The first issue to be addressed for this scenario concerned the potential for Las Vegas to expand sufficiently that population pressure would be placed on Frenchman Flat and Yucca Flat. Once this was established as a possibility, an influence diagram model was developed that started with the length of time Las Vegas might exist at that size. The remainder of the Las Vegas Expansion scenario influence diagram (Figure 4-9) essentially followed the Jackass Flats intrusion scenario model.

4.2.3.1 Inputs

Assessment of the probability of IHI proceeds in a manner similar to the previous scenarios, by determining the number of wells to be drilled during the evaluation period (node 8). The probability that one of these wells intersects the waste site, considering the total area available for siting homesteads and wells, is then determined. Replacement wells are considered by assessing their distance from the primary wells. The probability of IHI for this scenario (node 12) is calculated using these inputs and the areal sizes of Frenchman Flat, Yucca Flat, and the waste footprint. The diagram presented in Figure 4-9 again applies to Frenchman Flat and Yucca Flat separately.

4.2.3.1.1 Population distribution for Las Vegas over time (Node 1)

The SMEs believe Las Vegas may continue its current expansion into the future, and considered this pertinent information for the likelihood of people settling in the Frenchman and Yucca Flats area. Given current projections, the SMEs could envision Las Vegas growing to a size that would begin to put population pressures on Frenchman Flat and Yucca Flat. The SMEs asserted that the population of Las Vegas would have to reach three million to create such population pressure. While this growth seems possible under current population projections, the SMEs did not assume that sufficient growth to affect population trends in Frenchman Flat and Yucca Flat was assured. The SMEs assessed the probability that Las Vegas will expand to influence these areas as follows:

- The probability of the necessary population growth is at least 0.10.
- The most likely probability of such growth is 0.20.
- The probability of such growth is at most 0.60.

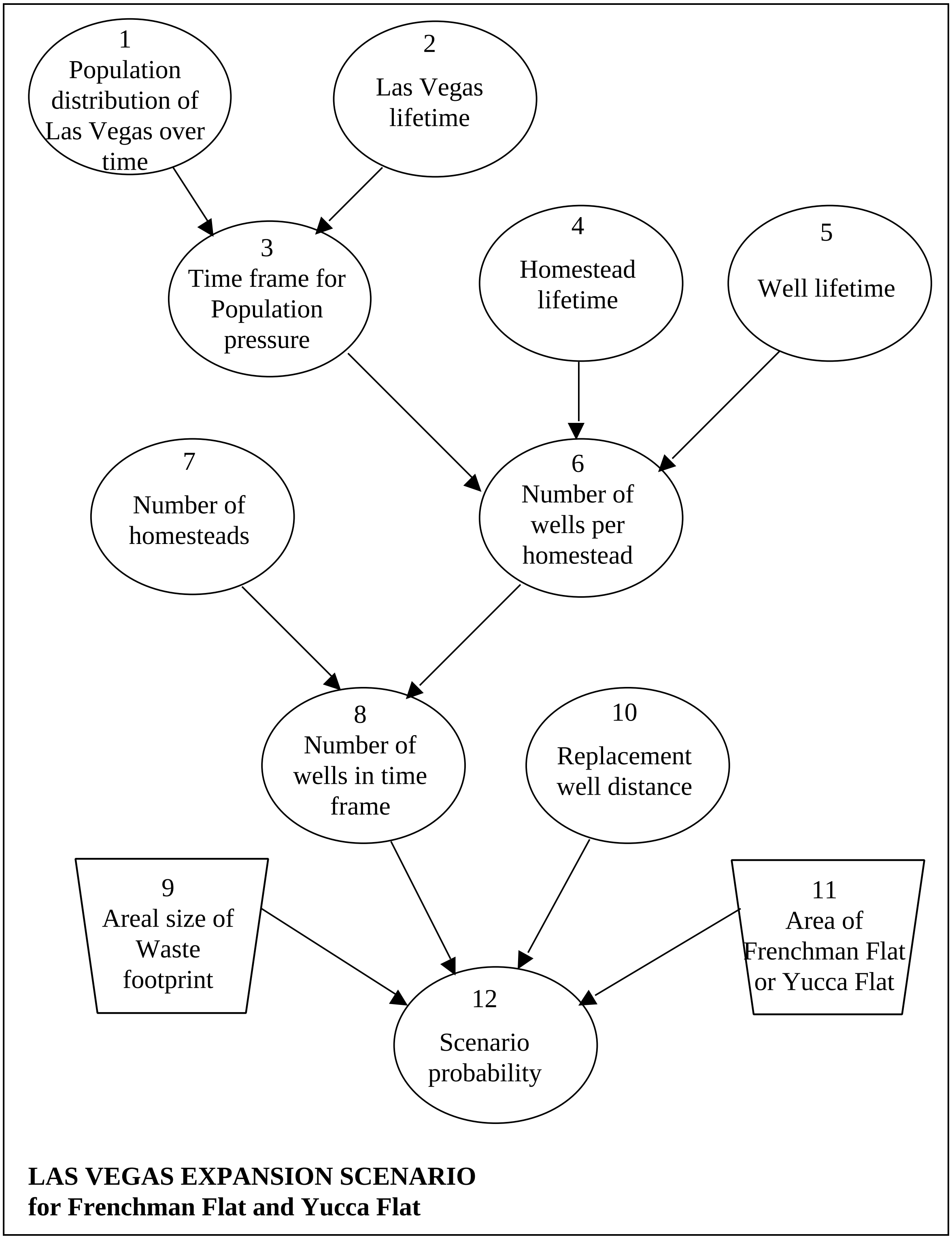

Figure 4-9 Las Vegas Expansion scenario influence diagram

It should be noted that the SMEs initially considered the current rate of population expansion of Las Vegas, which the SMEs suggested is around 10% per year. However, deciding that this rate of population expansion is unlikely to be maintained given past Las Vegas growth rates, the SMEs instead based their assessment on a rate of approximately 1% per year based on the national rate of population expansion. Using this rate of growth, the population doubles approximately every 70 years, in which case a population of three million in the general area of Las Vegas could be reached in approximately 100 years. It should be clarified that the SMEs regarded population growth rate information as current knowledge, and that it was appropriate information to use in this assessment.

4.2.3.1.2 Las Vegas lifetime (Node 2)

The city of Las Vegas is not single purpose like the smaller communities considered in the previous scenarios. However, the SMEs described Las Vegas as being based mainly on two industries: gambling and supporting the NTS. Given this information and a great deal of discussion of historical civilizations (see Appendix D), the SMEs provided a distribution for the expected lifetime of Las Vegas from the present time:

- The probability that Las Vegas will last longer than 500 years is 0.90.
- The probability that Las Vegas will last longer than 1,000 years is 0.50.
- The probability that Las Vegas will last longer than 1,500 years is 0.10.
- The probability that Las Vegas will last longer than 2,000 years is 0.01.

Further elicitation was conducted for this node in terms of the population distribution of Las Vegas over time. Based on knowledge of historical institutions, the SMEs indicated that, independent of population size, the population is likely to rise for the first third of the lifetime of Las Vegas and then to continually decline. This information was elicited to provide bounds on the number of years that population pressure from Las Vegas might be exerted on Frenchman Flat and Yucca Flat.

Given the values elicited from the SMEs, Las Vegas either lasts longer than knowledge of the waste site, or knowledge of the waste site lasts longer than the lifetime of Las Vegas. The first option is more likely according to the opinions expressed by the SMEs. Many examples were given by the SMEs of cities that thrived while knowledge of specific (and important) aspects of those cities was lost (e.g., buried structures being found under Mexico City, Middle Eastern cities that lost their records during political changes while continuing to grow, and so on). Indeed, the SMEs indicated the trend for knowledge to be lost in the locale of a large city is well documented, and has a high probability of occurring. Consequently, the SMEs felt very comfortable with the idea that Las Vegas will outlive knowledge of these low-level radioactive waste sites at the NTS.

With the estimates provided, it is also possible that knowledge of the waste burial sites may outlast the city of Las Vegas. The SMEs saw this as less likely to occur, but could imagine it under either the scenario that gambling is made illegal or that gambling is legalized in more areas of the U.S. in the comparatively near future. If either extreme event concerning gambling occurs, the SMEs indicated that the lifetime of Las Vegas as a viable population center is likely to be reduced.

4.2.3.1.3 Number of homesteads in Frenchman Flat and Yucca Flat (Node 7)

As for the Jackass Flats scenario, the impact on Frenchman Flat and Yucca Flat due to the expansion of Las Vegas is seen in terms of commuter homesteading. The SMEs indicated that the well information gathered for the Homesteader scenario is appropriate for this scenario. The SMEs provided distributions specific to this scenario for the number of homesteads that might exist in the areas of interest. These inputs were provided separately for Frenchman Flat and Yucca Flat, although their distributions were quite similar. For Frenchman Flat, the following number of homesteads is expected under the Las Vegas Expansion scenario:

- There is a 90% probability of one or more homesteads existing.
- There is a 50% probability of 30 or more homesteads existing.
- There is a 10% probability of 75 or more homesteads existing.

The expected number of homesteads in Yucca Flat under this scenario are as follows:

- There is a 90% probability of one or more homesteads existing.
- There is a 50% probability of 20 or more homesteads existing.
- There is a 10% probability of 75 or more homesteads existing.

4.2.3.1.4 Homestead lifetime (Node 4)

The SME panel decided to set the lifetimes of homesteads for this scenario equal to the length of time population pressure would be exerted on Frenchman Flat and Yucca Flat.

4.2.3.1.5 Well lifetime and replacement well distance (Nodes 5 and 10)

The SMEs again agreed on an assumption of one primary well per homestead, and that the well lifetimes and distance between replacement wells would be identical to those elicited for the Homesteader scenario (see Sections 4.1.1.3 and 4.1.1.4).

4.2.3.2 Results for the Las Vegas Expansion Scenario

The inputs for this scenario, along with the underlying model structure, provide the necessary information to calculate the probability of a homesteader who lives in the areas of interest because of pressures from the expansion of Las Vegas, inadvertently intruding into the buried waste while drilling a private water well. As for the Homesteader scenario and the Base Community scenario, the SMEs felt that the probability of IHI for this scenario would be quite small. The SMEs indicated through their assessments that, the population of Las Vegas was relatively unlikely to reach three million people. This factor was used directly in the calculations along with a related factor that described the population distribution across time if Las Vegas does reach a population of three million. The SMEs indicated that if this happened, then, on average, for only about one quarter of the lifetime of Las Vegas would the population of the city exceed three million. This factor was used to calculate the effective time period for which Las Vegas might place population pressure on Frenchman Flat and Yucca Flat. Considering the average lifetime of Las Vegas was assessed at around 1,000 years, the effective time frame of interest corresponds to approximately 250 years.

The period of time for which the population of Las Vegas exceeds more than three million people was used as the basis for evaluating IHI for this scenario. Homesteaders were assumed to last for the entirety of this time frame, implying considerable potential for the need to replace wells periodically. Given the median well lifetime of 35 years, it was not unusual for simulations to realize 6 or more replacement wells. Frenchman Flat and Yucca Flat were, again, evaluated separately. The simulation proceeded similarly to the algorithms for the other scenarios. Primary wells were evaluated for their potential to intersect the waste footprint, and if unsuccessful, then the evaluation switched to the comparatively large number of replacement wells. The simulation was performed spatially as described in Appendix E.

The scenario probabilities for Frenchman Flat and Yucca Flat under this scenario are provided in Tables 4-6 and 4-7 and are portrayed graphically in Figures 4-10 and 4-11, which portray probability density estimates overlaid on a histogram of the simulated output data (see Appendix E). The probability that a well intersects the waste footprint is very small for both Frenchman Flat and Yucca Flat, especially when compared with the results for the Jackass Flats scenario. The very small probabilities of IHI seem consistent with the SMEs' beliefs that population pressure from Las Vegas expansion is unlikely to significantly impact Frenchman Flat and Yucca Flat. The final factor included in the calculations was the probability that the population of Las Vegas will reach three million people. The small probability assigned to this factor, and the distribution for the expected lifetime of Las Vegas are the primary reasons for the small number of commuter homesteads, and hence the small probability of IHI for this scenario.

Table 4-6 Summary statistics for the propagated probability distributions of the total number of wells and the probability of inadvertent human intrusion for the Las Vegas Expansion scenario: Frenchman Flat

FRENCHMAN FLAT			
	Total Number of Wells		
Summary Statistic	**Primary**	**Replacement**	**Probability of IHI**
Minimum	0	0	0
5%	0	0	0
25%	11	62	0.000068
Median	30	180	0.00019
Average	**34**	**240**	**0.00029**
75%	54	350	0.00039
95%	85	680	0.00094
Maximum	110	1400	0.0022

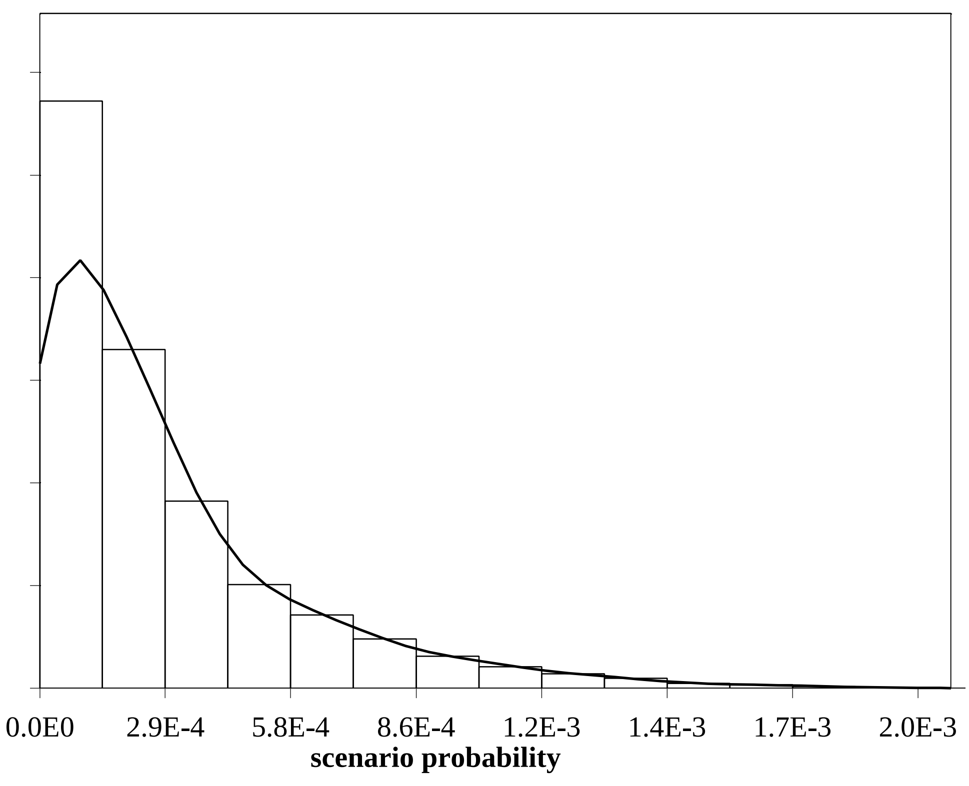

Figure 4-10 Distribution of the probability of inadvertent human intrusion for the Las Vegas Expansion scenario: Frenchman Flat

Table 4-7 Summary statistics for the propagated probability distributions of the total number of wells and the probability of inadvertent human intrusion for the Las Vegas Expansion scenario: Yucca Flat

YUCCA FLAT			
Summary Statistic	**Total Number of Wells**		**Probability of IHI**
	Primary	**Replacement**	
Minimum	0	0	0
5%	0	0	0
25%	5	32	0.0000042
Median	21	120	0.000016
Average	**29**	**200**	**0.000029**
75%	48	300	0.000039
95%	87	680	0.00011
Maximum	100	1400	0.00024

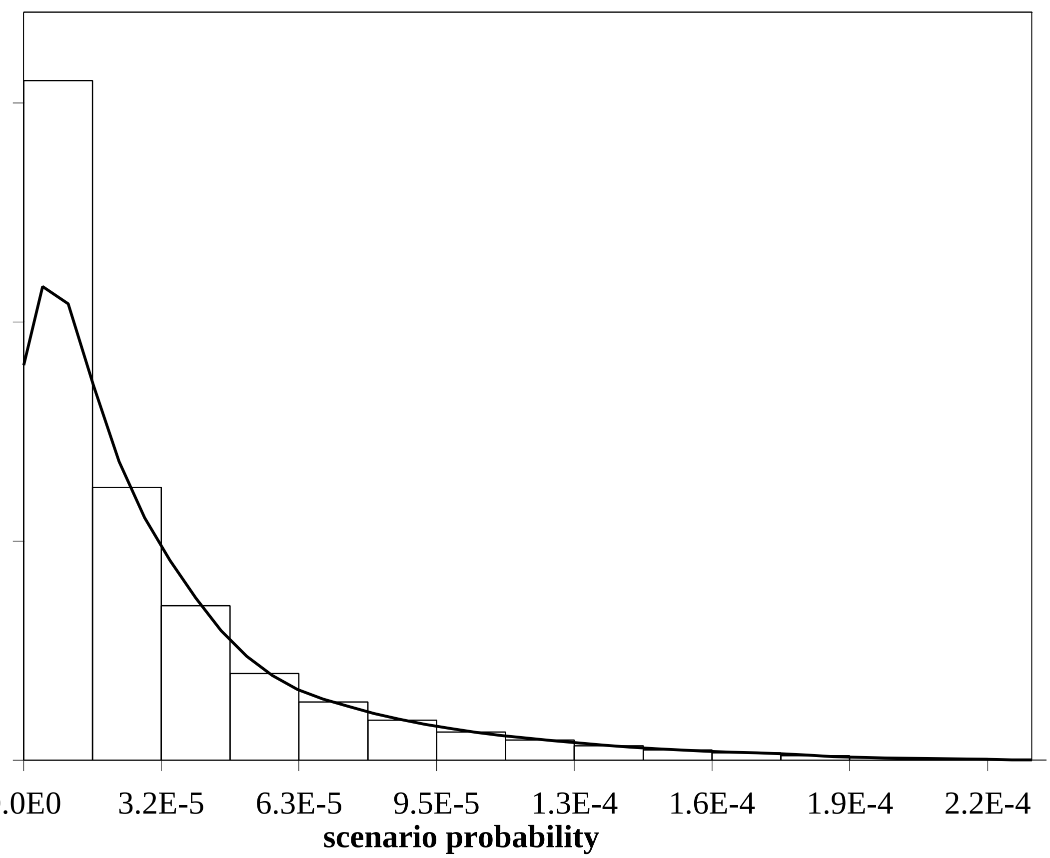

Figure 4-11 Distribution of the probability of inadvertent human intrusion for the Las Vegas Expansion scenario: Yucca Flat

4.3 Overall Probability of Inadvertent Human Intrusion

In the previous section the probability of IHI was calculated for each of the four scenarios. To obtain an overall probability of inadvertent human intrusion, these results need to be combined. Under different circumstances the method of combination should consider the potential for the scenarios to exist at the same time, or, more generally, on the effect that they might have on one another. However, in this case the probability of IHI is so much greater for the Jackass Flats scenario than the other scenarios that any reasonable method of combination will provide the same result (to a small number of significant figures). The Jackass Flats scenario, by itself, effectively provides the combined probability of inadvertent human intrusion.

Given the time frames for which the SMEs expected each scenario and institutional control or site knowledge to be in effect, it is possible that the scenarios would not overlap in time (i.e., approximately 250 years for institutional control and site knowledge, 200 years for the Homesteader scenario, 100 years for the Base Community scenario, 5,000 years for the Jackass Flats scenario, and 250 years for the Las Vegas Expansion scenario). However, it may be reasonable for some temporal overlap to occur (e.g., communities could exist in both Frenchman and Jackass Flats at the same time). Hence, it is conservative to merge the four scenarios by simple addition of their probabilities.

As noted, merging of the scenarios is dominated by the Jackass Flats scenario. Because one scenario strongly dominates the others, the actual method for merging scenarios does not greatly impact the final probability. Nevertheless, combination was performed by assuming the scenarios are separated in time (see Appendix E). The overall probability distribution, for each area was formed by adding simulated (re-sampled) realizations from each of the four scenarios. The Homesteader scenario results are included in the overall distributions of the probability of IHI for both Frenchman Flat and Yucca Flat. The average simulated overall probability of IHI is approximately 0.11 for Frenchman Flat, and 0.007 for Yucca Flat assuming all management controls are ineffective. The results are provided in Table 4-8, although the results are not very different than those presented for the Jackass Flats scenario in Section 4.2.2. Figures 4-12 and 4-13 depict the simulated data and the estimated probability density functions of the overall probability of IHI for Frenchman Flat and Yucca Flat, respectively.

Again, the results are conditional on the assumptions and conditions established in this assessment, including the two-acre waste footprint. In general, the range of values is conditional on the assumptions and constraints of the data collection process and the numerical methods used. The probability distribution is also conditional on ineffective "management controls" factors. The next section describes some of the information elicited from the SMEs regarding the management controls factors, all of which can be used to reduce the probability of IHI.

Table 4-8 Summary statistics for the propagated overall probability of inadvertent human intrusion

Summary Statistic	Frenchman Flat	Yucca Flat
Minimum	0.032	0.0013
5%	0.059	0.0037
25%	0.084	0.0052
Median	0.11	0.0068
Average	**0.11**	**0.0069**
75%	0.14	0.0084
95%	0.16	0.010
Maximum	0.21	0.014

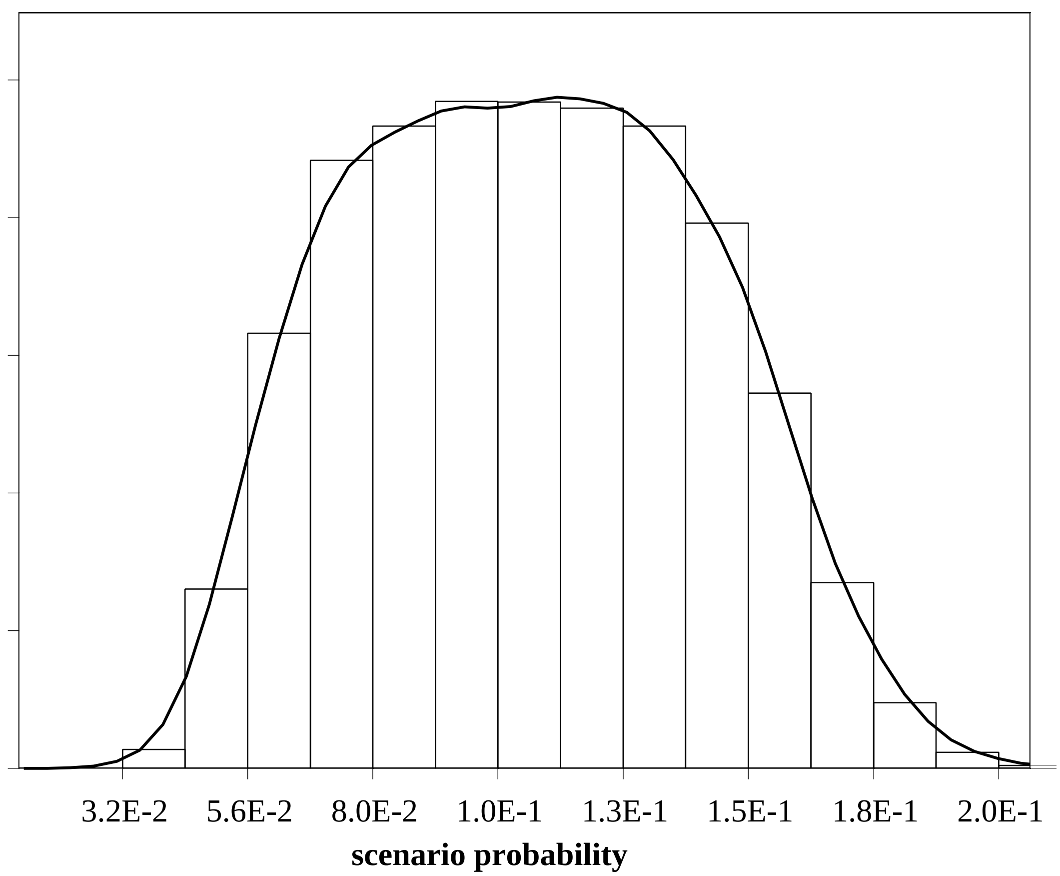

Figure 4-12 Estimated distribution of the overall probability of IHI overlaid on the simulated relative frequency distribution: Frenchman Flat

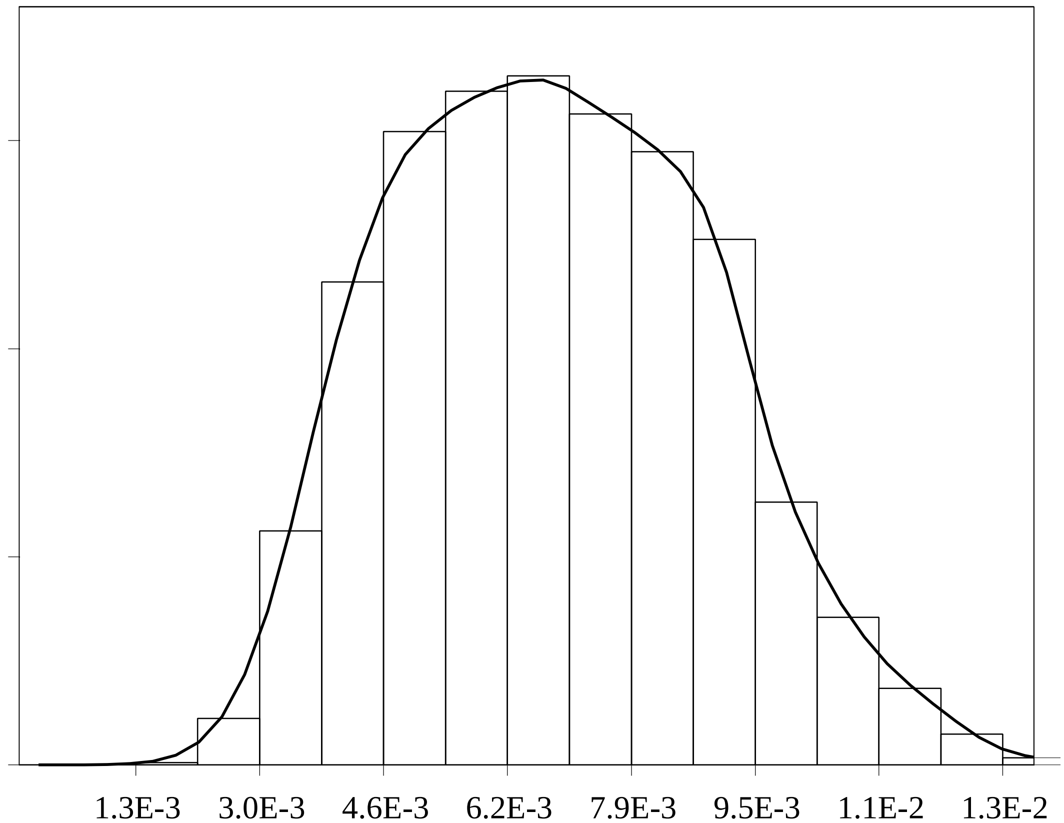

Figure 4-13 Estimated distribution of the overall probability of IHI overlaid on the simulated relative frequency distribution: Yucca Flat

4.4 Management Controls

The scenario probability results presented in the previous sections are specifically conditioned on ineffective management controls. That is, one of the basic assumptions of the assessment of the probability of IHI is that IHI cannot occur if management controls are effective. The purpose of this section is to assess the potential effectiveness of management controls options based on input provided by the SMEs. If management controls are found to be effective, then the scenario probabilities can be modified to reduce the probability of IHI. The SMEs provided input on several management controls options, and were introduced to various options that were being considered by DOE/NV. Also, their focus was only prevention of IHI by water-well drilling, whereas DOE/NV must consider other factors when planning for future maintenance of the RWMSs. In general, the SMEs felt that the management controls options were not well defined, in which case, they provided general information that might serve as a starting point if the issue of controlling well drilling becomes important. These results should, therefore, be considered preliminary and exploratory only.

4.4.1 Inputs

Five management controls were considered pertinent by the SMEs (Figure 4-14), and are termed: institutional control; site knowledge; placards and markers; surface barriers; and, subsurface barriers.

The first factor shown in Figure 4-14, institutional control, includes options ranging from maintaining current, security-controlled access to the NTS, to imposing zoning restrictions, to retaining federal or state ownership of designated lands. 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 compliance period, then the other nodes of the management controls, homestead, and community influence diagrams become important. That is, if institutional control is in effect then it is assumed that IHI cannot occur.

The second factor of the management controls module concerns knowledge of the waste disposal sites. The SMEs' definition of site knowledge refers to written or oral communication, or societal memory, of the existence of the waste disposal sites. This factor presumes that, if site knowledge is retained, IHI will not occur. The SMEs noted that persons settling in Frenchman Flat or Yucca Flat will either have, or not have, knowledge of past use of portions of the NTS as waste disposal areas. There is the possibility that some individuals may be attracted to, or knowingly intrude into waste disposal areas. These individuals, by definition, cannot be considered inadvertent human intruders, and therefore, such a possibility is not included in this probabilistic assessment.

The SMEs decided that institutional control or site knowledge lasting for 10,000 years was highly unlikely. The workshop participants and several other stakeholders reached the same conclusion. It was agreed that an appropriate way to deal with these factors was to ask questions in terms of the length of time management controls might remain effective. Modeled in this fashion, the length of time these management controls are assessed to be in effect would be used essentially as a discounting probability for calculating the probability of IHI. That is, if at least one of these management controls is in effect, IHI cannot occur.

Other management control factors that were presented to the SMEs included the following:

- Placards and markers (informational signs or symbols placed near or above the waste site to warn against intrusion into the underlying waste)

- Surface barriers (engineered structures placed over the waste or closure cap that may prevent siting of the drill rig, or the drilling operation)

- Subsurface barriers (engineered structures below ground surface, but above the waste, that are constructed to deter intrusion)

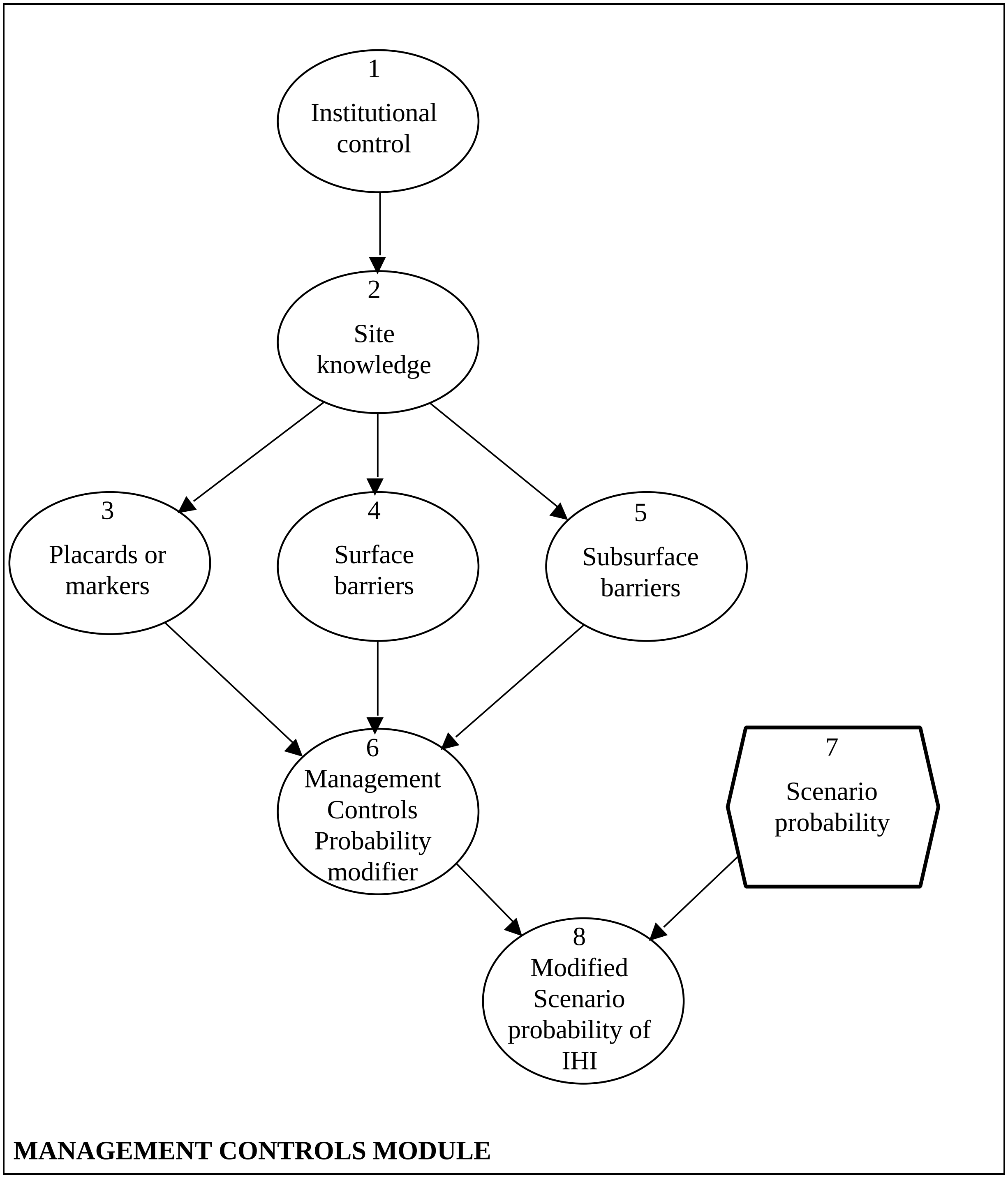

Figure 4-14 Management Controls influence diagram

The first two management controls factors are measured according to the length of time they remain in effect, whereas the remaining three factors are measured in terms of the probability that they will deter drilling for groundwater. In effect, institutional control and site knowledge are assumed to be completely effective deterrents to drilling while they are maintained, and then completely ineffective once maintenance has ceased. The remaining factors are assumed to be partially effective for the duration of the compliance period in the sense that they will deter some drilling events and not others. The degree of their effectiveness to deter drilling events is measured by the assessed probability that they deter drilling. Note that Figure 4-14 also indicates the point at which the scenario probabilities enter the model (see Figures 4-1, 4-3, 4-6, and 4-9) for final calculation of a scenario probability.

It should be noted that some of the management controls factors were not specified adequately for a thorough assessment. Specifically, these include placards and markers, surface barriers, and subsurface barriers, all of which were insufficiently defined to be able to obtain complete distributions of their probabilities of deterring IHI. However, valuable information was gathered from the SMEs for these factors. If these factors are ultimately considered important to DOE management, then further effort will be required to better evaluate their potential for deterring IHI at these waste sites. At this time, these factors have undergone a preliminary or exploratory analysis based on the SME input.

A further consideration that was raised by nearly all of the participating groups in this project concerned the possibility of advertent, or purposeful, human intrusion. The concern may best be expressed in terms of some of the proposed management controls features designed to deter IHI. For example, the SMEs suggested that the presence of placards and markers or visually apparent surface barriers might raise curiosity levels such that the possibility of purposeful intrusion may increase. The SMEs, in particular, suggested that the best course of action to deter purposeful intrusion might be to return the site to its natural surface condition so that surface features do not encourage intrusive investigation into the buried waste.

4.4.1.1 Institutional Control (Node 1)

Institutional control was defined in terms of institutional management of the waste site. The discussion centered on different forms of institutional control that might occur. For example, the SMEs opined that the federal government could be expected to pass institutional control to the state, which in turn might ultimately pass institutional control to the counties or to private industry.

The SMEs unanimously agreed that institutional control would not last for the duration of the compliance period, and focused instead on how long institutional control might last. The SMEs discussed three mechanisms through which loss of institutional control could occur. The first is erosion of control, or a gradual decline in perception of the importance of the site. The second is political instability such that control of the site might be relinquished during political upheaval or for economic reasons as political priorities change. Finally, loss of control through a catastrophic event was considered. The last option was rejected by the SMEs because they considered the chance of a catastrophic event to be extremely small. The SMEs provided input separately for the two dominant possibilities. Subsequently, the SMEs realized that their elicited distributions were essentially identical, hence, they agreed to combine them into the single distribution that is reported here.

The elicited inputs were provided in terms of the number of years until the Area 3 and Area 5 waste sites at NTS would no longer be under institutional control. Institutional control was considered any level of control (e.g., federal, state, county, private) that prohibited access to the site. The following inputs were obtained from the SMEs.

- The probability that institutional control of the waste sites will be lost within 50 years is 0.10.

- The probability that institutional control of the waste sites will be lost within 250 years is 0.50.

- The probability that institutional control of the waste sites will be lost within 1,000 years is 0.90.

The SMEs' inputs were used during the elicitation session to fit a lognormal cdf. This cdf was shown to the SMEs immediately following the elicitation of this input to demonstrate the distributional effect of their input, and to provide feedback on the consequences of their input at other quantiles. When the cdf was presented, the SMEs concurred that it reasonably matched their opinions. Further details of the elicitation and the fitted distributions are provided in Appendices D and E (Black et al, 2001).

4.4.1.2 Site Knowledge (Node 2)

Site knowledge was defined by the SMEs as sufficient knowledge (that the buried wastes are in some way dangerous) to deter IHI. Again, the elicited inputs were given in terms of years. Unlike the responses for institutional control, for which the count of years begins from the present, the SMEs indicated that site knowledge is assumed throughout the period of institutional control and that this factor measures the additional period of effective site knowledge. The starting point for this site knowledge factor is, hence, the year that institutional control is lost. The appropriate questions, given the influence diagram developed by the SMEs, were phrased in terms of the number of years site knowledge is expected to be maintained after the loss of institutional control. The SMEs again dismissed the potential for catastrophes to cause loss of site knowledge as extremely unlikely. The main focus of the SMEs was on an erosion of knowledge over time.

Similar to institutional control, the SMEs based their responses to the questions about the site knowledge factor on their expertise pertaining to historical civilizations and the ability of the human race to maintain knowledge about events, structures and buildings that were considered important in their historical time. For example, knowledge of the pyramids has persisted, presumably based on their obvious physical presence, while much of the specific knowledge about Incan civilizations has been lost. The SMEs also believed that far more knowledge has probably been lost of historical events and structures that were once considered important, than has been regained in modern times. Site knowledge was defined in terms of available written or oral history of the waste site that is sufficient to deter drilling for groundwater. Discussion centered, much as it had for institutional control, on populations whose ancestors had knowledge or control of various sites about which the current population has little or no specific information. The SMEs provided the following input:

- The probability that site knowledge will be lost within 50 years after the loss of institutional control is 0.25.

- The probability that site knowledge will be lost within 100 years after the loss of institutional control is 0.50.

- The probability that site knowledge will be lost within 140 years after the loss of institutional control is 0.75.

- The probability that site knowledge will be lost within 500 years after the loss of institutional control is about 0.95.

Similar to the elicitation process for the institutional control factor, the SMEs' inputs for this variable were used during the elicitation session to fit a lognormal cdf. This cdf was shown to the SMEs immediately following the elicitation of their input on this factor. The SMEs again concurred that the fitted lognormal cdf reasonably matched their opinions.

4.4.1.3 Placards and Markers (Node 3)

Discussion of this factor began with consideration of the permanence of language and symbology. The SMEs agreed that knowledge of language deteriorates over time, and that symbology has a much better chance of being understandable during the next 10,000 years. They felt that a set of symbols linked to the most permanent aspects of the surface of the site could be constructed such that they would almost certainly physically endure for the entire length of the compliance period. For example, such signs could be directly etched onto very large granite boulders, or etched on metal plaques that are permanently attached to large objects such as boulders or monoliths. Although the physical marker might endure for the 10,000-year period, the SMEs did not believe that the attached symbol or language was likely to maintain its interpretability for the duration.

An effective placard or marker was defined in terms of successfully deterring drilling at the site by an individual with no prior knowledge of the waste disposal system. That is, the marker would be designed to provide a potential water well driller with the understanding that there is something at the site that may be dangerous. The SMEs perceived this factor as follows. When a potential well driller comes to the site, either the placard or marker is still viable or it is not. If it is still viable, then , either the well driller correctly interprets the message, or the message is not understood. The placard or marker has been successful if the message is interpreted correctly and the potential well driller is deterred from drilling a well. If the potential well driller is not deterred, the placard or marker has failed, and a well is drilled. If the driller correctly interprets the message, but chooses to ignore that knowledge, then intrusion is assumed to be advertent and not within the scope of this project.

The SMEs decided to evaluate the potential effectiveness of placards or markers directly, implicitly accounting for the nuances described above. Their sets of input are for specific designs that were discussed, including some that they designed themselves. The following summary provides brief descriptions of the designs they considered, and the probability they attributed to each for deterring IHI; further discussion is contained in Appendix D and Appendix E.

The SMEs were shown one potential diagram, or sign, for consideration. This sign was prepared for DOE in 1984 (Human Interference Task Force 1984). Further details are provided in Appendix D. The SME panel found this design unnecessarily complex, and believed it may actually encourage interest in the site rather than convey dread or warning. The following SME input was obtained for this “complex” sign:

- The SMEs felt that the probability that this sign would be effective now was approximately 0.05 to 0.10.

- In 500 years, the SMEs agreed that the probability of this sign being effective will have declined to 0.

The SMEs then designed what they believed to be a more effective sign (see Appendix D). This belief was based on the premise that the meanings of simpler messages have a greater chance of enduring. The SMEs felt very strongly that messages can be interpreted in many different ways, and a simple message will be misinterpreted less frequently than a complex one. Based on this premise, the SMEs concluded that life and death is one of the most universal concepts, and the upright and prone bodies representing that concept are widely understood. However, the SMEs indicated that the sign must be understood by any potential inadvertent human intruder for it to be effective. The SMEs further recognized that, although anthropologists or other experts may be able to interpret a sign far into the future, potential water-well drillers, homesteaders or commuter homesteaders might not.

Two views were held by the two pertinent SMEs regarding the ability of their "simple" sign to convey the desired message over time. One of the SMEs felt that even a simple message is unlikely to retain its meaning over the course of time, whereas the other SME felt that the meaning of a simple life and death message should be equally effective throughout the compliance period. The following results are given separately for these two opinions:

Opinion 1:

- The probability that the simple design would be effective now is about 0.75 (ranging between 0.55 and 0.85).
- One thousand years from now, the probability of effectiveness will be about 0.35 – 0.40.
- At the end of the evaluation period (in 10,000 years), the probability of effectiveness will be about 0.125 (ranging between 0.07 and 0.25).

Opinion 2:

- The probability of effectiveness of the simple design will remain constant over the compliance period at a most likely probability of 0.20, although, given the uncertain nature of the problem, this probability could be as high as 0.50 (given as a 90% chance that the actual effectiveness is less than 0.50).

4.4.1.4 Surface Barriers (Node 4)

Effectiveness of surface barriers was defined by the SMEs in terms of deterring a driller from siting a well on top of a surface barrier placed over the waste site. Discussion of surface barriers was relatively brief because there was near-immediate agreement among the SMEs on what was necessary to form an effective barrier against IHI.

The SMEs were presented with a description of plans for a closure cap currently under consideration for the U-3ax/bl disposal pit at the Area 3 RWMS. There was wide agreement that this barrier would be essentially ineffective as a deterrent for well drilling. The SMEs felt that the proposed 5:1 horizontal slope was not sufficient to deter driving a drill rig onto the site. The SMEs indicated that the initial slope would have to be at least 2:1 in order to keep drill rigs from mounting the proposed barrier, and that at least a 10-ft-high mound of very large boulders would be necessary for deterring drilling.

The SMEs also considered a DOE/NV estimate that there is potential for up to 20 ft of subsidence over the waste area. The SMEs suggested that placing an outer ring of boulders around the impacted area would alleviate any concern that subsidence would negate the effectiveness of the barrier. Three slightly different barriers were discussed by the SME panel, all of which are presented in greater detail, and graphically depicted, in Appendix D. The focus of these designs was to prevent a well driller from being able to site a drill rig over a two-acre waste footprint. The expected probabilities of deterring drilling are given for each barrier, following a short description of the barrier design.

Barrier Option 1:

- Set approximately 10-ton (very large) boulders in a ring around the footprint of the buried waste. Build a mound of similar boulders that has a 2:1 slope up to approximately 10 ft in height, then continue to form a mound of boulders to a maximum height of approximately 35 ft. After subsidence, the center of the mound would still be at least 10 ft high. The SMEs felt that the slope, height, and size of the boulders would make it very difficult to place a drill rig on the site.

- The probability of this barrier deterring drilling at the waste site was assessed at about 0.9 – 0.95.

Barrier Option 2:

- Set approximately 10-ton boulders in a ring around the footprint of the buried waste, but with no further construction of a mound over the waste footprint. The SMEs felt that this ring of boulders would inhibit drill rigs from entering the waste area, but that having no boulders through the center would lessen the likelihood that this barrier would be effective.

- The probability of this barrier deterring drilling at the waste site was assessed at 0.50.

Barrier Option 3:

- Set approximately 10-ton boulders over the footprint of the buried waste such that it would be difficult to maneuver a drill rig between the boulders. The SMEs recognized that boulders, no matter how large, could be moved if necessary, and removing just a few boulders from this design would allow drilling to occur.

- The probability of this barrier deterring drilling at the waste site was assessed at 0.10.

4.4.1.5 Subsurface Barriers (Node 5)

Discussion of subsurface barriers was also opened with a description of the U-3ax/bl barrier, this time focusing on the subsurface portion. The SME panel again agreed that this proposed barrier would have no impact on the probability of water well drilling at the waste site.

The SMEs suggested that placing an angled shield that would deflect a drill bit over the waste area would be almost certain to ensure that no wells are drilled into the waste area. The cost of such a shield (made of some strong metal, such as titanium, that would deflect a drill bit) was considered prohibitive unless the waste footprint was relatively small (e.g., as for a greater confinement disposal borehole, which is approximately 12 ft in diameter). Due to the impossibility of developing a shield with sufficient slope and strength over an area as large as the proposed two-acre waste footprint, the SME panel felt that it would not be viable to construct any subsurface barrier that would strongly deter drilling over the large area of the waste.

As an alternative to physically deterring a drill bit, subsurface markers were considered. The SMEs entertained the idea of burying a layer of red sand, for example, over the footprint of the waste. Although they felt that this was an interesting idea, the SMEs did not believe that many water well drillers would be deterred by encountering red sand.

Following discussion with the SMEs and input from DOE/NV on potentially affordable options, opinions were elicited on three different types of subsurface barriers. The expected probabilities of deterring drilling are given for each barrier, following a short description of the barrier design. Further details are provided in Appendix D.

Barrier Option 1:

- Place a 30-ft layer of used rubber tires over the buried waste, sufficiently underground so as not to be discernible from the surface.
- The probability of this barrier being effective was assessed at 0.05 to 0.10.

Barrier Option 2:

- Place a 30-ft layer of galvanized bailing wire over the buried waste, sufficiently underground so as not to be discernible from the surface.
- The probability of this barrier being effective was assessed at 0.10.

Barrier Option 3:

- Place a 5-ft layer of reinforced concrete over the buried waste, sufficiently underground so as not to be discernible from the surface. The concrete was specified to be reinforced with 1-in. rebar set at 6-in. intervals throughout (so that a drill bit could not fit between the rebar).
- The probability of this barrier being effective was assessed at 0.50.

4.4.2 Application to the Probability of Inadvertent Human Intrusion

Management controls are considered effective deterrents to water well drilling so long as any one of the above factors is effectively deters a potential drilling event. Therefore, IHI is assumed to occur only if all these management controls factors are ineffective. With the input received from the SMEs, an overall probability (or percentage of time) for which management controls are all expected to be ineffective can be calculated. This result can then be used as a modifying factor for the probabilities of IHI calculated for the intrusion scenarios.

In general, the SMEs felt that current physical management controls suggested by DOE are likely to be largely ineffective at deterring well drilling at the waste sites. As described above, however, they described some surface barriers in particular that they felt could effectively deter drilling for the duration of the compliance period. The options that the SMEs considered potentially most effective are used in this report. Appendix E provides further analyses that indicate the potential effect on the overall probability of IHI for different management controls modifying probabilities.

The elicited inputs for institutional control and site knowledge were given in terms of the number of years they will be completely effective. The inputs for the other management controls factors (surface barriers, placards and markers, and subsurface barriers) were elicited in terms of the probability that they will be effective in deterring IHI throughout the 10,000-year evaluation period. Because institutional control and site knowledge were not expected to be long-lasting deterrents to IHI, the efficacy of the remaining factors becomes important to the modified probability of IHI. The efficacy of management controls depends substantially on the design choices for these three factors. Table E-22 in Appendix E presents 36 possible combinations of these factors based on the SME input. These 36 possible combinations cover a wide range of measures of effectiveness for the three factors, and provide a wide range of possible valuations of the overall effectiveness of management controls.

The overall effectiveness of management controls factors can be driven by any single effective factor. In this case, the SMEs indicated that surface barriers could be constructed to serve this purpose, which makes the other factors less important contributors. If the favored option for surface barriers is not implemented, then the efficacy of the other factors becomes more important. Appendix E provides an analysis indicating how the overall management controls efficacy is affected by changes in the input values.

The results section for each of the intrusion scenarios addresses the scenario probabilities (based on the assumption that all management controls are ineffective) as well as the final scenario probabilities modified by the calculated efficacy of management controls. The management controls modifying probability described in this section makes an assumption about the selection of management controls as described by the SMEs. That is, the management controls factors that are presented as an example reflect the SMEs' most favored design for surface barriers, input considered most likely by one of the SMEs for placards and markers, and input consistent with the SMEs' inputs for two of the three subsurface barrier designs they discussed. In particular, the following probabilities are assumed for this example to demonstrate how such information can be used in an assessment of IHI modified by management controls efficacy:

- Pr(Surface barrier effectively deters drilling) = 0.9
- Pr(Placards and Markers effectively deter drilling) = 0.2
- Pr(Subsurface barriers effectively deter continued drilling) = 0.1

The average probability for management controls effectiveness, using these inputs, is 0.93 (see Appendix E). Or, the probability that all management controls will be ineffective is 0.07. Note that a distribution of the probability for the management controls modifier is generated because of the distributional input provided for the institutional control and site knowledge factors. Although, the probability that these two factors are effective is very small given the 10,000-year evaluation period, in which case the range of possible values is small. For this example the range for the probability of ineffective management controls is only 0.060 – 0.071. These are the 0.05 and 0.95 percentiles of the distribution (see Appendix E).

The scenario probabilities can be modified by any overall management controls probability that corresponds to specific designs or intentions for maintaining control of the waste sites. This modification removes the condition that management controls are ineffective, which was an explicit component of the scenario probabilities presented in Sections 4.1, 4.2 and 4.3. The probability of IHI that includes management controls, should not be used without reference to the selected designs for various factors, such as surface barriers, placards and markers, and subsurface barriers.

Using the 0.07 probability under the design conditions of the example above, the overall probability of IHI with management controls is calculated by simple multiplication of the scenario probability and the management controls probability (see Appendix E). Table 4-9 shows the results for this overall probability of IHI (recall that the overall scenario probability of IHI is based largely on the results for the Jackass Flats scenario).

Table 4-9 Summary statistics for the propagated probability distributions of the probability of inadvertent human intrusion for Frenchman Flat and Yucca Flat modified by a management controls factor of 0.07

FRENCHMAN FLAT		
Summary Statistic	**Scenario Probability of IHI**	**Probability of IHI Modified by a Management Controls Factor of 0.07**
Minimum	0.032	0.0022
5%	0.059	0.0041
25%	0.084	0.0059
Median	0.11	0.0077
Average	**0.11**	0.0077
75%	0.14	0.0095
95%	0.16	0.011
Maximum	0.21	0.015
YUCCA FLAT		
Summary Statistic	**Scenario Probability of IHI**	**Probability of IHI Modified by a Management Controls Factor of 0.07**
Minimum	0.0013	0.000092
5%	0.0037	0.00026
25%	0.0052	0.00037
Median	0.0068	0.00047
Average	**0.0069**	0.00048
75%	0.0084	0.00059
95%	0.010	0.00073
Maximum	0.014	0.00095

5.0 SUMMARY AND CONCLUSIONS

The objective of this project was to generate an assessment of the probability of IHI into radioactive waste buried at the NTS Area 3 and 5 RWMSs. This objective was achieved by convening a panel of subject matter experts and obtaining relevant information from them using formal elicitation procedures. The SMEs formed a diverse group that contained the breadth and depth of knowledge to be able to grasp the essence of the problem that was posed. The SME panel represented social science disciplines such as anthropology and sociology, as well as more technical disciplines such as hydrogeology and geotechnical engineering. It was through this diversity that the models could be developed fully, and meaningful inputs could be provided to those models. The success of the project can be credited to the SMEs' willingness to participate fully, openly and enthusiastically; to engage in conversation and debate; and to apply their specific expertise to the challenge of understanding, modeling, and assessing the potential for IHI into buried waste.

This approach to assessing the probability of IHI was validated by several interested stakeholder groups prior to convening the SME panel. The elicitation process was successful in providing all the information necessary to be able to complete the assessment task. Inputs provided by the SMEs were presented back to the SMEs for certification to ensure that their inputs had been captured properly and were being represented fairly. The request for certification was accompanied by an evaluation questionnaire that provided feedback on the whole elicitation process. In their responses, the SMEs indicated a high degree of satisfaction with the process, their inputs, and the conclusions inferred from their inputs. While complete freedom was provided to the SMEs to redirect the approach to assessing the probability of IHI, the SMEs suggested that more time may have been helpful so that they could contemplate the approach further. However, none of the SMEs suggested that more time would necessarily change their personal endpoints.

It should be recognized that the information obtained from the SMEs represented their individual opinions at that time. The SMEs were not asked to represent any opinion but their own. Use of current knowledge of technology and society was a basic premise of the entire approach to elicitation. Speculation on the future was not allowed. However, it was permissible to use current knowledge of trends, such as population trends, provided the SMEs did not consider anything other than available information.

The idea of conditioning on current knowledge evolved from the need to be able to approach the problem without speculating on the future. Initial interactions among the project team led to observations that "the future is unknowable" and cannot be quantified in any justifiable manner. Given that the problem could not be quantified by assessing futuristic scenarios, the project team developed an approach that considered current knowledge that was then projected out for 10,000 years. The idea was that, although the future is unknowable, what is known in the present can and should form the basis of the analysis. To compensate for future changes in technology or society, it was further suggested that this assessment process should be reviewed periodically or when technological or societal conditions are clearly seen to change. In terms of assessing the probability of IHI this presents no real philosophical problem. The solution is simply conditioned on the current knowledge base of the SMEs. However, the decision problem changes if the current decision is to accept a waste stream. That is, the decision problem changes from one of deciding whether to bury the waste, to one of deciding whether to exhume or treat the waste. The PRG, DOE/NV management, and the participants at the stakeholder workshop enthusiastically approved of the approach. However, each of these groups strongly indicated a need to ensure that adequate funds are set aside both for future re-assessments and for exhuming the waste should that become a future decision. The consensus among these groups was not only that this whole approach, including periodic review and basing assessment on current knowledge, was the only one that was likely to meet with success, but also that it may have an additional potentially desirable effect of increasing the chance that institutional control of the site will be maintained.

Institutional control was one of several management controls factors that were considered during the elicitation and subsequent analysis. The SMEs had little difficulty dealing with institutional control and maintenance of site knowledge, indicating that both factors are likely to be effective for a relatively short time compared with the 10,000 year evaluation period. By comparison, the SMEs struggled with the other management controls factors, i.e., efficacy of surface barriers, placards and markers, and subsurface barriers. The SMEs as a group observed that the current design considerations for these three factors needed much more thought in planning and construction design beyond the initial ideas presented. In order to evaluate the various options that were considered during the elicitation session, including options presented by DOE/NV and options described by the SMEs, a decision, or cost-benefit, analysis is needed. Such an analysis would require that the design options be better defined. Their efficacy for deterring IHI and meeting other design requirements (e.g., prevention of infiltration of water, control of biotic uptake and mitigation of radon flux) should be evaluated and their costs should be included so comparative cost benefits can be measured. The SMEs indicated that the possibility of advertent, or purposeful, intrusion could also be considered in such an analysis.

The management controls evaluation provides input that might serve as a useful starting point for future considerations on design options; however, it also serves the purpose of modifying the probability of IHI calculated based on SME assessments. The SMEs developed several possible scenarios by which IHI might occur: the Homesteader scenario, the Base Community scenario, the Jackass Flats scenario and the Las Vegas Expansion scenario. Initial modeling and assessment for these scenarios were conditioned on completely ineffective management controls. That is, they allow no credit to be taken for management controls options that might prevent IHI from occurring. The management controls were evaluated for their effectiveness and then used to modify the scenario probabilities to arrive at an estimate of the overall probability of IHI for each scenario, based on a particular set of management controls.

The probability values calculated based on the SME input and the modeling process described in Appendix E suggest that the probability of IHI is very small. The one possible exception concerns the results for Frenchman Flat under the Jackass Flats scenario. The resultant scenario probability is approximately 11%. Several important observations can be made on the scenario results:

- The Jackass Flats scenario resulted in the highest probabilities, primarily because of the proportion of time that the SMEs assessed communities might exist.

- The results for the Yucca Flat community scenarios are always an order of magnitude or more lower than those for Frenchman Flat.

- A change in the size of the waste footprint can have a pronounced effect on the probability of IHI.

Considering the first point, the probabilities were so much higher for the Jackass Flats scenario that if the probabilities for all scenarios are summed, the result does not change in the second significant digit. Consequently, the reported overall probabilities of IHI conditioned on lack of management controls are the same probabilities as for the Jackass Flats scenario: 11% for Frenchman Flat and 0.65% for Yucca Flat. That the results for Yucca Flat are so much lower than those for Frenchman Flat should have some bearing on DOE/NV waste management decisions.

Several members of the PA Team expressed concern at the beginning of the project that acceptance of waste by NTS is a final solution and not an interim solution, so that future generations would not be burdened with having to remake waste disposal decisions. Although the SMEs and public stakeholders agreed that periodic review is necessary, the PA Teams' concerns are partially mitigated by the low probabilities calculated for IHI, which suggest that a change in the decision at some point in the future is not likely without substantial changes in technology or society.

The results of this project indicate very clearly that there is only a small chance of IHI into deeply buried waste at the Area 3 and Area 5 RWMSs. However, the probability of IHI increases as more waste is buried, effectively increasing the size of the waste footprint. For example, if the waste footprint size used in the analyses (two acres) is increased by an order of magnitude (to 20 acres) then IHI at Frenchman Flat becomes likely (probability of approximately 70% assuming ineffective management controls as described in Appendix F). DOE/NV can decrease the probability by constructing effective management controls that further prevent the possibility of IHI. If the size of the waste footprint is to increase, then it is more important to evaluate the management controls options in a formal decision analysis. Such an analysis of management controls options would allow DOE/NV to evaluate the comparative cost effectiveness of the available options, and select the most appropriate management controls strategy.

Since this study was completed, its results have been reported at the 1997 DOE Waste Management Conference (Black et al. 1997), and have been used to support the Area 3 and Area 5 PA processes at the NTS (Shott et al. 1998, Barker et al. 1998, Shott et al. 1999). Although the SMEs were told that the impetus for this study was the Fernald waste stream (see Chapter 1), it is not currently being considered for disposal at the NTS. The SMEs provided their input based on the knowledge that the results of this study would be applied to intermediate or greater depth waste disposal. Their input is conditioned on this assumption; however, it could reasonably be argued that the results are not dependent on any specific waste stream.

The results generated by this assessment apply directly to waste that is buried at depths that preclude the intruder-construction and intruder-discovery scenarios. These results are, however, applicable to shallow buried waste, but not without consideration of these other intrusion scenarios. The Area 3 and Area 5 PAs have used these results for shallow buried waste to evaluate the expected dose consequences, but have also included an evaluation of other intrusion scenarios.

The results have also been used as supporting information for a PA performed under 40 CFR 191 (EPA 1985) for the Greater Confinement Disposal boreholes that are located at the Area 5 RWMS (Sandia 2000). In each application, the areal size of the waste footprint is different, resulting in application of different values for the probability of IHI. The results of this study might be thought of in terms of providing an assessment of the number of water wells that might be drilled in Frenchman Flat and Yucca Flat over the course of the next 10,000 years. The number of wells drives the probability of IHI through the well-drilling intrusion scenario, and calculations can be used to support assessment of the probability of IHI for waste footprints of various sizes.

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APPENDIX A: QUALITY ASSURANCE

CONTENTS

A.1 INTRODUCTION

Quality assurance (QA) activities were considered an integral and vital part of this project. Although expert elicitation has been used since the 1960s (e.g., Raiffa, 1968), the process has not been applied previously to any components of a low-level waste Performance Assessment (PA) under DOE Order 5820.2A (DOE 1988). Because of this innovative approach to evaluating inadvertent human intrusion (IHI), QA activities were seen as fundamentally important for the ultimate success and acceptability of this project. Overarching reasons to address quality issues in this project were to ensure credibility with all stakeholder audiences and to be able to provide project defensibility should the assessment process be challenged. The following measures were taken to meet the quality assurance needs:

- Review of several internal iterations of the influence diagrams as they were developed by both technical peers and stakeholders
- Involvement of stakeholders such as the State of Nevada, the University of Nevada - Las Vegas, the Community Advisory Board, the Community Radiation Monitoring Program/Community Technical Liaison Program, Citizen Alert, the Nevada Nuclear Waste Task Force, and Department of Energy, Nevada Operations Office (DOE/NV) Waste Management Division
- Development of criteria to select subject matter experts (SMEs) and evaluation of potential SMEs against those criteria
- Training workshops for the SMEs in probability and elicitation techniques that would be used to elicit their input
- Preparation of evaluation forms for participants in the stakeholder workshop and the elicitation sessions
- SME review and formal acceptance that the inputs they provided during the elicitation sessions had been captured appropriately
- SME review of the draft final report with its findings based on their inputs
- Independent peer reviews of project findings by several groups
- Thorough documentation of all inputs and activities related to the IHI project

The following sections start with a discussion of the roles and responsibilities of key personnel and groups that supported this project. Their roles in QA activities are explained in the succeeding sections. More thorough descriptions of QA activities are often available in the main text, supporting appendices, or attachments to the appendices. References are provided to other sections of this report as appropriate.

A.2 ROLES AND RESPONSIBILITIES

This project involved many steps that required substantial support from a variety of participants. Project steps included planning and preparation, the stakeholder workshop, the elicitation sessions, and final calculations. Several distinct groups supported various aspects of this project:

- The project team from Neptune and Company, Inc.
- The PA teams from DOE/NV, Bechtel Nevada, and Sandia National Laboratories
- The peer review group that was assembled to provide peer review for each technical stage of the project, including review of preliminary models and the basic approach to elicitation, elicitation sessions, and the draft final report.
- A support group that provided significant logistical support for the elicitation sessions
- The workshop participants
- The SMEs
- External reviewers who performed review of various drafts of the main report and supporting appendices, and including representatives from the Nevada Risk Assessment/Management Program, the Argonne National Laboratory, and the Yucca Mountain Project.

The DOE/NV project manager for PAs at the low-level Radioactive Waste Management Sites (RWMSs) in Frenchman and Yucca Flats is Beth Moore. The project manager for Neptune and Company's efforts on this project is Paul Black. For further information regarding this project, they can be reached at the following addresses:

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A.2.1 Project Team

The project team from Neptune and Company, Inc. included Paul Black, Kelly Black, Lisa Mathai Stahl, Mark Hooten, Tom Stockton and Dean Neptune. Paul Black served as project leader for Neptune and Company and played vital roles in aspects of the preparation, development of preliminary influence diagrams, elicitation sessions and calculation of final results. Dean Neptune served as the QA lead for the project, and played a significant role in preparation, the stakeholder workshop, identification of SMEs, and the elicitation sessions. Kelly Black performed internal review of most aspects of the project, was engaged in the elicitation sessions, and in the calculation and reporting of the final results. Lisa Mathai Stahl's roles in the project included active involvement in the stakeholder workshop, identification of the SMEs, and the elicitation sessions. Mark Hooten participated in the development of preliminary influence diagrams and the elicitation sessions, and was responsible for preparing the computer code from which the results were extracted. Tom Stockton participated in development of the algorithms used to calculate the output distributions. Biographical sketches of each member of the project team are included below:

Paul Black

Ph.D. Statistics, Carnegie Mellon University

M.S. Statistics, Carnegie Mellon University

B.Sc. Statistics with Numerical Analysis, the University of Lancaster (U.K.)

Paul Black is a founding member of Neptune and Company, Inc., a company that specializes in decision support services for environmental programs. He has more than 15 years experience applying decision analysis techniques to a wide range of applications in support of government institutions including the Department of Defense, Department of Energy, and the Environmental Protection Agency. Prior to joining Neptune and Company in 1992, he worked for Decision Science Consortium, a company dedicated to basic research in probability theory, decision analysis, elicitation methods, and uncertainty analysis, and for ICF Kaiser, an environmental engineering company. Since his arrival at Neptune and Company, he has continued his research in these technical areas while applying his expertise to environmental problems. Paul has publications related to his research in several professional journals, and his applied work has been published in many government reports. Paul managed this inadvertent human intruder study, provided technical support to the statistical, probabilistic and elicitation aspects of the study, and was responsible for several sections and appendices of this report.

Kelly Black

M.S. Statistics, Carnegie Mellon University

B.S. Statistics (minor in economics), with Honors, Montana State University

Kelly Black has worked for Neptune and Company, Inc., for the past four years in the roles of statistician, public involvement specialist, and project manager. She has 10 years experience applying her statistics and sociology expertise to environmental problems for various government facilities. She has initiated a public involvement program and served as statistics team leader for the Los Alamos National Laboratory's Environmental Restoration Project, and has managed an effort to conduct visitor studies at the Bradbury Science Museum. Prior to joining Neptune and Company, she worked for The Smithsonian Institution, at which she was responsible for Institutional Studies, and for Research Development Corporation, at which she worked on projects aimed at teaching decision analysis to high school students. She has given several professional presentations relating to these various projects, and is currently team leader for the strategic interactions group for the Los Alamos National Laboratory's Environmental Restoration Project. Her roles in this study included performing internal review of project-related documents (as a QA activity), participating in the elicitation sessions, and supporting development of statistical and probabilistic models used to calculate the final results. Kelly was responsible for several sections and appendices of this report.

Lisa Mathai Stahl

M.A. Applied Anthropology, University of South Florida

B.A. Anthropology, American University

Lisa Mathai Stahl is an applied anthropologist who provides support relating to the social science perspective for Neptune and Company, Inc., projects. These projects have ranged from providing recommendations for public participation within the Los Alamos National Laboratory's Environmental Restoration Project to assisting Bradbury Museum staff in the mechanics of designing and conducting exhibit surveys. She has 7 years of experience applying qualitative research methods to a variety of evaluation projects. Prior to joining Neptune and Company in 1994, she worked on various research projects designed to evaluate health care services, and was involved in evaluating exhibits and participating in visitor studies at The Smithsonian Institution. She has given several professional presentations relating to these various projects, as well as participating in several round table discussions relating to the practice of anthropology in various environments. Lisa was responsible for identifying the need and opportunities for public participation aspects of this study. She also played an important part in the identification of the SMEs, participated in the elicitation sessions, and contributed to sections and appendices of this report.

Mark Hooten

Ph.D. Biological Sciences, Montana State University

M.S. Entomology, Montana State University

B.S. Environmental Planning and Management, University of California, Davis

Mark Hooten is a quantitative biologist with considerable experience in computer programming of probabilistic and statistical models for environmental problems. His expertise in Monte Carlo simulation and graphical analysis has been applied to projects for Neptune and Company, Inc., for the last two years. Mark's background in quantitative biology also gives him a broad environmental background that encompasses ecological risk assessment and biological processes that are important indicators of ecological or environmental concerns. His primary role in this project was to translate the SME input into useable computer models, and to develop computer programs that allowed the SME input to be propagated through the influence diagram models to generate simulated distributions of the probability of inadvertent human intrusion. He also was actively engaged in the development of preliminary influence diagrams, the elicitation sessions, and various sections and appendices of this report.

Tom Stockton

Ph.D. Environmental Decision Analysis, Duke University

M.EM. Water Resources, Duke University

Tom Stockton has fifteen years of experience in environmental statistics, modeling and decision analysis. As an environmental statistician and decision analyst with Neptune and Company, he is currently performing data analysis and transport modeling for Federal Facilities in support of environmental decision-making. Tom has worked as a water resources engineer and watershed modeler with the States of Maryland and North Carolina. Tom has conducted research in a variety of environmental modeling applications ranging from spatial and temporal modeling of regional associations between atmospheric deposition and surface water quality using Bayesian Networks and non-parametric smoothing approaches to multiple reservoir management for the economic potential of augmented water yields from various forest management practices for irrigation, hydropower, and fisheries resources. His primary role in this project was to translate the SME input into useable computer models, and to develop computer programs that allowed the SME input to be propagated through the influence diagram models to generate simulated distributions of the probability of inadvertent human intrusion.

Dean Neptune

Ph.D. Physiology/Biochemistry, Auburn University

B.S. Horticulture/Chemistry, Auburn University

Dean Neptune established Neptune and Company, Inc., to provide environmental planning services and probability-based survey design services to government and commercial clients. Primary clients are the DOE, DOE National Laboratory site management contractors, and private industry. As president of Neptune and Company, Dean provides consultation to senior executives and project managers on difficult problems where the cost-effective solution requires a quantitative identification and weighing of decision uncertainties. He has 30 years experience in the public and private sectors in the areas of analytical chemistry, QA, environmental data collection planning, regulatory development and compliance, and mixed waste laboratory design. Prior to forming Neptune and Company, Dean planned and implemented the development of the environmental protection agency for the Kingdom of Saudi Arabia and worked for the U.S. Environmental Protection Agency (EPA), where he played a key role in transforming an agency oriented toward laboratory quality control, into the major federal agency QA leader. While at U.S. EPA, he contributed to the creation of the only certainty-based planning tool available to facilitate decision making, and established the agency's area-wide waste management planning program. Dean played an integral role in the preparation of this study, conducting the stakeholder workshop, and identifying SMEs. He also participated in the elicitation sessions, and was largely responsible for the QA program implemented for this study.

One of the project team's main roles in this project was to provide facilitation support. The project team's approach to participation and involvement of all parties involved was that, while provision of a focus was necessary, otherwise the participants would run the public involvement and elicitation sessions. The project team's role was merely to collect the input and ensure that the focus of the meetings and discussions remained on track. The project team conducted elements of the study such as the workshop and the elicitation sessions in a semi-structured fashion. That is, the project team provided a starting point for the model (developed based on input from the other stakeholders). The workshop participants and SMEs were free to discuss the model as they deemed appropriate. In particular, the SMEs were permitted to revise the influence diagrams as they saw necessary to refine the model. In summary, the project team provided planning, facilitation, and computational support, whereas the SMEs were responsible for all input to the final models.

A.2.2 Performance Assessment Teams

Teams that are supporting the PAs at the Nevada Test Site (NTS) provided valuable resources for this effort. Their efforts included providing background information to familiarize the project team with PAs, particularly the IHI aspects. They also provided technical support in the form of background materials (presentations and documents) for the workshop participants and the SMEs. They performed review of work plans, preliminary influence diagrams, and reports; provided logistical support for the stakeholder workshop and the expert panel sessions; and contracted the subject matter experts to ensure their involvement in the project. The project team ensured through their involvement that the PA teams' inputs were not used in any way to affect the outcomes, but were used solely to provide information as needed and as requested. The most critical role of the PA teams was to provide technical support, information and resources that could not easily have been provided by any other groups.

The following individuals and organizations supported this project through their affiliations with the PAs conducted for the Nevada Test Site low-level radioactive waste management sites.

Beth Moore	Department of Energy, Nevada Operations Office
Wendy Clayton	Department of Energy, Nevada Operations Office
Kevin Rohrer	Department of Energy, Nevada Operations Office
Lawrence Barker	Bechtel Nevada
Curt Muller	Bechtel Nevada
Shannon Parsons	Bechtel Nevada
Stuart Rawlinson	Bechtel Nevada
Mike Sully	Bechtel Nevada
Alan Thomas	Bechtel Nevada
Theresa Brown	Sandia National Laboratories
John Cochran	Sandia National Laboratories
David Gallegos	Sandia National Laboratories

Bechtel Nevada played an important role helping to identify suitable SMEs, and letting the contracts for the SMEs. Because of their extensive role in this aspect of the project, Stuart Rawlinson and Shannon Parsons were integrally involved in preparing Appendix C of this report.

A.2.3 Peer Review Group

A peer review group (PRG) was formed in the early stages of this project to help ensure that the project was technically sound and to offer advice and assistance on all technical aspects of the project. In particular, the PRG reviewed all stages of development and preparation of preliminary influence diagrams, acted as a surrogate expert panel in practice elicitation sessions, provided critical review of reports and other documents developed in support this project (e.g., presentation materials), and provided critical review of the algorithms used to generate the final results. The PRG's review comments and the authors' responses to those comments are archived; as noted therein, in the rare case where a comment by a reviewer could not be resolved to that reviewer's satisfaction, the DOE project manager directed how to proceed. Brief biographical descriptions of the members of the PRG are presented below:

Bruce Crowe is a Science Advisor for the NTS Environmental Management programs with Los Alamos National Laboratory. He received a Ph.D. and an M.A. in Geology from the University of California, Santa Barbara, and a B.A. in Geology from Fresno State University. His areas of expertise include geology, volcanology, probabilistic risk assessment, performance assessment, application of expert judgment, and the geology and hydrology of the NTS. Dr. Crowe has prepared multiple refereed papers, book chapters, and consulting publications in geology, volcanology, probabilistic hazard assessment, tectonic processes, and impact on society and geological aspects of disposal of radioactive waste. He has extensive experience with the geology and tectonics of the NTS, and extensive experience with probabilistic hazard and risk assessment. Dr. Crowe has been a participant in national and international committees and panels on performance assessment and probabilistic hazard assessment, and served as an expert panel member on the National Research Council Panel on Active Tectonics and Impact on Society.

Charles Davis received his Ph.D. in Statistics from the Univ. of New Mexico. He lead the graduate program in statistical consulting in the Math. Dept. of the Univ. of Toledo from 1976 through 1992, after which he left academia to devote full-time efforts to environmental regulatory statistics. Dr. Davis is currently president and principal statistician of Environmetrics & Statistics Limited of Henderson, NV. He is author of numerous publications in the environmental regulatory statistics area, including the chapter "Environmental Regulatory Statistics" in the 1994 Handbook of Statistics Volume 12: Environmental Statistics, and is frequently invited to present papers and participate in conferences and workshops in this area.

Doug Duncan is the Hydrology Program Manager for the Nevada Operations Office of the U.S. Department of Energy. He has been involved in managing groundwater issues for DOE and the Nevada Test Site since 1990. Prior to his work at DOE, Doug worked for Lockheed Engineering and Sciences Co. in Las Vegas providing environmental support to the U.S. EPA. Previously, he worked as a geophysicist for Exxon for 6 years, the majority of that time exploring for oil in Nevada. He started his career in 1980 at the Hanford Nuclear Reservation in Washington as an environmental scientist. He has a Master's degree from the Pennsylvania State University and a Bachelor's degree from the University of Georgia, both in Geology.

Bill Roberds received a B.S. (with distinction) in Civil Engineering from Stanford University, and an M.Sc. and D.Sc. in Geotechnical Engineering. He joined Golder Associates in Seattle in 1980, after having worked for several other geotechnical engineering consulting firms and taught at several major universities. He is currently a Principal with Golder, specializing in risk assessment and decision analysis, especially applied to environmental systems. On this general topic, he serves as a reviewer for various professional journals and as a member of international and national committees, has over 70 publications, and has made numerous presentations to professional organizations, government agencies, and private clients around the world. Dr. Roberds has been actively involved with radioactive waste issues for private and public agencies (including regulators such as US NRC and US EPA) around the world since 1977, especially related to probabilistic analysis. He has successfully developed and used state-of-the-art probabilistic analysis techniques, including expert elicitation, on these and various other types of business and engineering projects, for which he has been recognized internationally.

In addition, Bill Roberds prepared and conducted a probability training session for the SMEs. This session was conducted at the end of the first elicitation session to provide the SMEs with an overview of probability theory and, more importantly, to familiarize the SMEs with probabilistic concepts that would be used during the probabilistic elicitation conducted in the second session. The probability training was also recapped at the beginning of the second session. Further discussion of this training session is found in Appendix D.

Other organizations that participated in peer review activities included Argonne National Laboratory and the Yucca Mountain Project. These organizations provided useful feedback through critical reviews of drafts of the final report. The following individuals were involved in this aspect of the project:

Jack Ditmars	Argonne National Laboratory
Jeff Keisler	Argonne National Laboratory
Ron Whitfield	Argonne National Laboratory
Wendy Dixon	Department of Energy, Yucca Mountain Project

The organizations and individuals identified above were involved throughout development of various drafts of this report. A later, external, review on the final draft document was performed by Brett Mattingly and Anthony Hechanova of the Harry Reid Center for Environmental Studies under the auspices of the Nevada Risk Assessment/Management Program (NRAMP). Brett Mattingly attended the elicitation sessions as an observer, and Anthony Hechanova has been engaged in a review capacity for Performance Assessments at the NTS, and is intimately aware of the use of the results of this project. Their comments resulted in several critical clarifications in the report.

The level of peer review included in this project provides substantial support for its credibility. The PRG essentially acted as an independent body with no direct professional ties to the PAs performed at the NTS. Through their participation, the process by which the final results were obtained, and hence the final results themselves, are provided a level of defensibility that could not be achieved otherwise.

A.2.4 Support Teams

The project also could not have achieved its successful conclusion without the assistance of several support teams. In particular, the stakeholder workshop and the expert panel sessions were hosted by the Desert Research Institute. Neptune and Company worked with the Desert Research Institute to ensure that the appropriate facilities, computer support, microphones, tape recordings, overhead projectors, and other meeting amenities were provided. This ensured that the SME input was recorded accurately and that complete records of the elicitation sessions were available. In addition, support was provided that enabled thorough documentation of many aspects of the project, and technical editing support was obtained to ensure quality in the reports produced. The following individuals and organizations provided invaluable support to the project:

Roger Jacobson	Desert Research Institute
Juana Blackburn	Desert Research Institute
Theresa Shaw	Bechtel Nevada Corporation
Michelle Heskett	Scrivener, Ink

A.2.5 Subject Matter Experts

The SMEs obviously played an integral role in this project. The participation of the SMEs lends great credence to the final product. Their credentials, including academic qualifications and experience, form the foundation of the results obtained. All other participants were involved to lay the groundwork for this study, and to provide facilitation support, but the SMEs knowledge and ability to translate their knowledge into quantifiable statements was crucial to the success of the project. A complete discussion of the means by which SMEs were identified and contracted to perform the work is provided in Appendix C.

A.2.6 Workshop Participants

The stakeholder workshop held during the early stages of the project was a crucial activity conducted to gain broad perspective on the approach to assessing IHI and to share information and ideas with a wide range of interested parties. The opinions obtained during the workshop were used to better define and improve the approach to assessing the probability of IHI, as well as to ensure the credibility of the project. This external validation of the process was crucial to obtaining wide acceptance of the project. A more complete discussion of the workshop and its participants, its purpose and the information exchanged, is provided in Appendix B.

A.3 INFLUENCE DIAGRAM ITERATIONS

This stage of the project QA process refers to the initial internal review and testing by the PA teams of the preliminary influence diagrams developed by the project team. An independent review of the influence diagrams was necessary for establishing the credibility of the proposed approach. This review was performed on two levels: first, peer review of the influence diagrams was sought for technical defensibility; and second, selected non-technical stakeholder acceptance of the influence diagrams, or of the concepts that underlie the influence diagrams, was sought to ensure that the final product of this project also would gain acceptance from a broader audience. Proceeding with a model that is unacceptable to either audience was considered unlikely to result in a successful conclusion.

Technical review was performed internally by the project team, and externally by the PA teams and the PRG. These reviews provided important feedback that was used to modify the influence diagram models for consistency and completeness. In order to maintain their technical objectivity and independence, the PRG did not participate in project planning until the last step before completing the final influence diagrams. Pre-testing the influence diagrams with the PA team and the PRG was considered important for verification that the effort was not misdirected. However, the assumptions and conditions for the influence diagrams and the elicitation approach were not subject to PA team review, as this could represent an opportunity for management bias.

Input gained during the workshop from stakeholders, the public living in the NTS area and various public interest groups, was considered necessary to gain the perspective of a broad audience and to allow for other input regarding issues that might have been overlooked in the influence diagrams (see Appendix B). Information gained from the workshop resulted in a further iteration of the influence diagrams, and provided verification of the proposed approach, including assessing IHI through expert elicitation, the need to account for community as well as homestead scenarios, and the need for periodic review if societal and technological practices change significantly in the future.

This broad-based review process was seen as critical. The overall approach was based on a concept of agreement on approach, assumptions and conditions, followed by objective collection of information (from the SMEs). With this approach, the results are simply a consequence of the planning stages (assumptions and conditions), and of the information collected. The results cannot be challenged directly; only the assumptions and conditions or the credentials of the SMEs can be challenged (see Appendix C).

A.4 STAKEHOLDER INVOLVEMENT

Public participation is becoming an important facet of DOE activities. The stakeholder workshop was called to obtain input about the adequacy and appropriateness of the approach and methodology proposed for assessing the potential for IHI at the NTS low-level RWMSs, and to share information on the purpose of the study. Stakeholder evaluation of the approach was important because perceived local customs and land-use activities were incorporated into the probabilistic determination. The project team needed stakeholder feedback to verify or correct conclusions made regarding local behaviors and activities. It was anticipated that through feedback from various stakeholders, this approach for evaluating waste would be a more site-specific process and therefore, better reflect local (community) activities.

A secondary consideration that was regarded as important for a successful conclusion to this project was to begin involving stakeholders in the DOE/NV PA process in a proactive and informed manner. This particular workshop was designed to complement the existing public involvement program at DOE/NV Waste Management Division to further their proactive approach in relation to various DOE/NV activities. Again, the purpose was to gain acceptance of the approach, assumptions and conclusions through open discussions with the stakeholder audience so that the final outcomes would be seen as defensible to all participating parties. A more complete discussion of the stakeholder workshop, its purpose and the feedback obtained can be found in Appendix B.

A.5 SELECTION OF SUBJECT MATTER EXPERTS

The first step in selecting SMEs was identifying applicable areas of technical expertise based upon the variables specified in the influence diagrams. Once these areas were identified (see Appendix C), the SME selection process was conducted as a two stage endeavor. The first stage involved establishing selection criteria against which possible candidates would be evaluated. Members of the PA team and the project team worked together to identify criteria that would meet these objectives. These criteria reflected both the need for SMEs with suitable qualifications and the necessity of determining any potential conflict of interest and bias. Primary requirements included recognized expertise in their field, experience with arid southwest environs, no perceived conflict of interest, and ability to express technical knowledge in qualitative and quantitative interpretations in their area of expertise. Potential conflict of interest was judged by obtaining information related to former work for the DOE/NV, affiliations with proponents of or activists against the nuclear industry, or strong perceptions about the effects of anthropogenic radiation on the public and environment. A detailed discussion of the selection criteria is provided in Appendix C.

Based on identified disciplines and criteria, a short list of at least three candidates per discipline was drafted by PA team members for the project. The short list was used instead of a general solicitation, because of the relatively short time frame involved for this project. Once identified, the prospective SMEs were sent the Request for Proposals (RFPs), and the submitted proposals were gathered for the second stage of the SME evaluation process.

The second stage consisted of an evaluation of the potential candidates by the PA team. In this stage, the PA team manager, two other representatives of the PA team, and two representatives from the project team participated in an independent evaluation of each SME candidate against the established criteria. Through discussion among all team members present, any clarifying or missing information was identified. Finally, each candidate was given a composite rating based on all information considered during these evaluations. These joint evaluation discussions were all overseen and assisted by two members of Bechtel's contracts office for contractual issues and appropriateness.

A.6 TRAINING WORKSHOPS FOR THE SUBJECT MATTER EXPERTS

The SMEs were contracted to participate in the expert elicitation based on their qualifications within their disciplines. They were not expected to be fully proficient in the probabilistic concepts required to obtain their input, or in elicitation techniques that would be used during the elicitation sessions. In order to ensure that the SMEs could participate most effectively, two training workshops were developed. The first training workshop was designed to familiarize the SMEs with the probabilistic methods that would be used during elicitation. The second was to share with the SMEs elicitation techniques that could be used and to inform the SMEs of management and cognitive biases that must be minimized throughout the elicitation. The probability training was provided by Bill Roberds, a member of the PRG. The elicitation training was provided by the project team. Further details of these sessions can be found in Appendix D. These QA activities were undertaken to ensure that the inputs elicited from the SMEs meaningfully and usefully captured their expert opinions.

A.7 EVALUATION OF PROJECT ACTIVITIES

Project activities were evaluated through continuing reviews by the project team, the PA teams and the PRG, and by requesting an evaluation from the SMEs and the workshop participants. These evaluations were performed with questionnaires that were designed to obtain feedback from the participants. The main purpose was to provide assurance that the workshop and the elicitation sessions achieved their goals.

Workshop participants were presented with an evaluation questionnaire for voluntary completion at the end of the session. Three out of the 19 participants completed and returned the questionnaire which requested opinions on the value and purpose of the workshop, and the adequacy and appropriateness of the information shared during the workshop. Appendix B contains a detailed summary of the workshop and the responses to the evaluation questionnaires.

The SMEs were also sent an evaluation form after the second elicitation session. All of the SMEs responded. Appendix D provides details of their responses. The evaluation of the elicitation sessions requested information and feedback from the SMEs similar to that requested of the stakeholder workshop participants. In addition, however, the SME forms sought evaluation of the technical adequacy of the elicitation session, with particular emphasis on the effectiveness of the training sessions and subsequent control of the potential for biasing in the elicited input.

A.8 SUBJECT MATTER EXPERT FORMAL REVIEW AND ACCEPTANCE

The SMEs provided their expert opinions during the elicitation sessions, and their opinions were captured by the project team. The next step was to document the SMEs' input in a formal summary report that would show the intended application of the inputs received. The purpose of this document (see Appendix D) was to ensure that the SMEs' input had been captured accurately and according to their intent. The SMEs were asked to review the summary report of their input, complete an evaluation questionnaire, and certify that their input had been captured correctly.

The report summarized the inputs provided by the SMEs during both elicitation sessions. The SMEs were asked to review and indicate where their input either required clarification or was incorrectly recorded and summarized. These inputs, with very few adjustments from the SMEs, were then used in the draft final report.

A.9 FINAL REPORT REVIEWS

Technical peer reviews were equally important for completeness, verification and defensibility. Several levels of review of the final report were anticipated: the project team performed internal reviews of the final report prior to submittal; the PA team and other DOE organizations provided review capabilities; the PRG's primary responsibility was to provide peer review of all aspects of the technical work, including the final report; and finally an external review of the report was received from the Nevada Risk Assessment/ Management Program.

A.10 DOCUMENTATION

Throughout this project, records documenting every aspect of the process were kept. These records include documentation of the preliminary influence diagrams that were developed both before and after the stakeholder workshop, documentation of the workshop and the elicitation sessions, and documentation of planning documents and reports that were written during the project. In addition, all background and presentation materials used during the project are available. All of the documentation, including tapes of the elicitation sessions, is available either in attachments to appendices in this volume, or in the archive of documents associated with this project. Any questions regarding planning and work application rationale, how conclusions were derived, or how decisions were made, can be addressed through this comprehensive history and an associated understanding of the processes. In order to meet this project requirement, complete copies of all documents, reports and data are available at Neptune and Company and at DOE/NV offices.

A.11 RELATED ARCHIVED DOCUMENTS

- Work plan
- Presentation to the PRG
- Review comments and responses

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APPENDIX B: STAKEHOLDER WORKSHOP

CONTENTS

B.1 INTRODUCTION

Public participation is becoming an important facet of Department of Energy (DOE) activities. Participation of stakeholders in the decision making process is a good business practice, and it is becoming integral to regulations to which the DOE and its facilities must adhere (DOE/NV 1993). DOE facilities across the country are learning the value of public participation in terms of both improved relations with stakeholders and a noticeable increase in savings and improvements for facilities based on these types of interactions (Carnes et. al. 1996:1).

This appendix describes the stakeholder workshop conducted in April 1996 in Las Vegas, Nevada. The purpose of this workshop was to evaluate the suitability of applying a site-specific approach for determining the probability of inadvertent human intrusion (IHI). The workshop was only one step in the determination of this probability; however, it proved to be a very important one by virtue of providing an opportunity for stakeholders to offer input to the process.

The approach taken to stakeholder and public involvement was to operate a very open discussion. Literature research reveals a distinction between a structured approach to public involvement that requires a structured list of questions with a formal question and answer sequence, and an unstructured (semi-structured) approach that paves the way for more open discussion (Meyer and Booker, 1991). The project team felt that in this case a structured approach would not promote the degree of comfort and freedom needed to obtain the full extent of the opinions of workshop participants. Instead, a semi-structured session was chosen to create a more relaxed atmosphere and promote open discussion and dialogue. Some level of structuring was necessary to keep the workshop sufficiently focused that objectives were met. This structure was provided by supplying written (unbiased) questions to which input was sought. The questions provided a starting point and ensured that the process ultimately maintained its direction and objectives. In the time allotted, however, the participants were free to discuss any relevant issue brought to the table. It was the job of the facilitator to make sure that deviations from objectives did not become so time consuming that the objectives could not be met. Based on the verbal feedback obtained at the meeting, the approach was well received. Follow up with the participants involved use of a questionnaire that was sent to each participant. The following sections describe in more detail the stakeholder workshop, its purpose, and the input received.

B.2 PURPOSE

This workshop was conducted primarily to elicit input from stakeholders about the adequacy and appropriateness of the probabilistic approach and methodology used to evaluate the potential for inadvertent human intrusion into waste streams considered for deep burial at the Nevada Test Site (NTS). Stakeholder evaluation of the approach was important because perceived local customs and land-use activities were incorporated into the probabilistic determination. The project team needed stakeholder feedback to verify or correct assumptions made regarding local behaviors and activities. It was anticipated that through feedback from various stakeholders, the approach to assessing the potential for IHI would be a more site-specific process and would, therefore, better reflect local (community) activities.

A secondary purpose was to begin involving stakeholders in the DOE/Nevada Operations Office (DOE/NV) Performance Assessment (PA) process in a proactive and informed manner. This particular workshop was designed to complement the existing public involvement program at DOE/NV Waste Management Division to further their proactive approach in relation to various DOE/NV activities.

B.3 STAKEHOLDERS

Stakeholders traditionally include members of the public who might be directly impacted by an institution’s activities, and special interest groups who oppose an institution’s activities. For the purposes of this project, stakeholders have been defined to include a larger group: impacted public, special interest groups, agencies at the state government level, representatives of various levels at the DOE/NV field office, and members of the PA team.

The decision to include representatives with these various interests reflects growing recommendations for stakeholder involvement activities to ensure that all appropriate and necessary people and organizations are involved in the activities. This inclusion makes it possible to understand the biases or interests inherent in different positions, what is valued by the stakeholders, and stakeholder motivations and interests (English et. al. 1995; Liebow 1988; DOE/NV 1993; Wiltshire and Williams 1995). The interaction of institutional and public representatives in any given circumstance can proceed with some difficulty, ranging from communication misunderstandings to criticisms regarding the progress of institutional activities (Fitchen 1988). Just as public representatives are influenced by their community, so too are institutional representatives influenced by their institution. Therefore, the project team opted to include as many stakeholders as possible in activities related to the evaluation process (as the schedule and budget allowed).

The following stakeholder groups were represented at the workshop: the State of Nevada, the University of Nevada - Las Vegas, the Community Advisory Board, the Community Radiation Monitoring Program/Community Technical Liaison Program, Citizen Alert, the Nevada Nuclear Waste Task Force, and DOE/NV Waste Management Division. Representatives of the state were actually from two different offices: Nevada Division of Environmental Protection and the Nevada Nuclear Waste Project Office. Representatives of the Community Radiation Monitoring Program were representing their respective communities, in addition to the Program. DOE/NV’s presence at this workshop was to serve a dual purpose: to hear the concerns and issues from the stakeholders themselves, and to participate in a facilitated discussion with these stakeholders for an open exchange of information. The Las Vegas Indian Center's representative was invited, but was unable to attend due to a schedule conflict. A complete list of participants is included as Attachment B.1. Members of the project team facilitated the discussion groups.

B.4 WORKSHOP DESCRIPTION

The stakeholder workshop was held in Las Vegas at the Desert Research Institute of the University and Community College System of Nevada on 11 April 1996. In order to optimize attendance, the workshop was convened from 8 a.m. to 12 p.m., a time frame that best suited most of the participants. The Desert Research Institute facility was chosen for two reasons: it was centrally located for attendees and it provided a neutral place for participants to convene. To ensure that all participants were familiar with the issues to be discussed, attendees were sent an information sheet prior to the workshop. Attachment B.2 is a copy of the information package distributed to the participants.

The list of individuals who attended the workshop and the capacity in which they attended is included in Attachment B.1. A total of 26 people attended the workshop in some capacity. This included individuals from the Desert Research Institute who provided logistical support, members of the PA teams who gave the presentations and participated in the discussions, members of DOE/NV public relations groups who observed the proceedings, facilitators from the project team, and 16 stakeholders from various community interest groups.

The first part of the workshop consisted of a series of short presentations given by members of the PA team. These presentations consisted of an overview of the Low-level Radioactive Waste Management Program, the regulatory basis for conducting PAs, and an introduction to the probabilistic evaluation approach as it had been developed to that point. The second part of the workshop involved focused discussions regarding presentation topics and aspects of the probabilistic approach. In order to focus these discussions, a series of questions was prepared in advance by the project team. These questions are presented in Section B.5 below, along with the participants' responses.

B.4.1 Presentations

The presentations related to different aspects of the probabilistic approach. The overview of the Waste Management Program consisted of important background material that described the purpose and objectives of the Program and provided the impetus for this study. The presentation on the regulatory basis (DOE Order 5820.2A) described the purpose of PAs and how they fit into the low-level radioactive waste management decision process.

The discussion of the approach to assessing the potential for IHI included an introduction to the preliminary influence diagrams, including inadvertent intruder scenarios and the management controls module, and a presentation regarding periodic review of intrusion. An overview of the inadvertent intruder scenarios was necessary in order to understand how possible exposure to potentially harmful waste might occur. The management controls module was presented to explain factors affecting the probability of inadvertent intrusion that result from management decisions (e.g. the duration of institutional control of the site, mechanisms for maintaining site knowledge, types and durability of placards and markers used to indicate waste site locations, and different types of surface and subsurface barriers to deter intrusion into the waste sites themselves). Periodic review of intrusion was introduced as a possible management mechanism to ensure that any appropriate technological advances in the storage and treatment of waste would be applied to existing waste disposal sites, contingent upon some type of institutional control and timely appropriation of sufficient funds. The presentation materials are included as Attachment B.3.

B.4.2 Discussion Groups

After the presentations were made, the participants were divided into two discussion groups, Group 1 and Group 2, with an individual from the project team facilitating each group. The participants were divided to ensure that all participants' views could be heard. By splitting into two groups, all participants had the opportunity to more fully join in the discussion. After the two groups had completed their separate discussion sessions, members of each group were asked to orally share a summary of their session with the entire group. This approach enabled every participant to engage in the discussions yet ensured that opinions were shared with all participants.

Discussion began with the facilitators asking the participants if the assumptions and topics, as presented, were understandable and sufficient as a basis for discussion. Representatives from the PA team were available if any participants required clarification on issues covered in the presentations. After questions regarding the presentations had been addressed, discussion was focused on specific questions meant to guide the groups through topics for which the project team needed input to complete the next steps in the project. A benefit to using focused questions was to keep the group focused on the task at hand, rather than digressing to other issues related to the NTS that were outside the scope of this workshop. This was not to negate the importance of any other issues for the stakeholders, but rather to clarify and meet the objectives of this particular workshop. Other stakeholder issues raised during discussions were noted and passed on to the Office of Public Affairs and Information at DOE/NV.

Discussion questions focused on different aspects of the probabilistic assessment as they had been developed up to that point. Workshop participants were asked to comment on the concepts behind the questions, as well as how they perceived and understood the questions in terms of the compliance period that was a required part of the probabilistic assessment. The compliance period specified by regulations was 10,000 years, so the participants were asked to contemplate these issues in that time context.

B.5 RESULTS

The discussion groups focused on management control issues, inadvertent intruder scenarios, and periodic review of intrusion. Despite the wide range of participant interests, there was general consensus regarding these issues. Overall, discussion among the participants was positive and constructive, with the participants listening thoughtfully to each other. Whenever some participants attempted to guide the discussion to a particular endpoint, the other members of the group or the facilitator were able to redirect the discussion without having a negative impact on the discussion or the agenda as identified early in the workshop. The following sections present the specific questions posed and the responses from each group. After presentation of the specific issues of interest (management control issues, IHI scenarios, and periodic review of intrusion), a brief description of other general issues raised during the workshop is presented.

B.5.1 Management Controls

Question 1: "Is it reasonable to expect that Government, or another controlling organization, will be able to maintain institutional control of the NTS for 1,000 to 10,000 years?"

Group 1 felt that it was doubtful that general knowledge of NTS and its use would be lost (i.e., as a test site for nuclear weapons). They also felt that control may be possible for about 10,000 years, but it's very unlikely. The group raised concerns that the memory or knowledge of the NTS waste disposal areas would probably not endure for 10,000 years. It was also agreed that, if monuments are used to mark the waste disposal areas, it is likely that their purpose would be lost over time. The participants offered an example of Egyptian markers (pyramids) that have lasted through time while their messages were lost. Group 1 decided to allow votes of yes, no, or maybe after discussion of each question. The final tally for the first question for Group 1 was three votes "no," zero votes "yes," and four votes "maybe."

Group 2 reached a consensus of an unequivocal no. A time frame that would be considered reasonable was about 100 years for some type of institutional control, but only if money was allocated in advance, as for a trust fund. Concern was expressed about the location of waste outside of the NTS. Other points raised for consideration included the need to build monuments to last 1,000 years if monuments are to be used at all. Group 2 participants were concerned that, if messages or placards are to be used, consideration must be given to how "language" might change over time. Otherwise, the messages might be misunderstood in the future. Further, the participants indicated there is a need to acknowledge that plutonium might become a valued resource in the future. Note that Group 2 did not choose to vote on each question.

> Question 2: "Is it reasonable that either the waste form or the waste disposal site at the NTS will be recognizable for 1,000 to 10,000 years?"

The majority of Group 1 felt the waste form and the site would not be recognized over the entirety of the 10,000 year time frame. For example, if drilling caused intrusion into the waste, the drill cuttings would probably not be recognized as waste. The group indicated that intruder recognition of the waste might depend on how the site was marked. It was also suggested by the group that if the waste form is recognized as dangerous, that exposure to a chronic dose could be avoided. Records and education were seen as instrumental for ensuring waste and waste site recognition. The final Group 1 tally was five votes "no," zero votes "yes," and two votes "maybe."

Group 2 did not reach consensus on this question. Time span was considered an issue. The participants indicated that this site has been proven relatively stable through trench dating methods and climate verification. They suggested that markers can be built to last in this type of dry climate, with oral and written history supplementing whatever markers are used. However, they also suggested that through time, the oral record will probably be distorted to make the site look attractive to people. They further indicated that it can be assumed that the waste form will be recognized as man-made artifacts; any more than that (for example, knowledge of whether it is dangerous) would depend on the sophistication level of the intruder. Group members noted that some people wouldn't recognize the waste now, let alone in 1,000 to 10,000 years. Without knowledge, technology, or instrumentation, the group did not feel that it can be assumed that the waste or the site will be recognized. According to this group, the estimated time during which the waste form will be recognized as something dangerous will probably be about 100 years. However, the group did not feel comfortable speculating on this issue. Institutional control is the only mechanism the group felt would be effective for waste and site recognition.

> Question 3: "Is it reasonable to expect that passive barriers can reduce the possibility of intrusion, or serve to warn against further intrusion, for 1,000 to 10,000 years?"

Most of Group 1 felt that passive barriers would not be effective deterrents to intrusion for 1,000 to 10,000 years. They felt that barriers might even serve to draw people to the site to attempt intrusion. To better limit the probability of intrusion into the waste, the group agreed that it might be better to dispose of the waste in fewer locations around the U.S. It was agreed that NTS might be one of the best places in the U.S. for disposing of radioactive waste, and that once waste is disposed of at NTS, it is likely to stay there. It was also suggested that the effectiveness of passive barriers might improve if this mechanism was used in various areas of the country where waste is already located. The final tally for this question was four votes "no," one vote "yes," and two votes "maybe." Group 2 arrived at a conditional yes, that passive barriers can be reasonably expected to deter intruders and to reduce the possibility for intrusion, although intrusion into the waste will ultimately depend upon intruder sophistication. If the intruder is relatively sophisticated, he/she will figure out a way to get into the waste ("If we can create the barrier, we can eventually figure out how to get through it."). They further indicated that if the intruder lacks the sophistication to get around the barrier, he/she will probably give up and find another spot for drilling.

B.5.2. Intrusion Scenarios

Question 4: "Is the homesteader scenario a credible and conservative rural scenario?"

Group 1 indicated that the homesteader scenario is conservative and realistic, and that it is the scenario that should be used. In particular, they expressed that the Community scenario should not be used in lieu of the homesteader scenario, which is similar to how some people in this area currently live. The group saw many factors potentially changing within the specified time frame, including climate, water levels, drilling technology and perceptions, which may lead to scenario re-evaluation. The final tally for this question was zero votes "no," seven votes "yes," and zero votes "maybe."

Group 2 did not think the homesteader scenario was realistic for Area 3 and Area 5. The group agreed, "everyone knows you can't grow anything in a lake bed or playa" where water is not easily available. Therefore, they reasoned, there is no incentive for anyone to live in these two disposal areas. Specifically, the group indicated that a homesteader will not have the technology to drill a 600-ft well, let alone the capacity to drill through the waste. The group felt that whichever scenario is used, it is very important to use the most conservative, worst case scenario.

Question 5: "Is the community scenario a credible and conservative urban scenario?"

Group 1 felt that the community scenario is not as conservative as the homesteader scenario and should not be used in lieu of the homesteader scenario. Though more than half of the group answered that the scenario is credible and conservative, the group was unable to see the benefits of the community scenario. The group felt it might actually end up being redundant if the homesteader scenario is used. Participants in the group indicated that the two scenarios may essentially be the same, but that the probability of intrusion in each case may be distinctly different. Another factor that caused members of the group to discount the community scenario was the expectation that communities are better informed than individuals. Therefore, members of a community are more likely to recognize waste materials as something potentially dangerous. It was also recognized that in the future, societal values may , and, if that were to happen, the risk would have to be re-evaluated. The final tally was three votes "no," four votes "yes," and zero votes "maybe."

Group 2 felt that the community scenario was more plausible than the homesteader scenario due to community growth in the surrounding areas. This group felt that urban encroachment is most likely because the urban infrastructure is already there, and as lands are released, communities will move to those areas. Intrusion was thought more likely to occur through excavation than drilling; however, both mechanisms were seen as likely routes for intrusion.

Following discussion of periodic review of intrusion, workshop participants rejoined to hear the other group's conclusions. It was important for the project team to have a clear indication of how the participants viewed the scenarios, so the facilitators spent more time identifying how the participants felt about the two scenarios. Through further discussion, it became clear that the participants felt that it was important for both homesteader and community scenarios to be included in the probabilistic assessment, as they both describe possible habitation activities.

B.5.3 Periodic Review of Intrusion

Question 6: "Is periodic review of intrusion an effective management approach?"

Group 1 had unanimous support for the idea of periodic review. It was suggested that the periodic review should be of the entire PA, and not just of the intrusion component. The group suggested that if the homesteader scenario was certain to be the most conservative scenario throughout the time frame (10,000 years) under consideration, revisiting the PA would never be necessary. However, they further suggested that a periodic review of PAs is essential because this scenario determination cannot be confirmed with any high degree of certainty. They recognized that the ability to perform a periodic review assumes that institutional control is maintained, and it was thought that by having or scheduling periodic reviews, there would be more chance of maintaining institutional control. Some in the group expressed concern regarding the ability for a PA review to be conducted if institutional control were to be lost. Some type of review was felt by the group to be appropriate and necessary to ensure that the standards used for each scenario are appropriate if technology changes. There was concern that conducting reviews during tight budget times may not be a high priority. The final tally was zero votes "no," seven votes "yes," and zero votes "maybe."

Group 2 also favored a periodic review, as opposed to just "walking away," because many factors change over time, making it necessary to revisit the scenarios. A representative from DOE/NV volunteered that there was some regulatory movement in that direction and that it would have a significant impact on institutional control. Three factors were seen by the group to impact the need to update and revisit the issue of intrusion into disposal areas: money, efficacy of techniques, and changes in organizations. Participants did not have any specific ideas of where the money would come from or who would be responsible for it, but they did think setting aside money was a good idea.

Question 7: "What is a reasonable time period for review of intrusion?"

Group 1 came to a consensus calling for review to occur at least every 10 years, to be consistent with National Environmental Policy Act (NEPA) requirements. One participant favored an annual review following the initial PA. Group 2 indicated that a reasonable time frame for periodic review was either 10 or 25 years, with the majority of the group agreeing on 25 years.

B.5.4 Other Issues Raised by the Workshop Participants

To ensure that all relevant views were included, the workshop participants were encouraged to participate in open discussions related to the main topic of the potential for IHI to occur. These discussions led to the following observations that some of the participants indicated need to be addressed. They are beyond the scope of this project, and are included here only to maintain a complete record of the workshop. The participants indicated the following:

- The most reasonable future land use scenario for NTS is industrial, which allows for different cleanup levels than those currently in use.
- The community representatives made it clear that waste migration into their groundwater is the communities' main concern.
- The stakeholders raised concerns regarding NTS waste disposal operations. Several participants noted that they were primarily concerned with site-wide risk from all past and current activities, and present and future waste disposal practices at NTS.
- The participants expressed the following concerns about PAs for NTS, specifically the low-level radioactive waste management areas:
  - The PA is being conducted in the wrong order because waste is already going to NTS.
  - Will the current PAs be rolled up into a composite PA?
  - This PA process was seen as too narrow, and it doesn't consider other avenues for exposure.

- Reducing the possibility of intrusion does not reduce the consequence of intrusion.

- Local residents expressed difficulty in separating out a small portion of the NTS (i.e., the waste management area) from NTS as a whole, particularly when examining activities and their impacts at the site.

The issues raised were shared with the Office of Public Affairs and Information at DOE/NV to ensure that they had been recorded with the appropriate authority, and to officially recognize concerns expressed by the stakeholders who participated in this workshop. The specific questions and issues raised are available in the archived documents associated with this project.

B.6 EVALUATION

Follow up with the participants was in the form of a summary report and an evaluation questionnaire that were sent to each participant. The purposes were twofold: to ensure that the information had been captured properly, and to request open feedback on the meeting, its purpose, its objectives, and its structure. The summary report simply reflected back to the participants their input as recorded by the facilitators during the workshop. The contents of the summary report were similar to the presentation in Section B.5 above. The participants were asked to respond if they felt that their input had not been interpreted correctly. None of the participants provided any corrections to this report.

Only three written responses to the evaluation questionnaires were received. One of the written responses was negative, suggesting that the decisions have already been made and that this workshop was simply “window-dressing.” No rationale was provided. The other written responses were more neutral. Although one response attacked the general purpose of meeting with stakeholders, none of the responses attacked the objectives or structure of the workshop.

A few observations about stakeholder interactions might benefit similar future efforts. While the stakeholder workshop provided positive feedback regarding the models and the approach proposed for assessing the potential for IHI, it was clear from this workshop that some participants remained skeptical of DOE/NV’s intentions. Feedback from the workshop suggested that some stakeholders questioned the interest that DOE/NV had regarding public input, and that DOE/NV had “already made the decision.” While only one participant put this in writing, another noticed that DOE/NV and the participants from the State of Nevada were talking but not listening to each other during the stakeholder workshop. During the workshop others verbally made similar observations regarding the distrust between DOE/NV and the State of Nevada.

B.7 WORKSHOP CONCLUSIONS

This workshop assisted the IHI study by providing the project team, DOE/NV staff and stakeholders the opportunity to meet on a common plane and to exchange ideas. Discussions from this workshop also helped to solidify the methods of analysis for the probabilistic approach. In fact, the influence diagrams were modified based on some of the input received:

- the homesteader and community scenarios were fully ensconced in the influence diagram models;
- waste recognition was removed from the influence diagrams because it has no effect on the potential for intrusion; and,
- periodic review of intrusion was acknowledged as a necessary step to ensure that a waste disposal decision reached today would be revisited if significant changes occur in technology or societal customs.

In summary, the workshop achieved its primary objectives: evaluating the suitability of applying a site-specific approach for determining the probability of IHI (which was well received), sharing information and opinions among stakeholders with a wide variety of interests, gaining useful input for the influence diagram models, and opening dialogue between DOE/NV and stakeholders regarding PAs at the NTS.

B.8 ADDITIONAL REFERENCES

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Fitchen, J. (1988). *Anthropology and environmental problems in the U.S.: The case of groundwater contamination*. Practicing Anthropology. Volume 10 No. 3-4.

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Wiltshire, S., and C. Williams. (1995). *A process for integrating public involvement into technical/social programs*. The Nuclear Waste Digest. The League of Women Voters Education Fund.

U.S. Department of Energy, Nevada Operations Office. (1993). *Public participation plan for the ERWM Program*. Revision 0, Environmental Restoration and Waste Management Division.

B.9 ATTACHMENTS

B.1 Participants in the Stakeholder Workshop

B.2 Information package

B.3 Presentation materials

B.4 Evaluation questionnaire: Original and responses

B.10 RELATED ARCHIVED DOCUMENTS

- List of invitees
- Sign-in sheet for the workshop participants
- Flip chart notes
- Responses to evaluation questionnaires
- Summary report of workshop findings
- Issues passed to Office of Public Affairs and Information at DOE/NV

APPENDIX C: SELECTION OF SUBJECT MATTER EXPERTS

CONTENTS

C.1 INTRODUCTION

The approach to assessing the probability of inadvertent human intrusion (IHI) used in this study was built around elicitation of expert opinion. To be able to achieve the objective it was necessary to convene a panel of subject matter experts (SMEs). The process of identifying, selecting, and contracting the SMEs involved many steps, all of which were subject to intense review:

- The process was initiated by identifying the disciplines that were considered important. These disciplines were identified using the preliminary influence diagrams that were subject to several stages of review and input.

- After the relevant disciplines were identified, the next step involved identifying potential SMEs that would be sent requests for proposals (RFPs).

- The proposals submitted were evaluated against administrative, technical, and cost criteria.

- Selected SMEs were sent contract packages.

C.2 DISCIPLINES

Initial selection criteria were based on the need for an interdisciplinary panel of experts to provide input into the elicitation. The disciplines to be included were chosen based on the preliminary influence diagram models that were constructed at the beginning of the study[1]. These preliminary influence diagrams were subject to several levels of review and input before a set of needed disciplines was established. The project team performed initial internal reviews, followed by review from the PA teams. The review from the PA team provided crucial input, identifying possible gaps in the initial influence diagrams constructed by the project team. These reviews established the basis for the preliminary influence diagrams, and hence for the set of disciplines for which expert opinion would be needed.

After these reviews, the influence diagrams were subjected to further review to ensure that they covered all aspects of the model needed for assessment of the probability of IHI. The influence diagrams were also adjusted based on input from the stakeholder workshop, although no new SME disciplines were identified as a result of these adjustments, although it became clearer that hydrogeology support would be needed both for rural and urban scenarios. The peer review team provided final reviews of the influence diagrams, again without identifying other disciplines that might be needed.

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[1] The preliminary influence diagrams were presented in a report (Black et al., 1996) that is available as Attachment D-2 to Appendix D.

An initial, broadly defined list of disciplines was narrowed to nine after discussions concluded that many of the disciplines were redundant and the same information could be garnered from another expert. Further, other disciplines were determined to provide information of little value for this panel. The nine disciplines identified through this process include the following:

- agronomy/soil science
- anthropology/archeology
- demography
- economic geology/resource-use
- geotechnical engineering
- hydrogeology
- land-use planning
- sociology
- water-well drilling

These disciplines covered the range of expertise required to fulfill the needs of the preliminary influence diagrams. The following sections describe how SMEs were selected and contracted to perform the expert elicitation.

C.3 SELECTION PROCESS

The selection process involved several steps that included both establishing selection criteria and identifying potential SMEs. The first step was to establish some general candidate qualifications, particularly regarding conflict of interest, as part of the Draft Scope of Work for the SMEs (see Attachment C.1). Primary requirements included recognized expertise in their field, experience with arid southwest environs, and no perceived conflict of interest.

Because of tight time constraints on assembling the panel, a short-list process was used to narrow the field of potential bidders while maintaining the legal requirements for competition. Professionals from Bechtel Nevada (Bechtel), Neptune and Company, and the U.S. Department of Energy, Nevada Operations Office (DOE/NV) compiled a list of known, established experts who were believed to meet the initial criteria. In addition, universities and engineering/environmental firms in the southwest were contacted. This initial list was expanded by asking those contacted if they could recommend others who might meet the initial requirements. Some disciplines, such as hydrogeology, were abundantly represented in the southwest. Others, such as land-use planning, were sparsely represented and candidates were difficult to locate. The experts were contacted by telephone, and a brief overview of the project and requirements was provided. The experts were then asked if they were interested in receiving an RFP package from Bechtel Contracting. Several potential bidders asked to be removed from consideration during the initial phone call. Only those experts who asked to receive the bid package were sent a package by facsimile or overnight express mail. The following table summarizes the number of experts contacted in each discipline, the number that eventually received RFP packages, and the number of bids returned.

It should be noted that all potential SMEs to whom an RFP was sent were expected to be qualified for the positions. This was a consequence of the telephone interviews that were conducted and the short-listing process. The goal of this competitive process was to find the candidates that rated the best according to the selection criteria. As Table C-1 indicates, for some disciplines the evaluation process was focused on a single individual. The evaluation proceeded for those individuals to the extent of ensuring that the qualifications were as good as anticipated and appropriate for the work.

The RFP package contained the scope of work for each discipline, a request for quotation form, and the terms and conditions of the request for quotations. In general, only the scopes of work were different for each discipline's RFP package. An addendum to the RFP was also sent out prior to the required submittal date to clarify some aspects of the package. Attachment C.2 includes a complete RFP package, with addendum, for the agronomist/soil scientist. Copies of the scopes of work for the other disciplines are included in Attachment C.3.

C.4 EVALUATION

Once initial selection criteria and primary disciplines were decided, nine discipline-specific scopes of work were developed and sent to potential candidates for their response. After all bid packages had been received, an evaluation committee comprised of Bechtel, DOE, and Neptune and Company personnel evaluated the packages to choose the best experts for the panel. Evaluations were based on an evaluation sheet devised for each discipline on which committee members awarded a range of points for each criteria. A copy of the evaluation sheets is provided as Attachment C.4. The evaluation sheets allowed both objective and subjective responses from the committee. The first requirements were considered critical, such as conflict of interest, personally performing the work, and meeting the performance period, and were evaluated as either pass or fail. A failure in any of these criteria removed the candidate from further consideration.

Table C-1

Summary of Potential SME Contacts

Discipline	Short List	Sent RFP	Submitted Bid Package
Agronomy/Soil Science	7	7	3
Anthropology/Archeology	8	8	5
Demography	4	4	2
Economic Geology/Resource-Use	7	7	7
Geotechnical Engineering	8	8	4
Hydrogeology	20	8	2
Land-Use Planning	3	3	1
Sociology	5	5	3
Water-Well Drilling	6	6	1

Once a candidate passed all the critical questions, evaluation of their experience and training began. These criteria allowed the committee to be slightly more subjective. A maximum score was provided for each criterion on the evaluation sheet. Provided that the minimum requirement was met, a partial score was given; however, if the requirement was met well beyond the minimum, the maximum score was given. For example, someone who had five years experience working as a team member on projects in their discipline may receive 7 out of 10 points, whereas someone who had five years experience as a project manager in their discipline may receive the full 10 points. This allowed the committee to recognize candidates with exceptional experience and training, thus allowing for the most qualified panel.

Each committee member individually read each proposal and rated each candidate. After each committee member had rated a given candidate, the committee discussed their scores. If the scores were highly variable, the committee would go back through the proposal and determine if some members had overlooked or misunderstood any qualifications. Occasionally, the committee members required some clarification of a candidate's qualifications. In these cases, the contracting officer contacted the candidate and requested a clarification be sent in writing. Evaluation of the responding candidate was suspended until the clarification was sent via facsimile to the committee. Upon receipt of the clarification, it was attached to the candidate's bid package and evaluation recommenced.

Based on the discussions and clarifications, a committee member occasionally changed the score for a given candidate. Once all the committee members were satisfied with their scores, the score sheets were submitted to the contracting officer who averaged the scores.

Committee members rated each candidate individually; comparisons between candidates in the same discipline were only subject to further scrutiny when two candidates' scores were extremely close and the contracting officer could not justify contracting with one over the other. The contracting officer was present at all times during the discussions to ensure that the committee remained as impartial as possible and to answer any questions about contractual concerns.

Committee members evaluated only the technical aspects of the bid packages exclusive of any pricing information. Pricing information was known only by the contracting officer until the end of the evaluation process. Pricing and technical expertise were weighted differently; technical expertise was worth 75 percent of the overall score and pricing was 25 percent of the overall score. This difference in weighting was to ensure, to the extent practical, that the most technically adept person for the SME panel was not underbid by someone with lesser qualifications for this position. In addition, pricing was considered only for the candidates' hourly rates, exclusive of travel expenses, so that local candidates did not have an unfair advantage over out-of-state candidates.

Based on these evaluation guidelines, all panel members were chosen in the most unbiased way possible. The hydrogeologist candidates caused some concern because none of the candidates met the requirements for experience in both urban and rural hydrogeology. As a result, the committee decided to award two contracts to hydrogeologists, one for rural expertise and one for urban expertise, although the contract language does not distinguish between the two. The committee and the contracting official all agreed this was the fairest way to settle the problem both technically and contractually.

C.5 CONTRACTING

Once the evaluation process was completed, the contracting officer contacted the successful candidates and explained the contractual obligations and stipulations to the candidates. All chosen candidates verbally agreed to the contractual requirements and accepted the position of SME panel member. The contracting official developed purchase orders which outlined the terms and conditions of the contract and sent them to the panel members. Any questions a panel member had about the contract were addressed verbally, and in writing if requested.

The selected panel members for each discipline and their professional affiliations were as follows:

- Agronomy/Soil Science - Dr. Alan Mathias, University of Arizona
- Anthropology/Archeology - Dr. Deward Walker, University of Colorado
- Demography - Thomas Perrigo, City of Las Vegas
- Economic Geology/Resource Use - Elizabeth Scott, Viceroy Gold Corp.
- Geotechnical Engineering - Dr. Robert Gilbert, University of Texas at Austin
- Hydrogeology, Urban - Terrance Katzer, Watersource Consulting Engineers
- Hydrogeology, Rural - Jerrold Kazynski, Geomatrix Consultants, Inc.
- Land-Use Planning - Jim Veltman, Veltman Consulting Services
- Sociology - Dr. Donald Carns, University of Nevada, Las Vegas
- Water-Well Drilling - John Singer, Retired from U.S. Geological Survey

A more complete listing of the candidates' qualifications is provided in Attachment C.5. Resumes are included in the archives for this project. Attachment C.5 contains summaries of the SMEs' credentials, including items such as education, experience, publications and presentations, professional affiliations, certifications, awards, grants, and recognitions.

C.6 ATTACHMENTS

C.1 Sample SME scope of work

C.2 Sample SME request for proposal

C.3 SME scope of work by discipline

C.4 Sample SME evaluation forms

C.5 Summary of SME qualifications

C.7 RELATED ARCHIVED DOCUMENTS

- List of potential SMEs
- RFP responses (including SME resumes)
- SME contracts
- Completed SME evaluation forms

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APPENDIX D: ELICITATION PROCESS AND SESSIONS

CONTENTS

D.1 INTRODUCTION

The elicitation process used in this project and described in this appendix commenced with preparation activities, continued with convening the subject matter expert (SME) panel to elicit expert opinions, and finished with an evaluation of the elicitation process. The purpose of this section is to introduce these steps, and to provide the rationale and justification, both regulatory and technical, for the approach taken to expert elicitation for this study. The remainder of this appendix more specifically describes the implementation of the approach.

The intention of this project was to determine if site specific conditions around the low-level waste disposal sites at the Nevada Test Site (NTS) could be evaluated and used to justify a probabilistic assessment of inadvertent human intrusion (IHI). A probabilistic assessment represents a marked deviation in approach compared to that described in Performance Assessment (PA) related guidance documents from the Department of Energy (DOE) [DOE Order 5820.2A, DOE 1988], the Nuclear Regulatory Commission (NRC) [NRC 1982], and the Environmental Protection Agency (EPA) [40 CFR 191] (EPA 1985), all of which suggest that a deterministic approach is adequate. Specific to PA for low-level radioactive waste disposal, Case and Otis (1988) provide sufficient material to suggest that a probabilistic approach is not only reasonable but necessary. Since this elicitation study was performed, an NRC draft document that provides considerable support for this type of approach to elicitation of expert judgment has been released (Kotra et al. 1996). The NRC document was based, in part, on an assessment of the use of expert judgment for the Yucca Mountain Project.

The NRC and the NAS have published draft documents on PA methodology that can be interpreted as offering an opposing view, suggesting that an assessment of IHI is not reasonable because of the complexities involved and the large number of possible mechanisms by which intrusion could occur. However, these documents present contradictory arguments that can be interpreted as both support for and arguments against the use of probabilistic methods for evaluation of inadvertent human intruder scenarios (Performance Assessment Working Group 1997; NAS 1995). Based on these recent documents, it could be argued that the approach used in this IHI study is not entirely consistent with existing regulatory documents. One of the purposes of this section is to explain any potential differences.

The PA Team supporting the Nevada Test Site (NTS) low-level waste disposal units decided to perform this study probabilistically, a view that should receive full support from any parties that are interested in defensible decision making in the face of uncertainty. Using a probabilistic approach is necessary to be able to answer questions for which data collection is difficult or cost prohibitive, and a probabilistic approach manages uncertainty more logically than a deterministic approach.

DOE Order 5820.2A (DOE 1988) is largely silent on the issue of methodology in support of a PA. The Order simply sets performance objectives that must be reasonably satisfied prior to licensing by DOE. Three documents are available that offer some guidance on the intent of the DOE Order: Case and Otis (1988) and Wood et al. (1992 and 1994). Case and Otis, in particular, suggest that site-specific credible scenarios should be considered when addressing the issue of IHI. Case and Otis do not address directly whether scenarios should be judged probabilistically; however, their language is highly consistent with such an approach. It is difficult to imagine how site-specific credible scenarios can be determined otherwise; at the very least a qualitative probabilistic judgment must be made.

The approach taken to expert elicitation in this study is consistent with the approach proposed in Kotra et al. (1996), with one notable difference. That is, Kotra et al. (1996) indicates that expert elicitation cannot be applied to speculative future events because the future is unknowable. The approach taken in this study recognizes the unpredictability of the future by requiring that the SMEs condition on current knowledge of society and technology, as they define it. To condition on current knowledge did not seem intractable, but the SMEs did agree to ensure that conditioning on current knowledge, including knowledge of current trends, would not be permitted to evolve into pure speculation on the future.

The IHI study, therefore, was based on a condition or assumption of a current knowledge base, and extrapolation into the future was based on this condition. Despite these precautions to limit speculation on the future, it could be argued that any study pertaining to future disposal of radioactive waste material involves prediction of the future to some degree. For example, fate and transport models rely on predictions of the future, and an assumption that IHI is prevented because of long-term institutional control involves speculation on the future.

Conditioning on current knowledge is consistent with any Bayesian decision analytic approach to problem solving: establish conditions to which all interested parties can agree, collect information (subjective or objective), and use the assumptions and the information as the basis for a decision analysis (or in this case a probability analysis). Following such an approach, the results of the study depend on the assumptions, on which all interested parties agreed, and the subjective information elicited from SMEs. This approach also accommodates the possibility of changes in assumptions (e.g., because conditions have changed over time due to new technology developments or changes in population patterns). If conditions are seen to change, then the probabilistic assessment should be reviewed to determine if the changes warrant a new probabilistic assessment. This process, termed "periodic review of IHI," received positive response from all workshop participants and SMEs. It is also fully consistent with a Bayesian approach to probabilistic analysis, which is to update based on new information.

Another recent NRC document "Performance Assessment Methodology for Low-Level Waste Site Licensing," endorses application of either deterministic or probabilistic approaches to performance assessments (Performance Assessment Working Group 1997). The document does contain inconsistencies that appear to partly contradict a probabilistic approach to assessment of scenarios; however, these appear to refer to societal conditions in the form of site-specific credible scenarios rather than intrusion scenarios. In particular, this NRC document often refers to "selection of credible scenarios," which begs the question of what criteria are used for selection if they are not probabilistic (at least qualitatively). Further, the document indicates that intrusion scenarios do not, in general, need to be considered for PAs because of the dominance of low-level waste streams by short-lived radionuclides, classification and segregation of waste, and effectiveness of engineered barriers. However, the document also indicates that several long-lived radionuclides are often found in low-level waste; that engineered barriers cannot be assumed to be completely effective, especially after 500 years; and that drilling cannot be prevented easily with engineered barriers.

The relevant section of the NAS recommendations is contained in Chapter 4, "Human Intrusion and Institutional Controls." This document indicates that "an assumption that inadvertent human intrusion can be prevented using management controls is not reasonable." This is a position with which the SMEs agree (based on their input on management controls). The NAS report also indicates that, on the time scale in question, "human institutions have come and gone." Again, the SMEs agree. However, the NAS then concludes "there is no scientific basis from which to project the durability of government institutions over the period of interest." From the perspective taken in this project, these statements are contradictory. Relevant information exists and has been recognized by the NAS (presumably based on anthropologic studies). This information can be used to judge the probability that, for example, institutional control will persist over given time frames. As indicated earlier, a Bayesian approach that requires establishing conditions and obtaining information that allows probability distributions to be assessed (either subjectively or using data) can and must be taken. In cases for which data cannot reasonably be collected, subjective input through expert elicitation is the only defensible alternative. If a probabilistic analysis is not performed, then no defensibility is provided for the conclusions because management of the uncertainties inherent in a complex problem cannot be documented easily.

As noted in Kotra et al. (1996), expert elicitation usually involves normative experts, generalists, and subject matter experts. The Project Team served as the normative experts for this study by providing facilitation, training, and knowledge of decision analysis, statistics, probability, and formal elicitation methods. The PA Team served as generalists for whom the results of this study are directly relevant, and who provided background information and training in the specific application. The role of the SMEs was to apply their expertise to the overall objective of model development and quantitative evaluation. In this study further participation was sought from a broader audience to include stakeholders (see Appendix B) and a Peer Review Group (PRG) (see Appendix A). The associated activities in this study go beyond normal requirements for an expert elicitation, but were considered crucial for a high profile project that ultimately could require concurrence from a wide variety of stakeholders.

The expert elicitation component of this project can be split into five components:

1. Pre-elicitation activities
2. Conditioning and Training
3. Model structuring
4. Quantitative elicitation
5. Evaluation

The pre-elicitation activities involved continuous interactions with the PA Team and the PRG, convening of a stakeholder workshop, and identification of suitable SMEs (see Appendix C). The main focus of these activities was to generate preliminary influence diagram models and an approach to assessing the probability of IHI, which had gained a level of acceptance, and hence credibility, amongst various peer reviewers and interested stakeholder groups.

The Project Team recognized the potential difficulty in presenting preliminary models to the SMEs. However, because the SMEs were contracted using criteria that required no direct knowledge of the problem, allowing them to initiate the entire process would probably have been too onerous. Any potential for bias could be overcome or at least mitigated by making it clear that the preliminary models were presented solely to help move the discussion forward in the early stages, and that a full and open discussion among the SMEs was expected to either confirm or modify these models. It was indicated very clearly to the SMEs that the role of the Project Team was to facilitate the elicitation, and the role of the PA Team and other observers during the elicitation sessions was to provide information if requested by the SMEs. These rules of participation were followed throughout, and the SMEs made some significant modifications to the preliminary influence diagram models (although the basic structure did not change). These changes demonstrate that the final models represented the SMEs views without substantial bias.

Influence diagrams were developed in the early stages of the project for the two basic scenarios (homesteader and community) and for the management controls module. The influence diagram structure was chosen because it is easy to use and understand. Influence diagrams have been in common use in decision analysis, policy analysis, and probabilistic assessment for the last 10 years. Used to provide a representation of a model that explicitly portrays the influences among the model variables, an influence diagram shows the essential qualitative structure of a model, unobscured by details of the numbers or mathematical formulas that may underlie it. This type of model provides an intuitive graphical view of the model structure portrayed as nodes connected with arrows. Each node depicts a variable of interest, and each arrow depicts a relationship, or an influence, between a pair of nodes (see influence diagrams in Chapter 4 and Attachments

D.2, D.6, and D.12). An influence arrow from one variable to another means that the value of the first variable directly affects the value of the second variable. Several nodes may impinge upon another node, depending on the modeled relationships among nodes.

Interactions with the SMEs consisted of three main phases: conditioning, structuring, and elicitation. The conditioning phase consisted primarily of providing the SMEs with sufficient information to be able to participate effectively in the elicitation sessions. This information included aspects related to the problem itself and the methods that would be used to obtain the expert opinion. While the experts were identified based on their knowledge of particular subjects deemed important for assessing the probability of IHI, it was recognized that they may not have sufficient site-specific knowledge pertaining directly to their individual expertise. Moreover, the experts would not have current or specific knowledge of the problem at hand because the conditions of their contracts required that they were not currently working on DOE/Nevada (DOE/NV)-related projects (see Appendix C). Consequently, background information had to be provided to the SMEs for them to be able to apply their discipline expertise to the problem of assessing the probability of inadvertent human intrusion.

It was also recognized that the SMEs would not be experts in subjective probability theory or elicitation techniques, although it was anticipated that at least some of the SMEs would be familiar with probabilistic concepts. To ensure that the SMEs could respond appropriately without bias when questioned on their area of expertise, both a probability workshop and an elicitation workshop were conducted for the SME Panel.

The second phase of the process related to structuring of the influence diagram models. As noted in Chapter 3, the form of the final models was determined by the SMEs. The objectives of the first SME panel session were to complete the conditioning and structuring phases of the elicitation process. The time between the two SME panel sessions was used to modify and refine the influence diagrams as necessary, and to prepare for the quantitative elicitation that occurred during the second SME panel session. This second phase included structuring of the management controls module, the homesteader scenario, and the community scenario. Further model structuring dealt with defining the distinction between homesteading and community settlements and establishing conditional independence assumptions among model components (e.g., between influence diagram models). Additional structuring also involved discussing the appropriateness of using basic assumptions of current knowledge of society and technology to underlie the basic approach and the issue of periodic re-evaluation of the probability of IHI, and addressing the issue of waste recognition if buried radioactive waste were to be brought to the surface inadvertently through well drilling.

One crucial part of the structuring process was to determine factors or variables that could be considered implicitly as opposed to explicitly. Explicit modeling of a factor resulted in inclusion of the factor in an influence diagram. Implicit modeling did not result in such an inclusion. There were competing needs for the model structure. At one extreme the probability of IHI could be assessed directly. A problem with such an approach is defensibility of the response. That is, such an approach might provide too little description or information to be able to adequately defend the answer. At another extreme a model could be constructed that includes very many factors (cf., an ultimate refinement in Savage 1972). Such a model could not be contemplated in any reasonable time frame. Somewhere between the two extremes lie models that reasonably approximate the underlying process, yet still provide adequate defensibility.

Savage (1972) goes on to discuss marginalization (neglecting distinctions between states) and conditioning (ignoring some states outright) by which the ultimate refinement can be reduced to provide a reasonable model. An example of implicit marginalization exists with respect to the management controls model, where the SMEs indicated that institutional control could be lost through means either voluntary (erosion of control) or involuntary (political instability), but that they could not sufficiently distinguish between the consequences of each possibility to warrant their separate evaluation. Instead, the SMEs were prepared to implicitly recognize the different mechanisms for loss of institutional control while explicitly evaluating the length of time until institutional control would be lost. An example of implicit conditioning occurred when the SMEs also considered loss of institutional control through catastrophic means. They determined that this possibility was not worth consideration and could be ignored.

Implicit modeling occurs, essentially, for every factor in the model. The influence diagrams ultimately represent a model that in the eyes of the SMEs, is sufficiently detailed to credibly or defensibly deal with the issue at hand, but not so complicated that factors included explicitly add to the complexity without adding significantly to the analysis. The SMEs were engaged in a full discussion of the consequences of implicit versus explicit modeling to ensure that the finalized influence diagrams appropriately reflected a model by which the probability of IHI could be assessed and defended.

After conditioning and structuring were completed, the third and final phase of direct interactions with the SME panel consisted of eliciting inputs to the finalized models. This was the main focus of the second SME panel session. During this second elicitation session, input to the management controls module and the homesteader and community scenario models was obtained.

Both the structuring and elicitation components were performed using group elicitation methods. There are a variety of methods available. The preference of the Project Team was to perform group elicitation in an open exchange of information among the SMEs. The theoretical difficulties of group elicitation are well known (e.g., Morgan and Henrion, 1995). Bayesian theory provides the most prescriptive approach to addressing such an elicitation problem.

There are several alternatives for overcoming or mitigating these concerns. One is to obtain input from each individual and specify a method of combining the information obtained from the different sources. A second is to provide the individuals within the group sufficient information that their conditioning events become shared, at least to some extent. The preference of the Project Team was to take the latter approach, partly because the SMEs were then able to share information openly, in which case all the participants could learn from each others' experiences, but also because it was the only method by which consensus could be achieved in general (with the exception of appointing a dictator). This approach does not guarantee that consensus will always be achieved.

Savage (1972) also, indirectly, can be used to support this approach to group elicitation. As noted above, Savage recognized that conditioning involves ignoring states of the world outright (i.e., assume they cannot occur), and that marginalization involves neglecting some distinctions between states. If the structuring process is effective it can be used to at least reduce the number of differences among the participants (SMEs). Perhaps experts can agree on distinctions between states that can be ignored (i.e., implicit modeling), and can agree on a broad set of assumptions or conditions. If this is the case, then the experts will naturally arrive at fairly common ground for the scope of their problem. This is not meant to imply that the process works perfectly and exact agreement on quantitative input can be obtained, only that the closer the agreement on conditions and margins, the greater the chance that reasonable consensus can be reached. This kind of consensus is best achieved by encouraging and realizing a full and open exchange of information or knowledge, as the Project Team attempted to facilitate with the SMEs.

Based on the results of the study, including the SMEs' evaluations of the elicitation process, it appears that the group elicitation approach worked well. There was only one question on which some SMEs significantly disagreed: the effectiveness of a simple placard or marker to deter intrusion. Even in that case the SMEs still agreed that the placard or marker would not be very effective. When the SMEs could not reach agreement their respective responses were used separately in the calculations. That is, both sets of answers were propagated through the influence diagram model (see Appendix E).

Following completion of the quantitative elicitation session, final interactions with the SMEs included quality assurance activities, such as obtaining SME approval of their inputs, review of a summary report, and completion of an evaluation questionnaire.

The first expert panel elicitation session was conducted at the Desert Research Institute in Las Vegas, Nevada from 8-11 July 1996. The primary purpose of the first session was to finalize the influence diagram models that would be used for the quantitative elicitation of the second session. The second elicitation session was conducted from 5-9 August 1996 at the same location. The two elicitation sessions were conducted in different ways. The first session, which primarily involved conditioning and structuring the influence diagram models, involved all the SMEs for all questions and issues. This was conducted as a largely unstructured elicitation session, although questions and issues were prepared to focus the SMEs and keep the discussion on track with respect to the project objectives.

The session was geared toward as full and open a discussion of the issues as possible given the need to fulfill project objectives within the allotted time. To further facilitate model structuring, the SMEs were also asked to provide written responses to these questions. The function of the Project Team was to encourage open discussion, but also to ensure that project objectives would be met within the time frame available.

The second session involved a more structured approach, in which smaller groups of SMEs with expertise that pertained to specific questions were involved directly in the responses, whereas the remainder of the SMEs were asked to provide observations and comments as they deemed necessary. For example, specific questions related to the distance apart of replacement wells were addressed primarily by the SMEs with well drilling experience; and the issue of length of institutional control was addressed primarily by the anthropologist and sociologist.

The remainder of this appendix focuses on the five components of the elicitation approach listed above. Several attachments that support the elicitation are included. Other documents, such as the background information documents, the original copies of the SMEs' responses to prepared questions, transcriptions of flip chart notes, transcriptions of notes taken by the project team, and tapes of the panel session are available as archived documents of this report.

D.2 PRE-ELICITATION PROCESS

The purpose of this section is to describe model development prior to convening the SME panel. Initial models were developed by the Project Team with input from the PA Team and the PRG. These models were presented to the Stakeholder Workshop participants for their review, which resulted in some modifications to the influence diagram models (see Appendix B). Preliminary models were developed before the first SME panel session, and they were used as the starting point for obtaining SME input.

The standard calculation of the probability of IHI into buried low-level radioactive waste involves development of an appropriate exposure scenario (the homesteader scenario), and implicit assumptions regarding the loss of management controls. The problems faced during initial model development were to assess the validity of the implicit assumptions as they might apply to NTS Radioactive Waste Management Sites (RWMSs), and hence to assess the probability that IHI will occur. It was realized that site-specific factors should be taken into account when assessing the potential for IHI to occur, and that such an approach is consistent with regulatory guidance (DOE 1988) and interpretations of that regulatory guidance (e.g., Case and Otis 1988). Two concerns were soon recognized. First, assessment of the probability of IHI occurring during the next 10,000 years appeared, initially, to require an assessment of the future. Second, if site-specific factors were to be taken into account, the standard homesteader scenario might be an inadequate representation of the scenarios by which IHI might occur.

Regarding the problem of assessing the future, research confirmed that there is an extremely wide range of views on what the future might hold (e.g., Hora et al. 1991), and that it is therefore not practically possible to bound the future. To overcome this potential problem, the Project Team decided to focus the study on current, plausible scenarios requiring re-evaluation of the base assumptions periodically or as changes in knowledge of current societal and technological practices are clearly observed to occur. Through this approach, speculating on the future is avoided, and dealing with current knowledge of society and technology provides a tangible basis for subjective assessment.

To address the second concern, an additional intrusion scenario (the "community" scenario) was developed to reasonably account for the possibility that future communities could impact what is now the NTS. Two basic scenarios would be offered to stakeholders and SMEs: homesteading and settlement via a community. Addition of the community scenario dealt with one aspect of site-specific conditions, namely that it seemed just as reasonable to consider a future community in the vicinity of the areas now occupied by NTS RWMSs, as it was to consider future independent homesteading in this area. This aspect, however, does not deal directly with possibilities within the homesteader scenario. For example, telecommuting, ranching, farming, and more stereotypical subsistence homesteading scenarios might also be envisioned given current knowledge of society and technology. Deviations from the standard homesteading scenario, as indicated in Case and Otis (1988), would be accounted for implicitly by framing all scenarios as either falling under the homesteading or the community definition. The final decision on admitting both of these scenarios, and the distinction between the two scenarios, would remain with the SMEs.

An apparent difficulty with the overall approach is that the exposure scenarios are evaluated as if management controls are ineffective, even though the basic premise of the approach is to assume current knowledge of society and technology and project that knowledge for 10,000 years. Clearly, management controls are effective now; so current knowledge includes effective management controls. However, there is no potential for IHI while management controls are effective. The underlying probabilistic assumption that must be addressed, then, is the probability that IHI will occur during 10,000 years conditional on current society and technology practices and ineffective management controls. As conceived in the logic of preparing the preliminary models, the final requirement of the elicitation must be, therefore, to assess the effectiveness of the management controls. The SMEs later modified and finalized the models.

The preliminary modeling process was split into three manageable components: the management controls module, the homesteader scenario, and the community scenario. Further considerations included defining dependencies among these modules and a distinction between homesteading and community settlements. Also considered were the potential benefits of revisiting the probability of IHI periodically or as conditions are observed to change substantially. Waste recognition issues were also discussed (for example, if the waste is recognized upon IHI then chronic exposure would be assumed to not occur, and only acute exposure would be possible). Preliminary positions on all of these considerations were established with the idea that all issues were to be taken to the PA Team, the PRG, interested stakeholder groups, and to the SME panel for validation, modification and refinement, as necessary. As it turned out, the models were modified and refined throughout the process, but the basic forms survived the scrutiny of the various audiences.

Preliminary influence diagrams are included in “Influence Diagrams Report,” (Black, et al., 1996), which is appended as Attachment D.2. This report was provided to the SMEs in the information package (see Section D.3). The SMEs had a significant impact on some aspects of these influence diagrams, although the basic forms of the models remained the same. The changes made by the SMEs are described in detail in Section D.4 below.

D.2.1 Preliminary Management Controls Module

The probability of IHI is influenced by a number of factors that are included under the item “Management Controls.” The term “Management Controls” is used to encompass aspects of potential future management of buried waste. The basic premise of the model is the goal of deterring IHI into deeply buried waste, such as what would be found at the Area 3 and Area 5 RWMSs. Meeting this goal corresponds to deterring drilling of a water well at the waste site. Accordingly, the influence diagram for the Management Controls module was set up initially to include the following elements: the effect of continued institutional control, the effect of knowledge about the location of the buried waste, the potential effectiveness of placards and markers that might deter drilling for water, other site recognition factors that might deter drilling for water, and the effectiveness of subsurface passive barriers that might deter completion of drilling.

Initial assessment of inadvertent human intruder probabilities in the preliminary models for the homesteader and community scenarios made the following specific worst case assumptions for these Management Controls: institutional control is lost, site knowledge is lost, placards and markers are ineffective, the location of the buried waste is not known or recognized, and passive barriers are ineffective. These extreme assumptions can be relaxed through the Management Controls module. Relaxing these assumptions allows the conditional scenario probability to be modified to account for the possibilities that institutional control and site knowledge are not lost, or that placards and passive barriers are effective deterrents to drilling.

For several of the factors described above two different measurement methods could be appropriate: probability of enduring for 10,000 years; or, cumulative probability of enduring for shorter time periods. The important point in these initial model development stages was to try to identify the relevant factors and to offer alternatives for how they should be modeled. The SMEs would choose the measurement method to be used during the elicitation process.

Finally, the influence diagram model for the management controls module indicated how the management controls outcome would be used to modify the scenario probabilities. The result of the direct multiplication of probabilities to accomplish this combination (see Appendix E for details) provides an assessment of the probability of IHI for each scenario. The next two sections provide brief descriptions of the homesteader and community scenarios as they were modeled prior to input from the stakeholder groups and the SMEs.

D.2.2 Preliminary Homesteader Scenario

The basic approach initially established for the homesteader scenario was to determine the total number of wells that might be drilled in a larger area than the waste footprint. The final probability would then be estimated by calculating the probability that at least one of those wells would be drilled into the waste site.

A number of factors were initially seen as required to fulfill those objectives. The first was a definition of "similar desert area" that could serve as a basis for determining a localized well count. This well count could then be used to determine well drilling possibilities. Once the similar area was established, the remaining factors to be considered included either the number of wells currently active in that area, or expected lifetimes of wells. From this information, the total number of wells to be drilled during the compliance period could be assessed, and the probability that at least one well would intersect the waste area could be calculated.

This simple form of the model does not fully convey the complexities that could be involved with assessing the requisite probability, but many of the intricacies were to be determined or resolved by the SMEs during the first session. For example, the number of wells could be obtained from the number of homesteads (if an assumption of one well per homestead is made), further, homestead lifetimes could be used to help determine the number of wells drilled in the compliance period. Many possible methods are available for translating the findings on number of wells and well lifetimes into a final probability. Many of the decisions on how to finally form the model, and how to perform the final calculations depended on input from the SMEs.

D.2.3 Preliminary Community Scenario

Assessment of the probability of IHI for the community scenario was expected to be performed in a manner similar to that used for the homesteader scenario. Differences were expected because the actual location of a future community cannot be known for certain. Consequently, not only must well density be considered, but the number of communities in the vicinity must also be considered.

The first step, therefore, was anticipated to involve assessing the number of communities in the similar desert area, followed by determining the probability that a community would encompass the waste site (i.e., by extrapolating from similar desert area to the RWMS areas). The next step was to determine the probability that a community water supply well would intersect the waste site if a community was appropriately located. This next step was expected to follow basically the same course as for the homesteader scenario, although with different inputs to the models. That is, assess the number of wells in a community and assess well lifetimes to calculate the total number of wells in a community that might intersect the waste area, and then spatially locate those wells within the community according to constraints on well separation. This mechanism would determine the probability that a well intersects the waste site.

Consequently, it was anticipated that the probability of IHI for the community scenario would be determined from the number of communities in the similar area, possible locations for those communities, the number or distribution of wells in a selected community, selection of well locations in a community, and the possibility of locating a well in the waste disposal area.

D.3 CONDITIONING

This section describes the conditioning activities conducted to ensure that the SMEs could participate effectively in the elicitation sessions. The first component of the conditioning phase involved providing background information on the NTS RWMSs, burial of low-level radioactive waste, the physical setting (geology, hydrology, etc.), and any other relevant factors. The second component dealt with teaching probabilistic concepts and the possible approaches to quantitative elicitation once the influence diagram models were finalized by the SMEs.

Care was exercised throughout these conditioning stages to ensure that the SMEs received only background information, thus avoiding the potential for biasing their input. Inclusion of preliminary influence diagrams in the information package could be considered an exception to the provision of background information only. However, as discussed in Section D.1, this was seen as both pertinent background information and as a necessary starting point to facilitate the elicitation. Care was taken to control any potential for biasing by involving stakeholders in the preliminary model development, and it was clearly explained to the SMEs that the purpose of these initial models was to help focus the initial stages of the elicitation and that all aspects of the models were to be considered, refined or modified, and finalized by the SMEs.

The following sections first describe the background information provided to the SMEs and the chronology of the corresponding activities, and then describe the probability and elicitation training sessions.

D.3.1 Chronology

The main purpose of providing the SMEs with background information was to enhance the SMEs' objective input to the elicitation process. The first interactions with the SMEs involved a request for proposals, including a scope of work, which provided the SMEs with an initial sense of the purpose and scope of the project. These activities are described in Appendix C. After selection of the ten SMEs, and before the first elicitation session, an information packet was mailed to each SME. The opening event for the first elicitation session was a day-long field trip to the NTS. On the second day, further background information presentations were made to the SMEs by members of the PA Team. Following these presentations, the Project Team introduced the preliminary influence diagrams (which were included in the information package), and the model-structuring task began.

The PA Team was available throughout the elicitation sessions to provide any further background information requested by the SMEs. The availability of the PA Team proved beneficial for a number of background technical issues, including physical characteristics of Frenchman Flat and Yucca Flat. The PA Team and representatives of the Desert Research Institute also provided maps and charts emphasizing characteristics of interest, at the request of the SMEs.

Two other conditioning functions initiated in the first session, following structuring of the models, consisted of a probability training class and a request from the Project Team for the SMEs to indicate any further information needs. The objective of the final step was to ensure to the extent possible that the SMEs would have access to all the information that they felt might enhance their understanding of the problem. This activity was termed the "data call." The importance of this activity to the Project Team was to attempt to provide the SMEs with as common a knowledge base as possible to ensure to the extent possible consensus among the elicited inputs during the second elicitation session. Probability training was provided at this stage to provide the SMEs with a sense of the requirements and challenge of the second session, which would focus on quantitative elicitation.

Although the primary focus of the first session was structuring the models, and the focus of the second session was elicitation, conditioning steps continued throughout the sessions as necessary. The models were not finalized until the beginning of the second session. The three week interval between sessions was used by the SMEs to continue with the conditioning steps through the data call, and by the Project Team to assimilate the information collected from the first session. The second session started with a few more PA Team presentations pertinent to the needs identified by the SMEs, continued with a recap of the first session and presentation of the revised influence diagrams, and finished with a brief reprise of the probability training. Elicitation training was also provided to familiarize the SMEs with expectations of the quantitative elicitation methods that would be used in the second session.

D.3.2 Background Information

The following sections provide more detail of the background information that was provided to the SMEs, including the information package, the field trip, background presentation materials from both elicitation sessions, and the data call items.

D.3.2.1 Information packet

The SMEs were provided with an information packet before the first SME panel session. The objectives of providing introductory and preliminary information were threefold: 1) to engage the SMEs, 2) to focus the SMEs on the problem of assessing the potential for IHI to occur, and 3) to provide sufficient background material that the SMEs could come to the first panel session with specific ideas and questions related to the project. The information packet was provided in two steps, each with accompanying cover letters. Attachment D.1 includes the cover letters and a reference list of the items included in the packet. The full information packet is included in archived documents of this report.

This information provided to the SMEs included general NTS information such as fact sheets, the draft Environmental Impact Statement (which was undergoing stakeholder and public review at the time of distribution), and information on the hydrogeology, climatology, biology, anthropology, and archeology of the NTS. Some background material was also provided on the regulatory basis for PAs, with emphasis on the inadvertent human intruder scenario, and on waste disposal operations and historical DOE waste management practices. The SMEs were also provided with preliminary influence diagrams in the form of a report (see Attachment D.2) and a tentative agenda for the first session.

D.3.2.2 Field trip

The first SME panel session opened with a site tour of the NTS. The agenda for this field trip is included in Attachment D.3. This field trip included stops at several points of interest relevant to assessing the probability of IHI. The SMEs were encouraged to request stops at other potentially relevant sites on the field trip.

The drive out to the NTS from Las Vegas (where the elicitation sessions were held) passes through approximately 60 miles of desert area that is similar physically to the areas around the RWMSs. This area is generally considered northern Mojave desert type, although RWMS 3 in particular falls in a transition zone to the southern Great Basin desert.

On the drive to NTS some presentations were provided by members of the PA Team on issues such as population growth of Las Vegas, geology and hydrology of the surrounding areas, socioeconomic conditions of Nye and other proximal portions of adjacent counties, and the history of water consumption for the Las Vegas area (see Attachment D.4). Some of these discussions continued throughout the day, particularly concerning local hydrology. Observations were made on the aquifer system, including effects of nuclear testing in the aquifer system, the depth to groundwater around the RWMSs, and the directional flow of the aquifers.

The first stop on the tour, after passing through the NTS support town of Mercury, was the aboveground nuclear testing area at NTS. The next stop was RWMS 5, located in Frenchman Flat, at which methods of waste disposal were illustrated and discussed. Following the RWMS stop, the SMEs were taken to a lysimeter experimental station where information was exchanged on water content in the soil and on rainfall and evapotranspiration at NTS. In the afternoon, the SMEs were taken to the Area 3 RWMS in Yucca Flat, where exploitation of subsidence craters for burying waste was demonstrated (note that waste at Area 3 is disposed in these craters, whereas at Area 5 waste is disposed in man-made trenches and pits). From there, the SMEs were shown Sedan Crater, which is the largest crater formed from underground testing at NTS. Discussion at this stop pertained to the magnitude of the nuclear testing, particularly the mobility of radionuclides in groundwater, and the levels of radiation received while standing at this site. The last point of interest within NTS boundaries on this tour was Cane Spring, one of very few perennial sources of surface water within NTS. Discussions at this stop focused on availability of surface and groundwater at NTS, and on past human activity at NTS. After leaving NTS, the SMEs were taken to one of the extant communities, Amaragosa Farms, located just outside NTS. Discussion at this stop related primarily to depth to groundwater and well density within the community. The SMEs were also taken to two springs in the vicinity, Devil's Hole and Crystal Spring.

D.3.2.3 Presentations

During both SME panel sessions, presentations were made to the SMEs to provide background information about the problem at hand. The presentations during the first session focused on the PA and composite analysis (CA) performed for the NTS RWMSs, and an overview of the roles and responsibilities and organization of the first session. The PA Team presentation focused on background information, including the location of the sites, types of waste that might be disposed at these RWMSs, the environmental setting, environmental management objectives of protection of human health and the environment, regulatory compliance and a brief overview of the findings of the PAs performed to date. The second presentation was conducted by the Project Team and provided an overview of preliminary assumptions and conditions, and the preliminary influence diagram models. Use of the available information with the SMEs expert knowledge was emphasized to develop influence diagram models that would be used during the second session to focus the quantitative elicitation. These presentation materials are appended as Attachments D.5 and D.6.

During the course of the first SME panel session, further data needs were identified by the SMEs. Some of the information requested was presented at the beginning of the second

SME panel session. The first presentation at this session focused on waste types and disposal configurations. The second focused on site conditions of the waste disposal areas (RWMSs) and the closure program for the RWMSs. The third was a recap of the first session, including how the input from the first session was used to refine and modify the influence diagram models.

The first presentation (Attachment D.9) focused on the Performance Assessment and Composite Analysis for the RWMSs. This presentation included discussion of: radioactivity; regulatory definitions of radioactive waste types (e.g., low-level radioactive waste, high-level radioactive waste, DOE regulated 11e(2) byproduct materials); Fernald OU4 11e(2) byproduct waste which might have been the first application of this probabilistic analysis; waste disposal configurations (e.g., boreholes, shallow burial trenches, and deeper burial pits); and, why well drilling is the most viable inadvertent human intruder scenario for this project

During the course of the first SME panel session, further data needs were identified by the SMEs. Some of the information requested was presented at the beginning of the second SME panel session (Attachments D.10 and D.11). The SMEs requested this information in part because they had indicated that it was difficult to evaluate management controls without more specific information on DOE's intentions. They requested information on the designs of engineered barriers and placards and markers in particular, so that they could better evaluate the potential efficacy of these specific management controls options. The presentation also indicated that the only waste for which this probabilistic assessment will be applied is waste that is buried deeply enough that no inadvertent human intruder mechanisms other than drilling are viable.

The last presentation at the beginning of the second session was given by the Project Team (see Attachment D.12). This presentation provided a recap of the first session, focusing mainly on assumptions and conditions that had been developed by the SMEs, and the input from the SMEs that led to some significant changes to the influence diagram models. Also presented was an agenda for the second session that indicated how the elicitation session would be conducted. The revised influence diagrams were presented for discussion to ensure that they captured the SMEs intent.

Throughout both SME panel sessions, representatives of the PA Team were available to provide further background information as needed. For example, impromptu presentations were given on hydrology, placards and markers that have been considered for use at NTS, subsurface and surface barriers that have been considered at NTS, maps showing the general geographic region of NTS and its environs, and information pertaining to the underground nuclear testing programs at NTS. Every attempt was made to ensure that the information was provided as objectively as possible to avoid the potential for biasing the inputs of the SMEs. This type of information was, in general, provided only at the behest of the SMEs.

D.3.2.4 Data Calls

Throughout the first session the SMEs were provided the opportunity to request additional information as needed to assist the quantitative assessments required in the second SME panel session. A number of data calls were made. The information contained in these data calls was used primarily as indirect support for positions taken by the SMEs. That is, none of the questions posed in the second SME panel session were answered based on hard data. Rather, the SMEs requested information that enabled them to be more confident in their judgments during the second session.

A reference list of items included in the data call is provided in Attachment D.8. A copy of all the data items requested is compiled in archived documents for this project. The type of information requested included geographical studies regarding the physical effects of radiation on the soil and vegetation directly over current radioactive disposal areas. Also requested were surficial soil surveys, detailed topographic contour maps, summary reports on geochemical analyses, and location maps of drill holes and surface sample locations. Further requests included hydrological studies, including safe yield or production estimates for alluvial aquifer, tuff aquifer, lower carbonate aquifer, and flood assessments; and socioeconomic information, including characteristics of settlements in Nye and Lincoln counties, population statistics, and number of land parcels and wells for Nye, Lincoln, and rural parts of Clark counties. Information requested on waste management included waste type and volume projections; references regarding the durability and life span of engineered materials for passive barriers, closure caps and waste containers for the waste sites; studies regarding the penetrability of subsurface passive barrier materials; and summary information regarding the extent of contamination from underground testing. Each item requested was not, in general, requested by all ten SMEs. For example, the geotechnical engineer was primarily interested in information regarding closure cap design and barriers that were under consideration by DOE. The anthropologist, sociologist, and demographer were most interested in the demographic information pertaining to Nye, Lincoln, and Clark counties. The economic geologist, hydrogeologists, and well drillers were most interested in the physical characteristics.

The data call information was assembled by Bechtel Nevada and distributed to the SMEs as items were obtained. Some of the data call items were handled through presentations at the beginning of the second session as described in Section D.3.2.3.

D.3.3 Probability and Elicitation Training

In order to prepare the SMEs for the quantitative elicitation of the second SME panel session, brief training workshops were held on probabilistic and elicitation concepts. These activities are also considered part of the conditioning phase of this study; however, they differ significantly in intent. As opposed to providing background information on the problem at hand, these training workshops were held to share information with the SMEs on technical requirements of the elicitation phase.

D.3.3.1 Probability Training Workshop

The purpose of this workshop was to ensure to the extent possible that the SMEs were sufficiently familiar with probabilistic concepts that they could respond effectively when questioned directly on matters within their field of expertise as it relates to the potential for IHI to occur. The probability training workshop was developed and presented by a member of the PRG (Dr. William Roberds of Golder Associates, Inc.). The presentation materials used are included as Attachment D.7.

The probability workshop first introduced the concepts of uncertainty and variability in parameter values leading to the idea of probability distributions. Both continuous and discrete probability distributions were discussed because both types of distributions were anticipated for different factors in the influence diagram models. The concept of probability distribution quantiles was also discussed because quantile assessment was to be used as a primary component of the elicitation techniques. Finally, a set of questions was posed to the SMEs on issues outside their areas of expertise for which quantile responses were requested. The intent was to familiarize the experts with providing quantitative probabilistic input to a question and also to demonstrate to the experts some of the types of biases to be avoided during the elicitation session. In addition the set of questions was used to demonstrate to the SMEs that improvements could be made in their responses through continuous feedback and comparison to known quantities. The exercise was initially performed at the end of the first session, and was repeated at the beginning of the second session. The performance of the SMEs noticeably improved between trials.

The probability training was first presented at the end of the first SME panel session, and was reinforced at the beginning of the second session. As expected based on their qualifications, many of the SMEs clearly had a grasp of probabilistic concepts. This workshop provided an opportunity to focus on probabilistic assessment as it relates to the potential for IHI to occur.

D.3.3.2 Elicitation Training Workshop

Following the probability training workshop at the beginning of the second session, an elicitation training workshop was also conducted. The main purposes of this training workshop were twofold: 1) to familiarize the SMEs with the elicitation techniques that are available and hence, to determine the elicitation methods with which they were most comfortable; and 2) to discuss the types of elicitation biases that are well documented in cognitive psychology literature (e.g., Kahneman et al. 1982). This objective was included so that the potential for biasing could be managed effectively. The focus of this workshop was the elicitation phase. That is, models were already developed (by the SMEs) and the next step was to provide quantitative input to fully specify the model parameters. The presentation materials used in the elicitation training workshop are included as Attachment D.13.

D.3.3.2.1 Elicitation Methods

Elicitation modeling involves defining methods for obtaining SME opinions that provide useful and pertinent input to the model parameters and that can be obtained by asking questions at a cognitively appropriate level. It is important to develop an elicitation process that allows for questions with which the SMEs are sufficiently familiar, so that answering the questions is not cognitively challenging beyond their domain of expert knowledge. In particular, it is not appropriate to ask questions about probabilistic or statistical parameters that are artifacts of a statistical model (i.e., in this case probabilistic or statistical functions that underlie a node in the influence diagram). Statistical models are made available to render difficult problems mathematically tractable. In general, statistical models are sought that adequately represent the underlying process while reducing the problem to a manageable scale. For elicitation models it is important to ask questions that are natural to the domain expert, but such that the answers to the questions can be translated into terms which fulfill the specifications of the statistical model.

A number of elicitation methods were discussed with the SMEs either directly or indirectly. These included variations on both indirect and direct probability assessment. All approaches essentially require either an assessment of a probability for a given value of the parameter of interest (e.g., asking for the probability that institutional control of the waste site will be lost within the next 500 years), or an assessment of a value of the parameter of interest given a probability (e.g., asking for the value, in years, at which there is an equal chance that institutional control will be lost before or maintained longer). Most of the methods used in the SME elicitation used a mixture of the two approaches as the SMEs became more familiar with the elicitation requirements.

Initially, examples were presented to the SMEs that allowed for indirect assessment of values given a probability. Examples were given in this manner so the SMEs would not become anchored to certain values. For example, it was proposed to the SMEs that the there was a greater than 50% chance that institutional control would last longer than 10 years, and it was suggested that there was a greater than 50% chance that institutional control would not be maintained for longer than 5,000 years. Thus extremes were offered based on input from the first SME panel session. Then values between these two extremes were offered until the SMEs indicated that they could no longer choose one side over the other. Other examples were also used that focused on the annual rainfall that might occur in Frenchman or Yucca Flat. While this variable was not included explicitly in the finalized influence diagram models, it was related to the problem at hand sufficiently that some valuable insights into the elicitation process could be obtained.

More direct elicitation methods were also suggested, such as comparison of the probability of interest with a randomization device such as a probability wheel, or more tangible devices such as die rolling, coin tossing, or probabilities related to decks of cards. For the most part, the SMEs rejected this sort of approach, indicating that comparison using auxiliary experiment was not necessary.

Several methods were shown to the SMEs, and input was sought on the methods with which they were most comfortable. The SMEs indicated that quantile elicitation was sufficient at the beginning, but that they envisioned that more direct assessment would be appropriate as the session progressed. Hence, the main method used at the beginning of the elicitation session to fully define a probability distribution was to continually halve the quantile of interest until no further useful information could reasonably be obtained. The process worked by first asking about some extreme values, then asking about a middle ground (i.e., the median). Median assessment methods as described in Raiffa (1970) were used to assess the 25% quantile value, then the 12.5% quantile value, etc., and also to ask for the 75% quantile value, then the 87.5% quantile value, etc. Through this method, questions could always be posed in terms of "which is more likely?." Alternative approaches, such as asking if one set of possibilities is twice as likely or five times as likely as another set of possibilities, often are difficult to administer because of the lack of sensitivity around larger ratios. As the session progressed, the SMEs required less assistance with specification of a distribution; they became more prepared to offer their own valuations on a distribution directly.

The final elicitation technique demonstrated in the training workshop was to present back to the SMEs distributions obtained during elicitation, and to read off "consequences" for other quantiles or values. The SMEs indicated their preference for this type of feedback, hence this mechanism was used during the elicitation session to verify or validate their initial input, and to allow adjustments as they deemed necessary.

D.3.3.2.2 Bias Mitigation

The second issue discussed during the elicitation workshop concerned biases that might be exhibited during the elicitation, and methods by which these biases might be mitigated or at least recognized. It is well recognized in cognitive psychology literature that untrained humans are very fallible when it comes to assessing expressions of uncertainty (cf., Kahneman et al. 1982). Biases fall into two main categories, termed motivational biases and cognitive biases.

On the issue of motivational biases, the elicitation presentation indicated primarily that the SMEs' individual objective opinions were being sought, and these opinions should not be muddied by perceptions of DOE management or the elicitor's opinions (management bias), or perceptions of conclusions that other experts have come to for other similar studies (peer pressure bias). It was also indicated that the SMEs should not err on the "safe" side with any of their inputs, because the statistics underlying the process would take care of conservatism more appropriately. The SMEs were also told that they must not provide responses on the basis of their own best interests, and that it was acceptable for one or more of them to disagree, although the ideal situation would be for the relevant experts for a given question to come to consensus. If this was not possible, then their differing views would be represented in the final analysis.

The existence of cognitive biases was also demonstrated. These included anchoring on starting values (insufficient adjustment), relying too heavily on availability of easily recalled information, relying on how representative an instance is of stereotypes, ignoring base rates (i.e., actual rates of occurrence of related phenomena), overestimation of small probabilities, and insufficient accounting for the effect of conjunctive events. These types of biases are well documented (cf., Kahneman et al. 1982). It was indicated that one purpose of convening a panel of SMEs is, in part, to mitigate the tendency for some of these biases to emerge. For example, the availability and representative biases should be mitigated to some extent because the SMEs should have a broad knowledge of their field of expertise. However, it was indicated that if such biases were suspected during the elicitation, further discussion would be encouraged to broaden the base of knowledge or the perspectives from which responses were provided. It was also indicated that these types of biases could be overcome, in part, by providing sufficient background information, which is one of the primary reasons the SMEs were given so much background information.

Direct elicitation methods were also discussed that could be used to mitigate some of these biases. For example, it was demonstrated that eliciting information first about extreme values forces adjustment to the center. Adjustment is then performed from both ends of the distribution, ensuring, in a sense, that sufficient adjustment must occur. The potential for countering biases was also demonstrated by asking for the same information in different ways (e.g., asking for quantile values given probabilities, asking for probabilities given quantile values, and validating the elicited distributions by indicating some further consequences of the elicited input).

Finally, it was recognized that these types of biases are more difficult to counter when dealing with emotional issues. Because disposal of radioactive waste can certainly be an emotional issue, the importance of contracting SMEs who could be objective about the problem at hand is underscored. As mentioned earlier, such objectivity was a selection criterion for the SMEs. In particular, it was indicated that the problems associated with biases, whether motivational or cognitive, are not insurmountable, but that it is extremely important to design an elicitation session that can obtain subjective information as objectively as possible.

D.4 STRUCTURING

The types of information described in Section D.3 were used to condition the SMEs with respect to expectations of their participation. The next step in the process was for the SMEs to structure the influence diagram models, and to assess the basic assumptions of the approach being taken. As indicated earlier, the Project Team prepared initial influence diagrams, which were subject to PA Team and PRG reviews as well as to interested stakeholder review and comment. These initial influence diagrams served as the starting point for the structuring stage of the process. The purposes of this section are to describe how the structuring phase of this study was facilitated, to provide a more detailed description of the SMEs' input to the structuring phase, and to provide a summary of the formal questions asked and the discussion, responses, and rationale for the SMEs' input.

The structuring phase was facilitated by the Project Team, while members of the PA Team were in attendance and were available to answer questions as they arose. Representatives of the PRG also observed the structuring phase. The Project Team presented information on the preliminary influence diagrams to provide a foundation for a series of related questions. The SMEs were asked to jointly and openly discuss issues related to the questions asked, and then to provide individual written responses. All SMEs were involved in all aspects of the structuring phase. The purpose of the discussion was to ensure that the SMEs understood the issues and adequately shared information to be able to provide the rationale for their responses. It was considered crucial to the credibility of the project that the SMEs' rationales for the model structure were clearly documented.

Several structuring steps were required: determining base assumptions; discussing periodic re-evaluation of the potential for IHI; defining the management controls module and the distinction between the homesteader and community scenarios; modifying the homesteader scenario and community scenario influence diagrams; identifying conditional independence assumptions or correlations between influence diagrams; and discussing issues pertaining to waste recognition should the waste be brought to the surface through drilling for groundwater.

The following information is based on written responses to specific questions for each issue. Questions were asked at two different "levels." Level 1 included general questions aimed at introducing the topics and stimulating SME thinking and discussion about these topics. Level 2 questions were more specific in nature based on the responses to the Level 1 questions. The following sections are presented in the order that they were discussed by the SMEs: base assumptions (including periodic review of intrusion), management controls, homesteader scenario, community scenario, and other issues. For each section a summary of the structuring process is provided, followed by a presentation of the highlights of the SME discussion, their responses to the questions, and rationales for their responses. Full details of the SMEs opinions can be found in the archived documents of this report.

D.4.1 Base Assumptions and Periodic Review

The base assumptions for the approach to assessing the potential for IHI to occur were provided to the SMEs to obtain their input in the form of comments and observations. The most basic assumptions behind the approach concerned the issue of conditioning on current knowledge of society and technology, and the related issue of periodic review of IHI or re-evaluation if the relevant knowledge base is seen to change substantially. While the base assumptions could not be changed, it was important to understand the position of the SMEs on these issues. If the SMEs did not agree with the approach, the results and conclusions would lack credibility even if the elicitation was still conducted. It should be noted that the PA Team had reviewed the approach with mixed results, although the majority were in agreement. The PRG had also reviewed and agreed to these basic assumptions. Finally, the stakeholders who attended the stakeholder workshop in April (see Appendix B) were in strong agreement that this was not only a reasonable approach, but that any other approach would be unlikely to produce credible results. Information about PA Team, PRG and stakeholder reviews of the basic approach was not shared with the SMEs. Again, the goal was to obtain from the SMEs objective input that was not tainted with the views of other participants in this study.

After discussion of the issues, the SMEs strongly approved the basic approach. The SMEs agreed that dealing with current knowledge of society and technology was the only credible path toward being able to assess the potential for IHI over the course of the next 10,000 years. Their reasoning was that the future is largely unknowable and that the only possible prediction of the future comes from what is known of the past. The SMEs also strongly agreed with the need for re-evaluation of the potential for IHI to occur periodically or as the relevant knowledge base changes substantially. Suggestions for periodic review every 10–25 years, were consistent with stakeholder input from the April workshop. It was recognized that some form of financial trust would have to be put in place to ensure that periodic review could occur, and that some form of review capability must be put in place to ensure that the problem would be re-evaluated if the knowledge base changes. SMEs noted a further benefit of a periodic review mechanism for this type of program: while periodic reviews are required there may be an increased probability that the government or another institution would maintain control of the waste disposal facility. Further, a periodic review mechanism might lead to consideration of other options should knowledge change to warrant it (for example, another 20 years of risk analysis technology might determine that the buried waste is either more, or less dangerous than currently thought).

Finally, it was recognized that, once the waste is buried at NTS, the decision problem changes from one of waste burial to one of waste exhumation. If the decision were to be made in the future to exhume the waste, then sufficient funding would have to be made available to accomplish the task.

In summary, the SMEs' collective opinion was that dealing with current knowledge of society and technology as it pertains to buried radioactive waste and the potential for IHI to occur was strongly accepted as a basic premise for the approach. Periodic review was strongly encouraged both to ensure protection of potential inadvertent human intruders, and to enhance the probability that institutional control and site knowledge could be maintained. A further recommendation was that sufficient funding be made available now to be able to cope with future changes or consequences of actions taken at this time.

The next related issue was to provide a working definition of the concept of current knowledge of society and technology. It was agreed that a suggested notion of current conditions was too limiting because, for example, there is current knowledge of population trends. Consequently, current knowledge was given as broad a definition as possible. Futuristic notions of society or technology were dismissed, but all relevant current knowledge was admissible, including projections based on current knowledge. This was a definition with which the SMEs felt comfortable without needing to place any more specific conditions on this assumption. It was also agreed that if there were any concerns about specific issues they would be handled as they arose.

There are a few other underlying assumptions, related to the influence diagram models and their interrelationships, that were also discussed. The homesteader and community scenarios would be evaluated as if all management controls are ineffective, and then the potential effectiveness of management controls would be evaluated to balance the equation. There was also a discussion about the standard homesteader scenario as presented in regulatory interpretations. The discussion centered on how the assessment of the probability of IHI would differ from the exposure assessment, which would still use a standard exposure scenario that would be applied to all versions of homesteading and community settlements. By contrast, no limitations were to be placed on those variations for assessing the potential for inadvertent human intrusion.

The final issues relating to assumptions concerned the distinction between homesteading and community settlement, and the inter-relationships between the influence diagrams. Because the wide range of possibilities and the multidimensional nature of the definitions made it extremely difficult to completely separate the two concepts, the SMEs chose to arrive at a working definition of the distinction, as opposed to a well-specified distinction. The working definition of the two scenarios hinged on the number of wells and existence of infrastructure. The working definition of a homestead was taken to consist of a settlement that had no fewer than one well per household and had no infrastructure or shared resources among households. This definition was based on expectations that homesteaders desire relative isolation from community settlements. Communities were alternately defined in terms of less than one well per household, the availability of a community water supply system, infrastructure, and shared resources.

One outstanding question concerned the impact of the community and homesteader scenarios on assessment of the management controls module. That is, should the management controls module be evaluated differently for the two different scenarios? It was quickly determined that evaluation of the management controls would not be affected by the type of scenario, primarily because the conditions for homesteading and community settlements in the area were precisely that all management controls are ineffective, and that current knowledge of society and technology is assumed. Consequently, there is no reason to evaluate management controls conditional on the scenarios.

Other conditions that were given to the SMEs concerned the compliance period, which was to be fixed at 10,000 years, the location and size of any buried waste, which would be determined by DOE/NV at a future date, and limitations on the types of subsurface barriers that could be contemplated based on cost effectiveness and available resources. The SMEs were informed that their input would result in all inputs required for determining the probability of IHI, with the exception of the areal size of the waste footprint. The final probability of IHI would be an increasing function of the areal size of the waste footprint.

Armed with an understanding of the base assumptions and the approach taken to solve the problem, the SMEs were then required to structure the management controls, homesteader scenario, and community scenario influence diagrams to their liking.

It should also be pointed out that the structuring step of the elicitation process involved all SMEs for all questions. This level of participation promoted full and open discussion among the SMEs for all issues. It allowed SMEs who had relevant expertise for a given question to hear the views of their peers, but more importantly, to obtain information more indirectly related to their specific questions. This largely unstructured elicitation approach to structuring the model appeared to appeal to the SMEs, who benefited from the open forum for discussion. Some limited elicitation structure was built into the process by using prepared questions and issues that needed to be addressed. This limited structure ensured that the SMEs remained on target with the project objectives. To further facilitate model structuring, the SMEs were asked to provide their written rationales for these questions after full and open discussion of the issues. The prepared questions and issues, the SME written responses, transcriptions of flip chart notes, transcriptions of notes taken by the project team, and tapes of the panel session are available in the archived documents of this report.

The following provides a summary of SME inputs on the issue of periodic review.

1. Do you think periodic review is an effective management approach?

Discussion

1) All of the SMEs felt periodic review could be an effective management approach.
2) The difficulty with periodic review is in the implementation should a drastic change in circumstances at the site warrant a change in waste management practices.
3) The SMEs asserted the importance of having some mechanism in place that would provide the funding for changes to be implemented.
4) Most of the SMEs felt that a periodic review process would help maintain some type of institutional control, as well as contribute to the maintenance of site knowledge.

Results

All of the SMEs felt periodic review of intrusion would be an effective management approach, provided there is some mechanism to ensure that funds and some type of institutional control are available to implement it. Many SMEs felt that this process may also contribute to technological advances that may help mitigate the waste problem itself.

Rationale
Periodic review may provide a mechanism for maintaining site knowledge and control, and a process to encourage technological advances. Periodic review as a management tool is only possible with a guaranteed funding source and an implementing body or agency.

2. What is a reasonable time frame for periodic review of intrusion?

Discussion
1) The majority of the SMEs preferred a 10- to 25-year time frame. Other time frames suggested were 3-5 years and 5 years.
2) The SMEs' main concern in establishing a time frame was to ensure that it would capture the changes in demographics and allow science the opportunity to make the needed technological advances.
3) The apparent interest in the 25-year time frame was the transmission of site knowledge from one generation to the next, thereby ensuring some type of enduring knowledge regarding the site.

Results
The majority of the SMEs preferred any increment from 10 to 25 years. At a minimum, periodic review could occur within 5 years.

Rationale
The 10- to 25-year time frame allows site knowledge to be passed from one generation to the next. This time frame allows science and technology to make advances in treating this type of waste, and possibly in mitigating its dangerous effects. This time frame also allows surveillance of the physical characteristics of the site itself (e.g. subsidence of the cover, contents, etc.).

D.4.2 Management Controls Module

The initial management controls module was presented to the SMEs to provide a basis for discussion. The SMEs were provided the opportunity to fully discuss the management controls issues and to modify or refine the influence diagram as necessary.

The first management control item on the agenda was institutional control, followed by site knowledge. The SMEs agreed that these two factors are important and that site knowledge will be maintained for at least as long as institutional control. Consequently the influence diagram model was constructed so that institutional control is a top-level factor followed by site knowledge (see Chapter 4). It was also agreed by the SMEs that the chance of institutional control or site knowledge lasting for 10,000 years was negligible and that a more appropriate way to deal with these factors was to ask questions in terms of the length of time that these management controls might remain effective. Modeled in this fashion, the length of time management controls are assessed to be effective would be used essentially as a discounting probability for calculating the probability of IHI. That is, while these management controls are effective, IHI cannot occur.

Institutional control was defined in terms of institutional management of the waste site. The discussion centered on different forms of institutional control that might occur. For example, the SMEs opined that the federal government could be expected to pass institutional control to the states, who in turn might ultimately pass institutional control to the counties, or to private industry. The SMEs did not believe institutional control would be lost through catastrophic means (the probability was too small). Voluntary means of loss were viewed as more likely, either for economic reasons or because the waste site might, over time, become less significant in the eyes of the ruling authorities or the public. Political instability was considered a further mechanism by which institutional control could be lost.

Site knowledge was defined in terms of written or oral history of the waste site that is sufficient to deter drilling for groundwater. Discussion centered, much as it had for institutional control, on historical entities that at one time had knowledge or control of various sites their descendants either no longer control or understand. The potential for loss of site knowledge due to catastrophic events was dismissed as extremely unlikely. The main focus, again, was on loss of knowledge through an evolutionary process.

Given the main mechanism by which loss of institutional control and site knowledge were expected to occur, a final issue for these two factors concerned the potential for regaining site knowledge or institutional control some length of time after they had been lost. While the SMEs viewed this as a possibility, it was considered extremely difficult to assess. The SMEs decided not to assess the possibility of regaining site knowledge or institutional control because they did not believe that it was likely, and ignoring such a possibility would result in a more conservative assessment of the probability of IHI (the more time that management controls are effective, the less time there is for IHI to occur).

Other management control factors that were presented to the SMEs included effectiveness of placards and markers, effectiveness of subsurface barriers, and a factor labeled site recognition. The SMEs agreed with the need for the placards and markers factor and for the subsurface barriers factor, but did not see a need for a factor that allowed for other forms of site recognition. The SMEs felt that placards and markers adequately covered surface recognition features, and any other surface features would have minimal effect. The SMEs did, however, suggest the addition of a surface barrier factor, measured by its effectiveness for deterring drilling for water at the waste site.

The placards and markers, surface barriers, and subsurface barriers factors were assumed to be partially effective for the duration of the compliance period, and the degree of effectiveness was measured by the assessed probability that they deter drilling. In the cases of surface barriers and placards and markers, it was felt by the SMEs that they could readily be constructed to endure for 10,000 years, so that effectiveness becomes the relevant measurement device. For subsurface barriers it was felt that, given cost and resource constraints indicated by DOE/NV, subsurface barriers that would have a significant impact on a well driller could not be created.

The remainder of this section provides a brief description of the questions asked for each of the management controls factors, the discussion that ensued as a consequence of the questions, more specific answers to the questions, and the rationales for those answers. Questions were asked of the SMEs in two distinct levels. The first level of questions was prepared to familiarize the SMEs with the elicitation process, gain initial insights from the SMEs, and use the responses as a basis for the second set of questions. These questions simply asked if the management controls factors could reasonably be expected to deter intrusion via well drilling. The second set dealt with more specific issues on the potential efficacy of the management controls options.

Level I Questions for Management Controls Factors

Institutional Control: Is it reasonable to expect government, or another organization, will maintain control over the waste site for 10,000 years?

Discussion

1) No, this is not a reasonable expectation. There is no historical precedent for any government institution or civilization lasting for this period of time. Ten thousand years predates any known urban civilization.
2) There is evidence of ethnic groups and religions lasting for extended periods of time; however, they neither require nor imply political affiliations or prospects for stability. This translates to the loss of knowledge or control of a given waste site over the specified time frame.
3) Iron law of history: "Who's in power now, won't be in the future."

Results

No, it is not reasonable to expect government, or another organization, will maintain control over the waste site for 10,000 years.

Rationale

History! No government or political civilization has lasted for this amount of time. There is little about the site that would indicate any type of significance for any current sociopolitical reasons (e.g. economic or military purposes). The wastes that would be found on the site would probably be less important than any possible resources found in the NTS area.

<u>Site Knowledge</u>: Is it reasonable to expect that knowledge regarding the waste site will be maintained for 10,000 years?

Discussion

1) It is "unlikely" that site knowledge could be maintained for 10,000 years. However, this is a non-zero value (group perspective) when compared to the question of institutional control.
2) If, on the outside chance there is some mechanism (e.g. libraries, universities) maintaining knowledge of this area, it is more likely to be general in nature than specific to the waste site. Is it enough to have knowledge of the test site?
3) Knowledge specific to waste sites will probably be lost, but knowledge of the NTS may be retained
4) Knowledge of ideas (e.g., farming) may be retained for 10,000 years.
5) We rediscover the past all the time, but it does not mean we <u>remember</u> these things.
6) Site knowledge is different than using or having access to that knowledge. That is, the existence of site knowledge in an information repository is not the same as site knowledge that resides in human consciousness and affects decisions made.

Results

It is unreasonable to expect that knowledge regarding the waste site could persist for 10,000 years and be a useful deterrent.

Rationale

Knowledge and records of recent waste sites have already become unknown to current populations. There is nothing significant about this particular site to warrant special notice if institutional control has been lost at the NTS.

<u>Placards & Markers</u>: Is it reasonable to expect that placards or markers will deter inadvertent intrusion for 10,000 years?

Discussion

1) It is possible for the actual placard or marker material to persist for 10,000 years; however, it is not reasonable to expect that the message will remain comprehensible.
2) It is possible that if information regarding the site is lost, the effectiveness of placards and markers is also lost?
3) The SMEs felt that this depended on the type of marker and its durability.
4) What language would be used that is expected to last 10,000 years?
5) If future generations saw the placards and markers and decided to conduct investigative studies, it would no longer be inadvertent intrusion.

Results

No, it is not possible for the message on a placard or monument to be understood for the duration of 10,000 years, although it would be possible to build a marker that would endure the 10,000 years.

Rationale
Comprehension of the message will not endure 10,000 years, both because the site itself may be forgotten over that time frame, and because of the evolutionary nature of language. A monument or marker could be made to physically withstand the test of time.

<u>Surface Barriers</u>: Is it reasonable to expect surface barriers to deter intrusion for 10,000 years?

Discussion
1) Surface barriers could be constructed to last 10,000 years, depending on the type of material used for construction.
2) It would be important to use material of low value so there would be no incentive for individuals to remove part or all of the barrier over time.
3) In order for the surface barrier to be effective, it would need to be designed “properly” and could be used in conjunction with placards and markers. One approach to ensure an effective barrier would be to make it large enough that it could not be easily removed or destroyed; and its size would deter any attempts at intrusion into the waste.

Results
Depending on the size and type of material used for the barrier, it could be effective and last for 10,000 years.

Rationale
Barriers could be constructed to last 10,000 years.

<u>Site Recognition</u>: Is it reasonable to expect that the waste site will be recognizable for 10,000 years? (Assuming institutional control is lost; historical site knowledge is lost; and placards and markers are ineffective.)

Discussion
1) Given these assumptions, it is unreasonable to expect the waste site to be recognized as such within the 10,000 year time frame.
2) The site may be recognized, but not as a waste site. The general areas (Areas 3 and 5) may be recognized as something out of the ordinary (due to subsidence craters); however, there will be nothing to signify that these areas contain wastes of any type.
3) It is possible that flora could develop distinctive attributes as a result of contact with the wastes, thereby creating a natural, visible signature that there is something in the ground in these areas that differs from the surrounding areas.
4) It is possible to build an engineered mound that could be recognized over 10,000 years, but it does not follow that the mound would meaningfully indicate waste is buried there.

Results
The site will be recognizable as an area where something happened; however, it is highly unlikely that it will be recognized as a waste disposal site.

Rationale
Given the three above assumptions, there is no reason why anyone would recognize the waste sites as such. At best, if above-grade cover systems are used, they may be recognized as something manmade. However, there is no assurance that the waste areas will be recognized as waste disposal sites.

Subsurface Passive Barriers: Is it reasonable to expect that subsurface passive barriers will deter intrusion for 10,000 years?

Discussion
1) The possibility of intrusion depends on the level of intruder sophistication and the intruder's determination to attempt to drill through an obstacle when it is encountered. Another factor would be the life span of the barrier itself.
2) The SMEs with drilling expertise felt that almost anything that was used as a subsurface barrier would eventually be drilled through by a determined driller.
3) There was some thought that if a "substantial" barrier were put into place, it may provide some mechanism for hindering intrusion. However, future drilling technology may render any type of barrier susceptible to intrusion by drilling.
4) Ultimately, the effectiveness of the barrier will be a consequence of cost, although even this would not be a guarantee. Cost should not be a factor in determining the type of barrier.

Results
Depending on the type and cost of materials used, inadvertent intrusion could be deterred given current technology.

However, within the given time frame, drilling technology may change sufficiently as to enable a driller to overcome any type of barrier material. The efficacy of the barrier material itself may lessen over time as well; that is, the material may break down enough over 10,000 years to allow intrusive drilling.

Rationale
Drilling experience has proven that determined drillers will are able to drill through almost anything with current technology.

Subsurface Markers: Is it reasonable to expect that subsurface markers will deter intrusion for 10,000 years?

Discussion

1) Responses to this question were very similar to that of placards and markers in that it is possible to construct something that will last for 10,000 years. However, it is less likely that subsurface markers will actually deter inadvertent intrusion for 10,000 years.
2) Discussion also referred to the possibility of the markers drawing attention to the waste form/site, which may serve to warn the intruder of the potential danger associated with the site.

Results

It is unlikely that subsurface markers will deter inadvertent intrusion into the waste site.

Rationale

Depending on the material type used for manufacture, they will probably last for 10,000 years. The message on the subsurface markers may not be adequately comprehensible to deter inadvertent intrusion during the 10,000 year time frame.

Level II Questions for Management Controls Factors

<u>Institutional Control</u>:

1. What factors might influence the maintenance of institutional control?

Discussion

1) Political change, loss of political will, or loss of collective memory may influence maintenance of institutional control.
2) The possibility of voluntary vs. involuntary loss of institutional control was discussed. In terms of 10,000 years, however, these distinctions were determined not to matter.
3) Voluntary loss is defined as the government deciding through various activities, for example by removal of funding for political or budgetary reasons, to relinquish control of the NTS. Voluntary loss of institutional control would most likely occur over a period of years, possibly more than 100 years.
4) Involuntary loss of institutional control refers to a drastic change in government and its operating responsibilities, for example through war or natural catastrophes. Involuntary loss of institutional control would occur within a shorter time frame of less than 100 years.
5) This factor was treated more generally as the overall possibility of losing institutional control rather than specifically as a voluntary or involuntary loss of control.

Results

The SMEs agreed that voluntary and involuntary loss of institutional control would be the two primary mechanisms for loss of site control.

Rationale
A loss of or change in political will could lead to either voluntary or involuntary loss of institutional control, depending on how quickly the change occurred.

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2. How soon do you think institutional control could be lost?

Discussion

1) Some SMEs distinguished loss of institutional control with respect to voluntary and involuntary causes, although it was generally felt that the probability of involuntary loss of institutional control was very low. Therefore, most of the SMEs looked at the loss of institutional control through voluntary means. There were some SMEs who felt that the distinction between voluntary and involuntary was insignificant when looked at in perspective of the 10,000 year time frame.
2) A range of years was given for the voluntary loss of institutional control: the "immediate future" or 1 year, 50–100 years, to 200 years on the outside.
3) The SMEs recognized there was a lot of uncertainty associated with this question.

Results
The SMEs' range for the earliest loss of institutional control is 1–200 years. Five of the ten SMEs said 100 years, with the other five stating a time frame either less than or greater than 100 years.

Rationale
Given the federal government's desire to downsize due to financial constraints, and the pressure to minimize nuclear deterrents, this process would take about 100 years to occur, changing by the manipulations of political and social pressures.

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3. How long is it feasible for institutional control to be maintained? What's the longest time you think institutional control could be maintained?

Discussion

1) These responses again reflected SME views on voluntary versus involuntary loss of institutional control. Control of some type would be feasible given a gradual, voluntary loss of institutional control, as opposed to a more abrupt, involuntary loss of institutional control.
2) The overall range of times suggested by the SMEs was 100–2,000 years. Five SMEs suggested 100–1,000 years and five SMEs suggested 1,000–2,000 years.

Results
The upper bound of times the SMEs believed institutional control could be maintained was 1,000–2,000 years.

Rationale

The time frame chosen reflects the known length of time some well-known civilizations, such as Chinese dynasties and the British Empire, or religious organizations such as Christianity and Judaism, have existed.

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4. Given the above, how long do you expect institutional control to be maintained? What's your best guess at how long institutional control could be maintained?

Discussion

1) None of the SMEs have an expectation that institutional control will be maintained for more than 100–500 years.
2) Discussion for this range centered around the expectation that no catastrophic events occur. Given this condition, the SMEs determined it would take approximately this amount of time for sociopolitical will to erode enough that control of the site is lost. This time period was also viewed as necessary for the collective memory of the American public to "forget" why we were protecting this area in the first place.

Results

The SMEs believed institutional control could be maintained for 100-500 years.

Rationale

The time frame represents the projected amount of time needed for sociopolitical interest in the site to wane.

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5. If institutional control is lost, is it reasonable to expect it to be regained?

Discussion

1) Many of the SMEs had a difficult time estimating a time period for this question.
2) Six of the SMEs felt that the longer institutional control was lost, the less likely it would ever be regained. Further reducing the possibility of regaining institutional control is the fact that this is a small, relatively insignificant site.
3) Three of the SMEs felt that institutional control over the site could be regained if future generations had the technology or ability to recognize the site as having health risks. People would then realize they have a vested interest in regaining control over the site. One SME felt that the loss of institutional control would be temporary, lasting perhaps 50-100 years.
4) The incentive for regaining institutional control of this particular site would be rediscovery of the hazards associated with the site and the effects/input of oral or written history.

Results

The majority of the SMEs thought that the longer institutional control is lost, the less likely for it to be regained. A few of the SMEs felt institutional control could be regained if future generations were able to recognize the hazards associated with the waste disposal areas. In general, the SMEs believed that the low-level waste sites are relatively insignificant and that regaining knowledge or institutional control was unlikely. Consequently, the SMEs decided not to assess regaining institutional control. This can be regarded as another condition of the model that, according to the SMEs, does not have significant effect on the results. The effect of ignoring this factor, if any, is to slightly overestimate the probability of IHI.

Rationale
Once site knowledge has been lost or forgotten, there are few incentives for remembering or rediscovering this knowledge. If future generations have the capability to track illnesses and trace them to their source, or if future generations "uncover" information regarding the hazards associated with the site, there may be a greater impetus to reclaim these areas and exercise some type of institutional control.

<u>Site Knowledge:</u>

1. What factors might influence the maintenance of site knowledge?

Discussion
1) Most of the SMEs identified factors such as universities, public libraries, local culture, writings, government agencies, current mapping activities, and oral history/traditions. All of these resources were identified because of the current role of the site in national security issues and its local economic importance.
2) These resources were seen to be viable sources of information for many years following the loss of institutional control, unless institutional control occurred through involuntary or abrupt means.
3) Because of environmental toxicity due to industrialization, there could be more incentive to maintain site control.
4) Importance of Yucca Mountain was seen to also influence the maintenance of site knowledge.

Results
Any of the current information repositories, such as public libraries, university institutions, and local agencies or resources could serve to maintain site knowledge following the loss of institutional control, assuming this loss is not through abrupt and disruptive means.

Rationale
Information about the NTS, including the importance of site activities and their consequences (e.g., environmental toxicity and subsidence craters) is available in a variety of resources.

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2. How soon do you think site knowledge could be lost after institutional control is lost?

Discussion

1) Most of the responses for this question were predicated on how institutional control was lost and all information repositories were no longer accessible or functioning. If institutional control was lost due to catastrophic events, site knowledge would be lost almost immediately. If institutional control was lost due to more of a "phased" approach, then site knowledge was estimated to be lost within 50-200 years.
2) Most of the responses were given in terms of both years and generations, so there is a perceived connection between loss of site knowledge and the passing of generations.

Results

Loss of site knowledge could be expected to occur within 50-200 years, or within 2-8 generations, after the loss of institutional control, passing of generations, and declining importance of the NTS as a whole.

Rationale

Even with the use of information repositories, the maintenance of continuous site knowledge is likely to decline with the loss of institutional control and the passing of generations.

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3. How long do you think site knowledge could be maintained after institutional control is lost?

Discussion

1) Most of these responses are predicated on the assumption that information repositories and other avenues interested in collecting and preserving information are maintained despite the loss of institutional control of the NTS.
2) Given this underlying assumption, the time frame for maintenance of site knowledge has been estimated to be from 100 years to more than 10,000 years. The longer length of time for maintaining site knowledge can be attributed to the sophisticated level of current information systems.

Results

Maintenance of site knowledge could be expected to last 100-10,000 years, depending on how institutional control has been lost. This time frame is based on a gradual loss of institutional control

Rationale

Assuming a gradual loss of institutional control, the existing information repositories will not have been destroyed. The maintenance of continuous information resources therefore, would rely primarily upon people's interest in the site.

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4. How long do you expect site knowledge to be maintained after the loss of institutional control?

Discussion

1) Responses to this question are based on the assumption that current mechanisms for recording and storing information are still in working order.
2) Based on (1), the range of time given for the maintenance of site knowledge is 75-1,000 years, with 1,000 years being on the very outside.

Results

It is expected that site knowledge could be maintained for 75-1,000 years.

Rationale

It is assumed that with the passage of time, information about the site will be applied and used less. Year estimates are based on current levels of historical knowledge and mechanisms used for maintaining this knowledge (e.g., oral and written methods).

5. If site knowledge is lost, is it reasonable to expect that site knowledge could be regained?

Discussion

1) A majority of the SMEs felt it was very likely that site knowledge could be regained. Recovery of site knowledge assumes there is sufficient motivation and enough information left from before institutional control was lost to reconstruct the necessary information base.
2) One SME said that regaining site knowledge was not possible. Because the sites are small, with low priority for money expenditure and low development interest, there would be no motivation for regaining site knowledge and information.

Results

Nine of the 10 SMEs felt that at some point after the loss of site knowledge, it would be possible to regain site knowledge.

Rationale

There would be enough interest, either through just interested individuals, or through awareness and subsequent concern regarding the wastes that have been buried at these areas, that people would want to rediscover what was buried there.

<u>Placards & Markers:</u>

1. What factors might influence the effectiveness of placards & markers?

Discussion

1) The primary factors identified by the SMEs were the durability and interpretability of the placards and markers over time.
2) Petroglyph meanings have been hotly debated between archaeologists and tribes for years.
3) Other related issues raised were the size and language of symbols that would be used on the markers, and the possibility of vandalism (especially graffiti).

Results

Durability and interpretability of placards and markers are the main factors that would affect their effectiveness.

Rationale

If people can't see a placard or marker, and are unable to understand the message, then the placard or marker will be ineffective.

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2. How soon do you think placards and markers could become ineffective after institutional control is lost?

Discussion

1) All of the SME responses are based on the assumption that institutional control has been lost. Given this assumption, the placards and markers would no longer be maintained in physical form or message.
2) For some of the SMEs, the durability of the placards and markers was not an issue. Rather, the ability of the message to be understood through time was a concern, directly related to the complexity of the message.
3) A range of 1–1,000 years was given by all SMEs. The justification for one year was that one of the SMEs wasn't convinced that the placards and markers would work now, let alone in the future.

Results

The soonest the SMEs thought that placards and markers would become ineffective was 1–1,000 years. One SME did suggest that a simple message may last for a long time.

Rationale

This time frame for effectiveness of placards and markers is based primarily on the interpretability of the placards and markers themselves. The SMEs did not feel that any message would be understood throughout the entire 10,000-year time frame.

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3. How long do you think placards and markers could be maintained after institutional control is lost?

Discussion

1) Factors that were identified as influencing the maintenance of placards and markers were vandalism and the understanding of the message on the placards and markers.
2) With the absence of institutional control, the placards and markers would be much more susceptible to vandalism and other forms of defacing, thereby affecting their effectiveness in deterring inadvertent human intrusion.
3) The time frame given by SMEs was 100–10,000 years, with most of the uncertainty originating from the possibility of physical alterations.

Results

Placards and markers are perceived to be able to last 100-10,000 years after institutional control is lost.

Rationale

The variability of this time frame stems from the uncertainty associated with effects of vandalism on the durability of the physical placard or marker, and the comprehension of the message through time due to language evolution.

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4. How long do you expect placards and markers to be maintained after the loss of institutional control?

Discussion

1) Ambiguity between this question and the previous one led to a variety of responses blurring the distinction between expectation and reality regarding maintenance of placards and markers during the compliance period of 10,000 years.
2) One SME limited the lifetime of placards and markers to approximately 25 years, based on one generation's time span. This SME felt that with the passing of the World War II generation, which has collective memories of the war and associated events and places, the current generation's interest in and memory of nuclear devastation (e.g. mushroom cloud, radioactive symbol, etc.) would wane.
3) The time period identified by this SME was 25–1,000 years. This time span takes into account loss of institutional control and the evolution of language and symbology.

Result

The time period identified for the expectation of maintaining placards and markers was 25–1,000 years.

Rationale

The time period in question depends on the extent of site knowledge and the population's interest in the site.

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5. If placards and markers were to become ineffective, is it reasonable to expect that they could regain their effectiveness?

Discussion

1) Most of the SME comments were conditional. If some type of institutional control is re-established, then it would be possible for placards and markers to regain their effectiveness. However, while there are many ways knowledge can be regained, effectiveness is a different issue.
2) Another avenue for regaining effectiveness of placards and markers was through the activities of researchers in the future (assuming information repositories are accessible).
3) Among SMEs who said it would not be possible to regain effectiveness of placards and markers, they reasoned that once a placard or marker was vandalized or the message was no longer comprehensible, the knowledge about that site would be lost.

Results

Most of the SMEs felt that if institutional control was re-established, then it would be possible for placards and markers to regain their effectiveness. However, it was agreed that there was a lot of uncertainty associated with this conclusion.

Rationale

In order for effectiveness to be regained, there must be an organizational body or individual motivation to rediscover and continue sharing knowledge about the site with future generations.

<u>Surface Passive Barriers</u>

1. What factors might influence the effectiveness of surface passive barriers?

Discussion

1) The whole discussion regarding surface passive barriers was based on information from DOE's proposed passive barriers.
2) Factors influencing the effectiveness of surface passive barriers include water and wind erosion, waste subsidence, height and stability of barrier slope, and durability of materials used in constructing the surface passive barrier.
3) There is also the attractiveness of the barrier to humans. This attractiveness was perceived to come from either the attractiveness of the material used to construct the barrier or actual use of the barrier for activities such as hiking or climbing.
4) A barrier was seen to be, in essence, the same as a marker.

Results

Physical factors, forces of nature, and human activity were viewed as influential regarding the effectiveness of surface passive barriers.

Rationale
Surface barriers are subject to the forces of nature. The longer the surface barrier lasts, the greater the chance of humans being drawn to explore it. However, an intentional activity with the purpose of exploring a barrier changes intrusion from inadvertent to advertent, and no longer falls under the auspices of this effort.

2. **How soon do you think surface passive barriers would become ineffective after institutional control is lost?**

Discussion
1) The SMEs suggested that passive barriers could be effective for the full 10,000 years, depending on the design.

Results
The SMEs felt that the surface passive barrier, provided it is constructed properly, could be effective for the 10,000-year time frame.

Rationale
Most media that would be used to build a surface passive barrier could endure for 10,000 years.

3. **How long do you think surface passive barriers could remain effective?**

Discussion
1) The SMEs felt the barriers could remain effective for the entire compliance period given no major changes in climate or catastrophic events.

Results
Surface passive barriers could remain effective for 10,000 years

Rationale
Conclusion assumes no major changes in climate and no catastrophic events.

4. **What is the most likely time for surface passive barriers to remain effective?**

Discussion
1) Two SMEs gave time frames estimates for effectiveness that did not assume a period of 10,000 years. The reasons provided for shorter time periods were a blended average between worst- and best-case scenarios, and assumption of the long-term stability of land forms at the NTS.

2) The rest of the SMEs thought that the surface passive barriers could be effective for 10,000 years.

Results
Assuming properly constructed surface passive barriers, the SMEs felt that these barriers could be effective for 1,000-10,000 years.

Rationale
Conclusion assumes no major changes in climate and no catastrophic events.

D.4.3 Homesteader Scenario

The preliminary homesteader scenario influence diagram was presented to the SMEs to provide a basis for discussion. The SMEs were provided the opportunity to fully discuss the homesteader scenario and to modify or refine the influence diagram as necessary. Note that a working definition of the homesteader scenario was also provided by the SMEs (i.e., no shared resources and one well per household).

The first issue discussed under the homesteader scenario was that of "similar desert area." The SMEs argued that there is no environment truly similar to that of the NTS, particularly to Frenchman Flat or Yucca Flat, in which the RWMSs are located. Specifically, the SMEs felt that either the climate, soil conditions, availability of surface water resources, depth to groundwater, distance from settled areas, or some other variables would be significantly different in most other areas. Given the differences between the NTS areas of interest and other desert areas, the SMEs opted not to conduct direct comparisons. Rather than considering separate areas that exhibit commonalities with the NTS, the SMEs decided to directly consider hypothetical homesteading on Frenchman and Yucca Flats. That is, rather than focusing on a larger similar desert area, the SMEs opted to focus on what might happen in the areas of interest. This decision led to removal of the "similar desert area" node from the influence diagram, and to an assumption that the homesteader influence diagram would be applied to Frenchman Flat and Yucca Flat directly. It should be noted that, in later discussions, the SMEs frequently used comparisons with other desert areas, although related factors were now included implicitly rather than explicitly in the influence diagram model.

The next issue to be addressed was how many of the next 10,000 years homesteading might be expected to occur at Frenchman Flat or Yucca Flat. This number would provide a limit on the time frame for which IHI could occur for this scenario. The SMEs agreed that it was then necessary to assess the number of homesteads that might occur during that time frame. The influence diagram model developed included factors relating to number of homesteads, homestead lifetime (the number of years that a homestead remains viable), number of wells, and well lifetimes. The SMEs eliminated the need to distinguish between number of wells and number of homesteads by making an assumption that there is one well per homestead. Number of wells and number of homesteads were to be treated as the same factor. The SMEs modified the influence diagram model to include a distribution of the number of homesteads at a given point in time, homestead lifetime, and well lifetime, in order to determine the number of wells that might be drilled during the compliance period. Other parameters that must be included in the model to complete the probabilistic calculation are size of the area of concern (i.e., Frenchman Flat, Yucca Flat, or subareas thereof), and areal size of the waste footprint (to be determined by DOE/NV).

Other factors that the SMEs then considered potentially important included distance apart of replacement wells. Replacement wells needed to be considered because well lifetimes were expected to be shorter than homestead lifetimes. That is, if a well collapses or becomes unusable for any other reason, then a replacement well is assumed to be drilled until the duration of the homestead lifetime has expired. Replacement wells are assumed to be relatively close to the original well location.

It should be noted that other factors were considered implicitly. In particular, there was considerable discussion about different manifestations of homesteading (including telecommuting, ranching, farming, subsistence homesteading), and there was considerable discussion about factors that might impact the siting of a homestead within Frenchman Flat or Yucca Flat. For example, remoteness, depth to groundwater, slope, cratered area, playas, flood plains and other factors were raised.

Finally for this scenario, the SMEs decided to evaluate Frenchman Flat and Yucca Flat together. This decision was made largely because they felt that the type of independent homesteading envisioned for this scenario was very unlikely to occur, in which case the probability of IHI was likely to be very small. The influence diagram presented in Chapter 4 reflects a combination of Frenchman Flat and Yucca Flat as a base assumption. It should also be noted that this homesteader scenario was to be applied only to independent homesteading. That is, these homesteads are not linked in any way to a community settlement. The reason for this clarification should become clearer as the community scenarios are explained in the next section.

The following presentation includes the questions that were used in this structuring phase. Through the SME inputs, several changes were made to the preliminary influence diagram model. These changes were assimilated into a modified influence diagram that was presented and discussed at the beginning of the second session.

1. Is it a credible rural scenario?

Discussion

1) Seven SMEs felt this scenario is a credible rural scenario. Of these seven, about half considered this scenario appropriate to only rural areas. The other half examined this scenario in terms of the NTS and felt it could be a reasonable application for possible future activities.

2) Three SMEs felt this was an unreasonable scenario because they looked at it in terms of people homesteading at the NTS. They felt that it was very unreasonable to expect anyone to homestead that area particularly since there are so few resources to provide motivation for locating a homestead.

Results
The majority of SMEs felt that the homesteader scenario is a credible and reasonable scenario.

Rationale
Scenario attributes appear to be reasonable for homesteading activities. Possible future population pressures could increase the attractiveness of the NTS areas. It seems reasonable to expect someone homesteading might use drill cuttings in a vegetable garden.

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2. Definition of Homestead

Discussion
1) The SMEs stated that a homestead would have at least one well per household. There could be more wells, depending on the type of activity performed by the homestead (e.g., ranching, irrigated vegetable farming, washing).
2) Another attribute of a homestead is relative isolation and independence from any type of shared services with other homesteads.
3) The primary function of activities for the homestead are focused on subsistence.

Results
A homestead may have more than one water well per household. It is relatively isolated from other homesteads and does not share any type of services with other homesteads.

Rationale
The number of wells relates to the size of habitation sites. Isolation of homesteads implies a lack of dependence on shared services.

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3. Homestead Lifetime: Which characteristics do you feel are most important in determining a homestead's lifetime?

Discussion
1) Well lifetime was seen to be a factor for all of the SMEs. Well lifetime was examined in relation to the homestead lifetime as a way to see how one factor impacted the other. The homestead lifetime was seen to be longer than the well lifetime.
2) Other factors identified by the SMEs included aggressive soils; a falling water table; availability of water to support the homestead and sustenance activities associated

with the homestead; and relative land values. It was felt that the depth to groundwater was more of a limiting factor than aquifer yield.

Results
Based on the development status of the model for this session, the SMEs identified well lifetime to be about 50 years, with 100 years being an upper bound.

Rationale
All of the SMEs agreed upon 50 years for well lifetime based on input from experts in this area and the current development of the models at this time.

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4. Estimates for number of homesteads on the area: minimum, maximum, most likely.

Discussion
1) For this question, the SMEs provided estimates for the minimum, maximum and most likely number of homesteads.
2) Responses reflect SME estimates of the impact a homestead or group of homesteads would have on water well drilling, given subsistence needs and potential limits on the actual numbers of homesteads that would be supported in Frenchman and Yucca Flats.
3) One SME claimed that the areas under consideration would not be attractive to anyone for habitation.

Results
Eight of the minimum estimates were between 0 and 10, with two more estimates, of 100 and 200, respectively. Of the maximum estimates provided, only two were below 100, with the rest of the estimates between 100 and 2,000. For the most likely estimates, five of the estimates were for 10 homesteads and under, two estimates were for 20–50 homesteads, and the remaining estimates were for 500–1,000 likely homesteads for these areas.

Rationale
There is a potential for community and associated rural living as population increases in Las Vegas. Limitations are imposed by drilling difficulties and water supply given subsistence activity needs and potential limits on the number of homesteads that could be supported in this desert environment.

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5. Estimates for size of homesteads on the area: minimum, maximum, most likely.

Discussion
1) Differences in the type of homesteader were discussed.

2) A telecommuter homesteader who was interested in solitude, but relied on another area for a living wouldn't require a large homestead to sustain his or her lifestyle.
3) A homesteader who did rely on the land to support the homestead itself would require a larger tract of land in order to sustain all activities on the homestead.
4) One SME remarked that it would not be possible to make a living off the land, that the homesteader was only interested in some space for his family.

Results

Minimum estimates ranged from 1 acre to 1,000 acres (n=1). Specific breakout of this minimum estimates were (in acres) 1(n=3), 5, 10, 60, 100 (n=2), and 1,000 acres. Maximum estimates ranged from 100 acres to 200,000 acres, depending on the area in question. The specific estimates for this category were (in acres) 100, 500, 650, 1,000, 100,000, and 200,000 acres. Most likely estimates ranged from 1 acre to 100,000 acres. The specific estimates for this category were (in acres) 1, 50, 80, 100, 200, 1,000, and 100,000 acres.

Rationale

The current actual size distribution of farms in Nevada was considered. Only a small amount of land is actually required by the homesteader who is either earning a living outside of the homestead area or only using the amount of land necessary to "just get by." Larger acreage would be needed to sustain the homesteader family with animals and vegetables.

6. Estimates of distance between homesteads: minimum, maximum, most likely.

Discussion

1) Comments reflected the different types of homesteads that were possible; smaller land tracts for the telecommuter, and larger tracts for the self-sustaining homestead.
2) Other factors considered as affecting the distance between homesteads were the harsh and limited conditions that currently exist in the NTS areas. These conditions would likely increase the distance between homesteads.

Results

Minimum estimates ranged from 0-1,250 ft to 5 mi. Specific minimum estimates were 0 (n=2), 800 ft, 1,250 ft, 0.5 mi, 1 mi (n=2), and 5 mi (n=2). Maximum estimates ranged from 750 ft to 50 mi, specifically, 750 ft, 3,000 ft, 5 mi, 5–10 mi, 10 mi (n=2), 15 mi, 25–50 mi, and 50 mi. Most likely estimates ranged from 1,000 ft to 40 mi. A breakout of this range is 1,000 ft, 2,000 ft, 2 mi. (n=2), 2–3 mi, 3–5 mi, 10 mi (n=2), and 30–40 mi.

Rationale

Homesteaders stay farther apart due to harsh and limited conditions in waste areas. There is limited capacity for homesteads in the valleys in question. Smaller homesteads would be for those just interested in "elbow room." Larger homesteads would be needed for self-sufficiency.

7. Estimates for homestead lifetimes for area of interest: minimum, maximum, most likely.

Discussion

1) Several factors were seen to impact this issue: well lifetime, homestead lifetime, population pressures, rediscovery of the original purpose of the site, attractiveness of other homesteading possibilities, and future generations' interest in the site.
2) Many of the SMEs saw the disinterest of future generations as a main reason for abandonment of a homestead in these areas. This disinterest stems from the likely unwillingness of future generations to endure the harsh climate.

Results

Minimum estimates ranged from less than 1 year to 100 years. Specific minimum estimates were less than or equal to 1 year (n=4), less than or equal to 10 years (n=2), 20 years, 25 years/1 generation, and 50 years. Maximum estimates ranged from 100 years to 10,000 years. Specific maximum estimates were 100 years (n=4), 100–150 years, 200 years, 1,000 years, and 10,000 years (n=3). Most likely estimates ranged from 10–25 years to 2,000–5,000 years. Specific most likely estimates were 10–25 years, 20 years, 25 years (n=2), 50 years/2 generations (n=2), 100 years, 500 years, 2,000-5,000 years, and 7,500 years.

Rationale

A homestead would endure one generation, or two generations at the outside. Rediscovery of the original purpose of the site may occur. Abandonment of the site may occur for various reasons, including a well drying up, or a lack of interest in staying in such a harsh environment.

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8. Estimates for well lifetime for area of interest: minimum, maximum, most likely.

Discussion

1) This discussion was also influenced by the SMEs' collective feeling that no one would want to live in these areas in the first place.
2) Assuming someone would be living in these areas and drilling for water, the well lifetime would be subject to the driller's expertise in drilling. Some of the factors the SMEs felt would impact the longevity of a well were quality of the drilling, falling water table, clogging, encrustation, or catastrophic failure.
3) Replacement wells were expected to be located approximately 10 to 50 ft from the existing well.

Results

Minimum range for well lifetime was less than 1 year to 25 years. The actual breakout for this range was less than 1 year, 1 year (extremely poor construction), 10 years (n=2), 20 years (n=4), and 25 years. Maximum range for well lifetime was 50 to 100 years based on input from the SMEs in drilling. The breakout was 50 years (n=2), 50–70 years, 60 years, 75 year, and 100 years. (n=4). The most likely range was 20 to 50 years. The breakout for this category was 20–30 years., 25–50 years., 40 years (n=2), and 50 years. (n=5).

Rationale
Quantities are based on input from the SMEs in drilling. The drillers' input reflects current drilling knowledge, practices, and standards. Assumes a fairly stable and consistent water table.

D.4.4 Community Scenario

The preliminary community scenario influence diagram was presented to the SMEs to provide a basis for discussion. The SMEs were provided the opportunity to fully discuss the community scenario and to modify or refine the influence diagram as necessary. Note that a working definition of the community scenario was also provided by the SMEs (i.e., shared resources and less than one well per household).

As noted in the previous section, the SMEs decided to evaluate the probability of IHI by considering what might happen at Frenchman Flat and at Yucca Flat rather than dealing with a similar desert area for which more tangible information might be available. However, many of the later discussions about the scenarios involved comparison of these two areas with other desert areas. Consequently, the idea of using a similar desert area was incorporated in an implicit rather than explicit manner.

The main concern raised by the SMEs was that the two scenarios (homesteader and community) as envisioned did not adequately account for the possible ways settlement in Frenchman Flat or Yucca Flat could occur. While the difference between independent homesteading and having a community in Frenchman Flat or Yucca Flat was clear, the SMEs felt that other hybrid scenarios were equally realistic and probably more likely to occur. Consequently, the SMEs suggested three alternate community scenarios. The first, termed the "base community scenario," corresponded to the original notion of evaluating the potential for siting a community in Frenchman Flat or Yucca Flat, regardless of motivating factors.

The second, termed the "Jackass Flats scenario," involved siting a community in a neighboring area, with some portion of the population living outside the main "Jackass Flats" community, in Frenchman Flat or Yucca Flat. Jackass Flats was suggested as a more desirable candidate for community settlement than Frenchman Flat or Yucca Flat because of favorable living conditions such as more surface water and proximity to an existing major highway to Las Vegas. Jackass Flats appeared to be close enough to both Frenchman and Yucca Flats that population pressure seemed reasonable to evaluate. Other possibilities were also considered, such as a community settlement based at the current NTS town of Mercury. The inhabitants of Frenchman Flat or Yucca Flat under this scenario were assumed to be commuters operating under homesteading conditions. This scenario was distinguished from the independent homesteading scenario in, which a direct link to a community was not envisioned.

The third scenario involved similar population pressure on Frenchman and Yucca Flats; this time caused by an expansion of the city of Las Vegas. The SMEs did not envision Las Vegas expanding to encompass Frenchman Flat or Yucca Flat, but they could see Las Vegas expanding far enough that it could cause population pressure on these areas for people who desired to live outside the city and have access to a relatively large space. In view of the SME desire to consider three different community scenarios, this section addresses each possibility separately.

D.4.4.1 Base Community Scenario

The first issue to be addressed for this scenario concerned the potential for a community to be located in Frenchman Flat or Yucca Flat. That is, for how many of the next 10,000 years might a community be expected to be present at Frenchman Flats or Yucca Flats. This would, again, provide a limit on the time frame for which inadvertent human intrusion could occur for this scenario. The SMEs agreed that it was necessary to assess the number of communities that might occur during that time frame.

The developed influence diagram model included factors relating to the number of communities, community lifetime (the number of years a community might be expected to exist in this area), number of wells supporting a community water supply, and well lifetimes. The SMEs made an assumption that there would not be more than one community located in either of the two areas at any one time. The number of communities factor corresponds to a count of the number of communities that might appear during the course of 10,000 years. That is, the types of community under consideration are assumed to rise and fall, or to eventually become ghost towns. Community types that were discussed included communities based on a research industry (e.g., nuclear energy, solar energy), space technology, mining communities, communities based on military or prison bases, religious communities, and Native American communities. Although the SMEs included many types of communities implicitly, the evaluation of this community scenario in terms of wells drilled was performed for a standard planned community. This standardized community was to be used in much the same way that the regulatory driven homesteader scenario is used as a standardized exposure scenario. Overall, the SMEs modified the initial influence diagram model to include community lifetime, well lifetime, and number of community water supply wells needed for a single community.

Other factors the SMEs then considered potentially important included distance apart of replacement wells. Replacement wells needed to be considered because well lifetimes were expected to be shorter than the community's lifetime. That is, if a well collapses or becomes unusable for any other reason, then a replacement well is assumed to be drilled. Replacement wells are assumed to be relatively close to the original well location.

It should be noted that other factors were considered implicitly. In particular there was considerable discussion about factors that might impact the siting of a community within Frenchman Flat or Yucca Flat. For example, depth to groundwater, slope, cratered area, playas, flood plains, and other factors were raised. The SMEs decided to handle most of these factors implicitly, although they did decide that the Frenchman Flat and Yucca Flat playa areas would not be inhabited under any circumstances, and that the heavily cratered areas were much less likely to be inhabited than the remainder of Yucca Flat.

Under this scenario, the SMEs assumed that the community would be planned and that the community water supply would be fully supported by a community water supply system. Consequently, private wells were not considered for this scenario. By contrast, the SME models for the Jackass Flats and Las Vegas expansion scenarios, both described below, included private well drilling only.

The community under consideration for this scenario was assumed by the SMEs to be relatively independent of Las Vegas. That is, this scenario involved an independent, self sustaining community in Frenchman Flat or in Yucca Flat. Unlike for the independent homesteader scenario described in the previous section, the SMEs decided to address Frenchman Flat and Yucca Flat separately for the community scenarios. Consequently, the influence diagram presented in Chapter 4 applies equally to either area, and the model was used separately for each area.

D.4.4.2 Jackass Flats Scenario

The Jackass Flats scenario involved development of a new community in an area neighboring Frenchman Flat or Yucca Flat. This community was expected to put population pressure on the two areas of interest, primarily in the form of homesteading. This scenario is distinguished from the base community scenario, which considers siting of a community in Frenchman Flat or Yucca Flat. It is also distinguished from the homesteader scenario, for which a it is assumed that there is no supporting community.

The first issue to be addressed by the SMEs for this scenario concerned the potential for a community to be located in Jackass Flats, or some other area in the vicinity of Frenchman Flat or Yucca Flat, such as Mercury, Indian Spring, or Pahrump Valley. That is, for how many of the next 10,000 years might a community be expected to be present in the vicinity of Frenchman Flat or Yucca Flat? This would, again, provide a limit on the time frame for which IHI could occur for this scenario. Once the possibility of such a community coming into existence was recognized, the next step was to assess the number of related homesteads that might be located in Frenchman Flat or Yucca Flat. Again, this scenario should be distinguished from the original homesteader scenario for which homesteading was regarded as independent of any community settlement.

This influence diagram model (see Chapter 4) included factors relating to community lifetime, number of homesteads attached to the community, homestead lifetime (the number of years that a homestead might be expected to remain viable in this area), and well lifetimes. The types of community considered for location in the neighboring area were the same as those considered for the base community scenario described above. The community was also considered independent of Las Vegas.

One primary well per homestead was assumed; and each homestead was assumed to have a lifetime equivalent to the lifetime of the related community. It was recognized as a somewhat conservative assumption, but given the relatively short expected lifetimes for the envisioned communities, the SMEs regarded it as a reasonable assumption. Community lifetime was to be used to gauge the number of communities that would be expected to occur during the 10,000 year time frame. Then, the number of homesteads attached to the community would be used with well lifetime to determine the overall number of wells that might be drilled during the compliance period under this scenario.

D.4.4.3 Las Vegas Expansion scenario

This scenario involved sufficient expansion of Las Vegas that population pressure would be placed on the two areas of interest, primarily in the form of homesteading. This scenario is easily distinguished from the base community scenario, which considers siting of a community in Frenchman Flats or Yucca Flats. It is also distinguished from the homesteader scenario, for which a it is assumed that there is no supporting community. The city of Las Vegas is approximately 80 miles from Frenchman and Yucca Flats, and the SMEs recognized that considerable expansion of Las Vegas is necessary before any population pressure might result in settlement of such currently remote areas. The first issue to be addressed for this scenario concerned the potential for Las Vegas to expand sufficiently that population pressure would be placed on Frenchman and Yucca Flats. Once this scenario was established as a possibility, the SMEs developed an influence diagram model that started with the length of time Las Vegas might exist as a sufficiently large entity that population pressure might occur in such currently remote areas. Then, it is necessary to assess the number of related homesteads that might be located in Frenchman Flat or Yucca Flat.

Subsequent to assessment of these factors, the remainder of the Las Vegas expansion scenario influence diagram followed essentially the Jackass Flats model. For example, the types of commuter homesteads envisioned were assumed to last for the entire time period for which Las Vegas puts population pressure on these two outlying areas. It was recognized, again, that this is a somewhat conservative assumption, but given the relatively short time frame for which it was expected that Las Vegas would put population pressure on Frenchman and Yucca Flats, the SMEs regarded it as a reasonable assumption.

One primary well per homestead was assumed. The number of homesteads assessed for this scenario would be used with well lifetime to determine the overall number of wells that might be drilled during the compliance period. Other factors, such as distance apart of replacement wells from primary wells, determining the area of Frenchman and Yucca Flats, and areal size of the waste footprint applied equally to this scenario as to the previously discussed scenarios.

D.4.4.4 Community Scenario Structuring Questions

This section presents the questions asked during the structuring phase of the project, including highlights of the important discussion points, the results or responses from the SMEs to each question, and the rationale provided by the SMEs for the results. The responses to these questions, and the discussion supporting the responses formed the basis for modifying the influence diagram models.

1. Is it a credible urban scenario?

Discussion

1) Most of the SMEs looked at this scenario in relation to the possibility of a community actually developing at the NTS.
2) Seven of the SMEs thought that this is a plausible scenario. Some had a few reservations about the particulars in the scenario, such as that the options for exposure were very limited. Exposure through a community garden would not be the most likely avenue, rather, exposure would occur through commercial agricultural mechanisms, etc.
3) SMEs who said this was an unreasonable or highly unlikely scenario, were looking at it in relation to the possibility of a community settling out in the NTS areas. To these SMEs, it was too much of a stretch to put a viable planned or unplanned community in the areas in question.
4) One SME did note that if a community were to develop out in these areas, there would be a decreased chance of penetrating the waste area. A lower incidence of waste penetration was identified because wells would be shared among a higher number of households in a community. However, if contamination were to be released, there would be a higher exposure number because many households would be sharing the same water source.

Results

Seven SMEs thought this was a reasonable scenario to consider, three felt it was highly unlikely or an unreasonable scenario to consider.

Rationale

These scenarios are too limited in options for exposure to hazardous materials. There is no incentive for a community to be located in these areas, there is nothing out there to which groups of people would be attracted. If there were a community, the actual chance of penetrating the waste would be small; however, the population that would be exposed would be greater. Current population growth rates for the desert southwest, along with current growth activity in Las Vegas make this scenario plausible. This scenario is reasonable given the existence of small communities currently surrounding the NTS, and the possibility of communities developing following settlement by homesteader.

2. Definition of Community

Discussion

1) Sharing of resources, services, cultural practices, and knowledge were the primary community living factors identified by the SMEs. The important distinction between the community and the homesteader scenarios is the sharing of resources and services among households and the size of these household groupings.
2) Type of community, as illustrated through planned and unplanned communities, is important for determining the size of the community. The size of household groupings then determines the number of wells needed to provide a given community with water.
3) A planned community has a more definite estimate of the number of wells needed for a given sized community.
4) An unplanned community is more likely to have a larger number of wells for its community because it will have evolved from individual homesteads requiring their own water supply.
5) The gradient effect between homesteaders and communities was discussed; e.g. isolated households, marginal households, and integral households.
6) Three possible types of communities that would settle in the Flats were identified: religious or communal, prisons, and the military. These types of communities were identified because of the historical preference for harsh climates or less desirable areas because the land was available or offered more freedom.
7) One SME remarked that within the community, factors in management controls would probably be more effective since there would be a larger collective memory from which to draw. Site knowledge was seen to be a secondary effect of the collective memory of the community.

Results

A community is a collection of households that share resources, services and socio-cultural knowledge.

Rationale

Less than one well per household was assumed. Households would be close enough to share information, knowledge, decision making, culture, etc. Households are dependent upon each other and external mechanisms for community existence and maintenance of services. There is a possibility for grouped households to begin small and then grow into larger groups, or larger and denser communities.

3. Community Well Allocation

Discussion

1) The community well allocation would depend on how the community was formed and for what purpose (e.g., a prison community, religious community, or suburban area), and its well usage.
2) Perennial yield and aquifer recharge were important components regarding new and replacement well allocation.
3) SMEs took into account the possibility of replacement wells and wells for other uses, such as irrigation.
4) There was some discussion regarding the number of households a given well could support.

Results

If the community is a planned community, the number of wells is estimated to be no more than five wells (per input from the SME in land-use planning). If the community is planned for institutional or economic reasons, the number of wells would be based more on water need. If the community is one that has evolved from homesteads, the number of wells would be much higher based on the number of pre-existing wells (10-100 wells), depending on the number of original homesteads that become part of the community.

Rationale

Should the community be an outgrowth of existing homesteads, there would be an almost equal number of individual wells per household. If the community is planned, then it is estimated that one well could serve approximately 5,000 people. Therefore, there would be a fewer number of wells per household.

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4. Length of Community Endurance: minimum, maximum, most likely

Discussion

1) Factors influencing a community's endurance were identified as the following: the reason for a community's existence (economic, political, etc.), external population pressures, resource availability; and harshness of the environment.
2) Availability of resources and the harshness of the environment were viewed as some of the primary factors that would influence a community's longevity.

Results

The range for the minimum number of years a community would endure is 1–500 years. These numbers represent the upper and lower bounds for this range. The average minimum number of years for a community to endure is 73.2 years in these areas. Maximum range is 50–10,000 years. The average maximum number of years a community was seen to endure is 1,686 years. The most likely range is 25–5,000 years. The average most likely number of years a community would survive is 746 years.

Rationale
Population pressures, the reason for the community's existence, and the environment's long-term ability to sustain the community were the major factors in estimating the time frames.

5. Areal Size of Community on Yucca and Frenchman Flats

Discussion
1) Once again, the size of the community would reflect the reason for the community existing. If the community was developed because of mining or other institutional purposes, it would most likely be small in size. A community might be larger in size if people receive larger tracts of land (as for example, in a retirement type of community).
2) Limitations on available resources such as groundwater were seen to possibly limit the size of a community in these areas.
3) Some SMEs thought that a community in these areas would only form through the collectivization of homesteads. Therefore, these types of communities would be small in size.

Results
The minimum range of sizes is 10–3,200 acres. The average minimum community size is 528 acres. The maximum range is 400–80,000 acres. The average maximum community size is 18,565 acres. The most likely range is: 10-40,000 acres. The average most likely size for a community is 6,204 acres.

Rationale
Size depends on the type of community (for example, mining, institutional uses, etc.) and the resources it can provide. Availability of groundwater and aggregation of homesteads are other factors.

6. Number of Communities in Yucca and Frenchman Flats

Discussion
1) In this discussion, the limitation imposed by the environment really affected the SME responses. Such limitations included lack of resources, desirability of the area for habitation, developmental patterns for rural Nevada communities, and types of sustainable cultivation.
2) It was further discussed that once communities or agrarian-based businesses were established in these areas, not only would the environment not be able to support a large number of either enterprise, but some of the SMEs felt that it would be highly unlikely that new communities would form. Instead of forming new communities, SMEs felt that future settlements would be drawn to existing communities.

3) While it was very hard for most, if not all, of the SMEs to envision a community in these two areas, it was even harder for them to envision more than one community in any given area.

Results

The minimum range was 0–2 communities in either Yucca Flat or Frenchman Flat. Specific values given by the SMEs were 0 (n=5), 1 (n=4), and 2. The maximum range was 1–5 communities. The specific estimates were 1, 1 per 2500 acres, 2 (n=4), 3–5, 4, and 5 (n=2). The most likely range was 0–3. The specific values for this range were 0 (n=3), 1 (n=3), 2–3 (n=2), and 3.

Rationale

Harsh environmental conditions may not be able to support a large community or many communities. Current developmental patterns of rural Nevada support remote, widely spaced, small communities. Limited resources would limit the size and number of households within a community.

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7. Distinctions between Yucca and Frenchman Flats that affect the potential location of a community.

Discussion

1) The SMEs felt that there were enough environmental factors differentiating the two Flats to affect the siting of a community.
2) These factors were remoteness from existing or predicted urban centers, existing infrastructure, depth to groundwater, existence of site craters from weapons testing and subsequent contamination, soil quality, and slope stability.
3) Of these factors, the cratering and existing infrastructure were seen as primary determining factors for settlement. Due to cratering and contamination in Yucca Flat, Frenchman Flat was seen as a more suitable site for a community. Existing infrastructure would influence settlement in that, because there are approximately 10 old wells in Frenchman valley, someone might be more likely to attempt to drill for water in proximity to the old wells.
4) Despite all of these factors in the siting of a community, some SMEs felt that by the time the two valleys were rated or scored, the difference between the two would be insignificant.

Results

Consensus was that there are distinctions between Yucca and Frenchman Flats that would influence the potential siting of a community. The SMEs appeared to favor Frenchman Flat over Yucca Flat because of the absence of cratering and its proximity to some basic, pre-existing infrastructure.

Rationale
The amount of cratering in Yucca Flat has a negative impact for community siting. Frenchman Flat is more attractive because it is less remote than Yucca Flat, has more pre-existing infrastructure, less depth to groundwater, is more flat, and has available land and less groundwater contamination.

8. Are distinctions enough to consider these sites individually?

Discussion

1) There was some discussion that this question may require more information in order for the SMEs to answer. The SMEs were interested in rating factors such as physical and socioeconomic attributes of the two areas.
2) Through further discussions the SMEs felt that it would be more likely for a community to settle on Frenchman Flat because of all of the more favorable attributes when compared with Yucca Flat.
3) There were two SMEs who said this distinction did not matter in community settlement possibilities and two more who were not convinced that these distinctions were important.
4) The two SMEs who felt the distinctions did not matter, reasoned that the factors affecting community development were unknown when applied to future communities. They felt it would be inappropriate to project current socioeconomic preferences into the future.
5) The two SMEs who were not sure whether or not distinctions between the two sites mattered based their response on the need for more data.

Results
The majority of the SMEs felt that the distinctions between Yucca and Frenchman Flats did matter enough to consider the two areas independently. The SMEs who did not agree with this position, felt it was inappropriate to apply current socioeconomic factors in the siting of a community to future community development.

Rationale
Interest in Frenchman Flat over Yucca Flat as a community site is due to cratered areas of Yucca Flat. Input from the SME in land-use planning regarding desirable features for establishing a planned community bear this out.

D.4.5 Other Issues

A number of other issues were either raised with or by the SMEs. The first of these concerns issues of waste recognition. This question was raised because of its potential impact on the exposure calculations. Both acute and chronic exposure calculations are performed in the PA, but chronic exposure might be handled differently if the SMEs expected that waste would be recognized if brought to the surface through a well drilling operation. The SMEs were confident that most well drillers, intent on reaching water, would not recognize such a small volume of potentially unusual material in the normal course of well drilling operations. Consequently, both acute and chronic exposure need to be treated fully in the exposure assessments for NTS PAs.

Further issues were raised on drilling for groundwater as the main mechanism by which IHI might occur. Drilling for reasons other than obtaining groundwater (e.g., for natural resources) was raised as a possibility, but dismissed based on current knowledge of the area. Also, other mechanisms for intrusion, such as mining and building foundations, were raised. These also were dismissed, the first because it is not likely to occur based on current knowledge of the areas around the waste sites, and the second because this assessment pertains only to waste that is buried sufficiently deep that drilling becomes the only viable mechanism by which inadvertent intrusion can reasonably be expected to occur.

One further issue that was raised by the SMEs concerned the potential for placards and markers, and possibly surface barriers, to attract attention to the site, potentially causing advertent intrusion as opposed to inadvertent intrusion. While this was recognized as a possibility that should perhaps be addressed by DOE, it was agreed that the subject is outside the scope of this project and that inadvertent intrusion must be assessed without recourse to any consequence for advertent intrusion. That is, placards and markers or surface barriers should be thought of in the context of deterring inadvertent intrusion, even if the designs for these factors might seemingly promote advertent intrusion.

The following presentation provides a summary of the SMEs' inputs on the issue of waste recognition.

Waste Recognition: Is it reasonable to expect that the waste form will be recognizable for 10,000 years?

Discussion

Most drillers will not pay attention to the drill cuttings as they come to the surface.
Any waste that is encountered may be recognized as waste; however, it probably would not be recognized as hazardous waste.

Results

If a driller is paying attention to the drill cuttings as they come to the surface, it is very likely the cuttings will be recognized as waste. However, it is unlikely that waste cuttings would be recognized as hazardous.

Rationale

Drillers are not always aware of what the drill cuttings consist. Most people would not recognize the waste now, let alone 10,000 years in the future.

D.5 ELICITATION

With the model structures established, elicitation of the necessary inputs from the SMEs was required. Rather than including all ten experts for each question, the SMEs with pertinent expertise were asked to provide input for each top-level node of the influence diagrams. All other members of the expert panel were given the opportunity to comment, ask questions, or disagree with the key experts. The responses elicited through this process, along with the underlying model specifications, made possible estimation of probability distributions for each factor, followed by calculation of the probability of IHI by propagating the distributions through the influence diagram model.

The elicitation process involved assessment of various quantiles of the distributions, using the methods described in Section D.3.3.2. The elicitation began with the management controls module, then moved on to the homesteader scenario, and concluded with assessment of the community scenarios. In this elicitation phase, the SMEs participated in discussions as their various areas of expertise became applicable to specific influence diagram variables. Quantitative inputs were sought following thorough discussion of each variable.

The following sections reflect the high points of these discussions, the elicited inputs, and the primary rationales for the SME inputs. The SMEs who were considered key contributors to specific questions are also identified. A descriptive summary of these elicited SME inputs is provided in Chapter 4, and more complete descriptions of all aspects of the elicitation can be found in the archived documents of this project.

Before proceeding with the SME input, it is worth noting that the level of input varied from factor to factor. Some factors were clearly very important to the model, and were tangible enough that reasonable input could be obtained. However, there were a few management controls factors, in particular, for which the possibilities were not considered adequately definitive for a thorough quantitative assessment. Specifically, these included the effectiveness of surface barriers, placards and markers, and subsurface barriers, all of which the SMEs considered insufficiently well-defined to be able to provide complete distributions (proposed designs under the Integrated Waste Closure program are presented in Attachment D.11). If these factors are ultimately considered important to DOE management, then further effort will be required to better evaluate their potential for deterring IHI at these waste sites. At this time, these factors have undergone a preliminary analysis based on minimal SME input. The SMEs developed rough draft designs for these factors that they felt would provide adequate deterrence for potential intruders. The designs developed by the SMEs are included in the discussions below, and each alternate description of a design that was considered during the course of the elicitation sessions is presented pictorially.

D.5.1 Management Controls

<u>Institutional Control</u>

Discussion

1) Voluntary (stable) loss of control versus involuntary (unstable) loss of control was a focus of discussion.
2) Voluntary loss is not possible because it requires a change in current conditions or knowledge, such as a movement away from the political culture of environmentalism or a new level of knowledge that views the waste as harmless, or at least less harmful.
3) Involuntary loss is more likely.
4) Catastrophic loss, whether by physical factors (e.g., earthquakes, floods, meteors), disease, or political upheaval (war) are considered of negligible probability.
5) The SMEs considered two methods through which loss of institutional control may be likely to occur. The first is erosion of control, or the gradual decline in perception of site importance. The second method is political instability such that control of the site might be given up during political upheaval or because of economic reasons as political priorities change. The SMEs gave separate distributions for these potential causes of loss of control, but the distributions had very similar probabilities of occurring, and the time-frames for each were essentially identical.

Elicited Inputs

The probability that institutional control will be lost within 50 years is 0.10.

The probability that institutional control will be lost within 250 years is 0.50.

The probability that institutional control will be lost within 1,000 years is 0.90.

Rationale

Political systems are historically unstable; and maximum historical civilization lifetime is about 2,500 years.

Key SMEs: Donald Carns, Deward Walker, Jim Veltman

<u>Site Knowledge</u>

Discussion

1) Site knowledge is defined as knowledge that the exact location of the waste is known, and that it is known to be dangerous.
2) Site knowledge is expected to be maintained indefinitely through formal means (e.g., libraries and information repositories), but access to that knowledge is expected to decline as time from the major events that took place at NTS increases.
3) Regaining site knowledge after it has been lost is possible through the placards and markers, the surface barrier, or even without any of those physical reminders. Troy

was discussed as an example of regaining knowledge of a site. The waste site will be different than Troy in that it may be easier to locate because it will be marked by placards or markers as well as a surface barrier. However, the motivation to rediscover Troy was very high, whereas it could reasonably be expected to be quite low for rediscovering a small waste disposal area. Regaining site knowledge could lead to regaining institutional control. The length of time for which institutional control or site knowledge would then be expected to remain would be no longer than the current estimates. One possible means of regaining knowledge could be through investigation following airborne electromagnetic or gravity surveys. The probability of regaining site knowledge is considered sufficiently small, and very difficult to quantify, that it was agreed that it will be ignored as a bounding, conservative case.

Elicited Inputs
The probability that site knowledge will be lost within 50 years after the loss of institutional control is 0.25.

The probability that site knowledge will be lost within 100 years after the loss of institutional control is 0.50.

The probability that site knowledge will be lost within 140 years after the loss of institutional control is 0.75.

The probability that site knowledge will be lost within 500 years after the loss of institutional control is about 0.95.

Rationale
Many examples of knowledge of important information from the past being lost were cited (e.g., Mayan culture, Native American cities under present-day Mexico City, etc.

Key SMEs: Donald Carns, Deward Walker, Jim Veltman

Placards and Markers

Discussion
1) It is possible to create a marker that will physically endure for 10,000 years.
2) Language changes quickly, so symbology will have a much greater chance of being understandable over time.
3) The fact that warning signs on the dangers of digging near utility lines are understandable, but often ignored, led to considering whether the message is understandable and whether a person coming upon it will understand it.
4) The diagram presented on page 182 of *At Work in the Fields of the Bomb* was discussed (see Figure D-1). Reaction was strong in opposition to this diagram. The SMEs found it unnecessarily complex, and were concerned that it might encourage interest rather than imply dread or warning.

5) A simpler diagram with a message that could reasonably be expected to endure far into the future was roughly designed and discussed (see Figure D-2).
6) The SMEs made the assumption that the sign will be linked to the most permanent part of the surface barrier, for example, engraved directly on a very large boulder.

Elicited Inputs
Complex Sign (Figure D-1):
The probability of this marker deterring drilling now is between 0.05–0.10.

The probability of this marker deterring drilling after 500 years is 0.

Simple Sign (Figure D-2):
Note that the key SMEs had disparate opinions on the efficacy of this marker. Their opinions are presented separately.

SME 1:

The probability of this marker deterring drilling now is 0.75, with a lower bound of 0.55 and an upper bound of 0.85.

The probability of this marker deterring drilling in 1,000 years is 0.35–0.40.

The probability of this marker deterring drilling in 10,000 years is 0.1-0.15, with a lower bound of 0.07 and an upper bound of 0.25.

SME 2:

The probability of this marker deterring drilling is 0.20, with an upper bound of 0.50.

This probability will be constant over the 10,000 year compliance period.

Rationale
Complex Sign (Figure D-1): The message is so complex that it wouldn't be understood by many people today, and probably by even fewer in the future. Interpretation of ancient signs and symbols have some inherent confusion and speculation. That would be the case for this sign as well.

Simple Sign (Figure D-2): Because the message is so simple, it will rarely be misinterpreted. The upright and prone bodies have widely understood meaning. Life and death is one of the most universal concepts. Signs that represent nature have remained fairly constant over 30 to 40 thousand years. The expectations on probability of understanding these signs are based partly on studies conducted in Nevada on recognition of nuclear-related words and symbols.

Key SMEs: Don Carns, Deward Walker

Surface Barriers

Discussion

1) The SMEs agreed it is easier to consider the probability of efficacy of surface barriers, than to consider years of efficacy.
2) The surface aspects of the current cap design for the U3ax/bl disposal unit were considered, and determined to have no effect on the probability of drilling at the site. It was stated that steeper sides and larger rip-rap than the current design would be essential to deter drilling.
3) Potential subsidence of soils was considered, and information was shared concerning studies of Areas 3 and 5 that described a maximum expected subsidence of 25 ft.
4) The SMEs described three alternate designs that they felt were more likely to deter well drilling (Figures D-3 through D-6).

Elicited Inputs

Option 1: Current DOE U3ax/bl cover design (Figure D-6).

The probability of this barrier deterring drilling is 0.

Option 2: Large boulders 10 ft apart placed over the entire waste site (Figure D-3).

The probability of this barrier deterring drilling is 0.10.

Option 3: A 10-ft-high ring of boulders with a 2:1 immediate slope placed around the perimeter of the waste site (Figure D-4).

The probability of this barrier deterring drilling is 0.50.

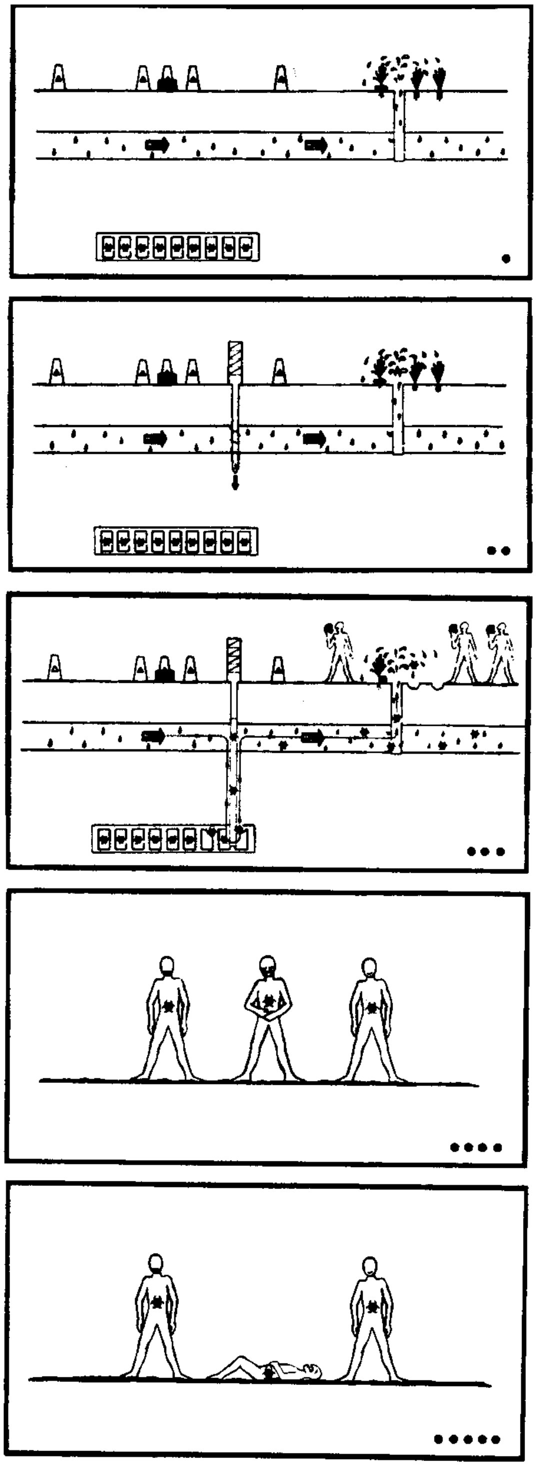
Option 4: A 35-ft-high mound of boulders with a 2:1 immediate slope (to 10 ft) placed over the entirety of the waste site (Figure D-5).

The probability of this barrier deterring drilling is 0.95.

Rationale

It would be very difficult to get a drill rig up a 2H:1V slope, and difficult to set up to drill if boulders are placed through the center of the mound also. If the outer ring of boulders is set outside of the waste area, then there will still be a hill of boulders after subsidence that will deter drill rigs. A ring without boulders in the center will not appear as clearly as a ring for 10,000 years as it would if it had boulders throughout the center. If boulders are spaced at approximately 10-ft intervals over the space, a drill rig would not be able to set up there. However, if just a few boulders were moved or taken away, the physical deterrent would be gone.

Key SMEs: Bob Gilbert, Terry Katzer, Jerry Kazynski, Beth Scott, John Singer



Pictographic Presentation of Biohazardous Caution Message

Figure D-1. This illustration is the "complex sign" prepared for DOE as presented in *At Work in the Fields of the Bomb*, by Robert del Tredici.

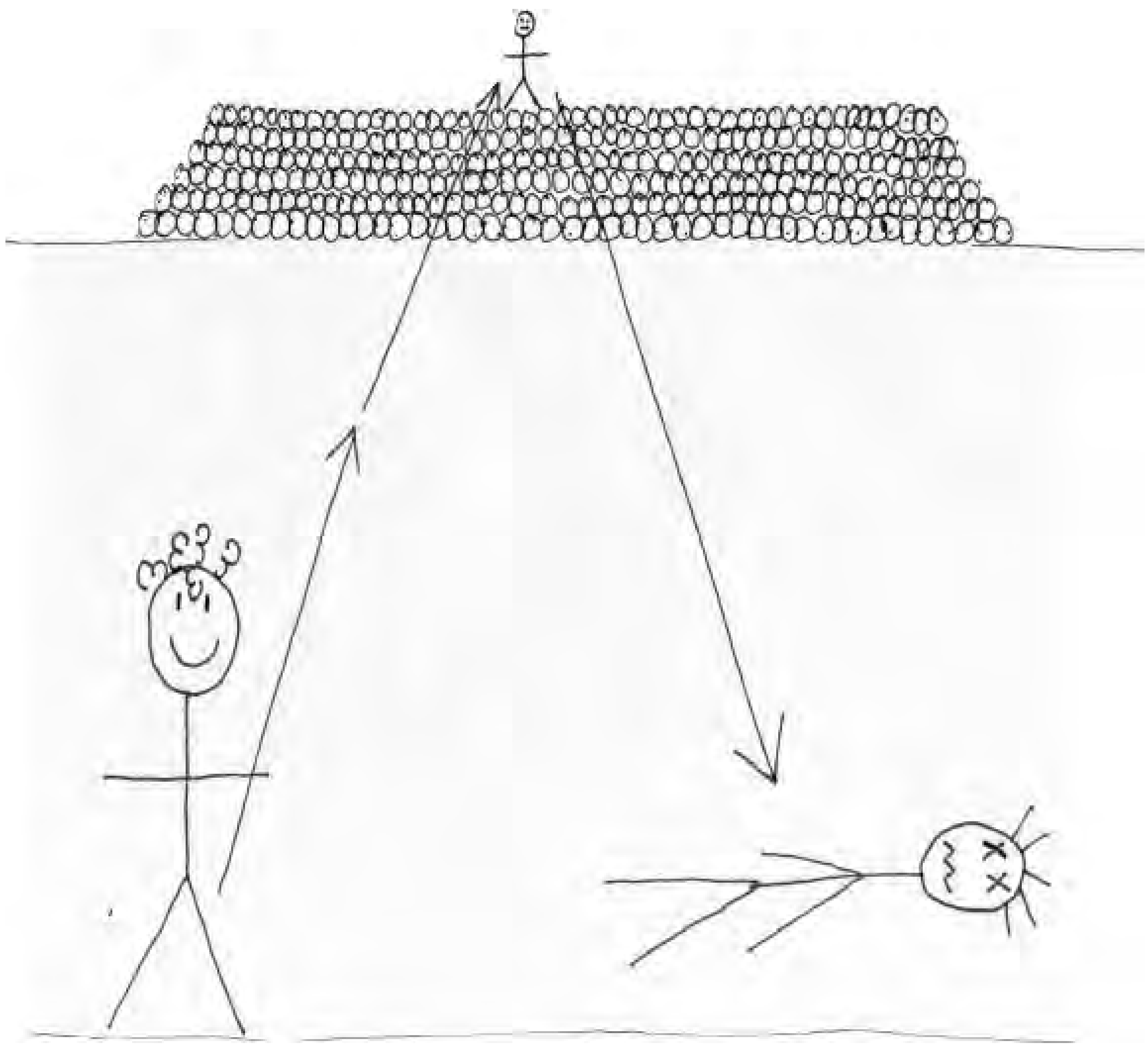


Figure D-2. This illustration is a representation of the "simple sign" the SMEs discussed during elicitation. The SMEs concluded that the life and death cycle is one of the most universal concepts, and that it is best represented by the upright and prone bodies.

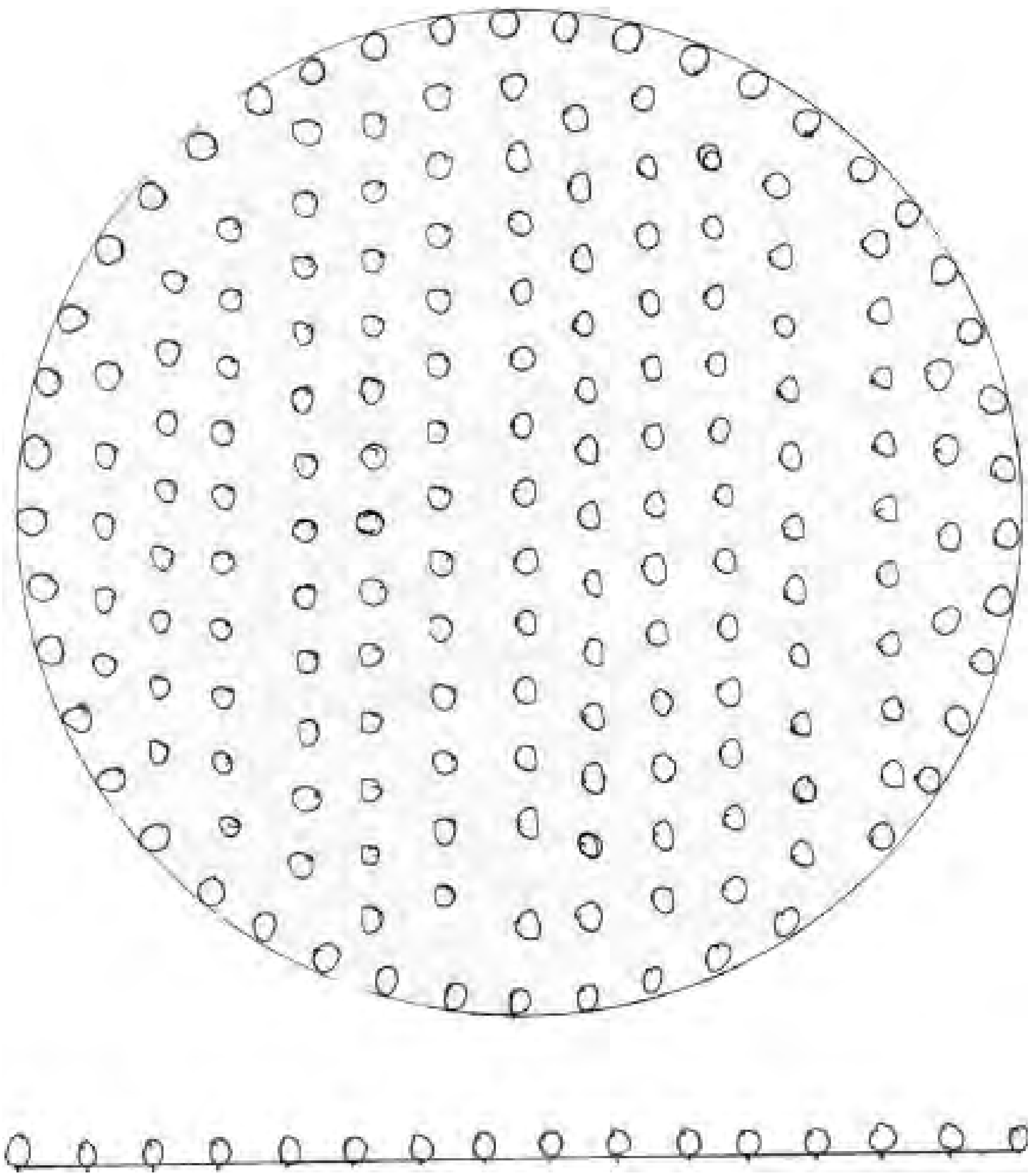


Figure D-3. This illustration represents "Barrier Option 2," discussed by the SMEs during elicitation. This option spaces approximately 10-ton boulders over the footprint of the buried waste, such that it would be difficult to maneuver a drill rig among the boulders.

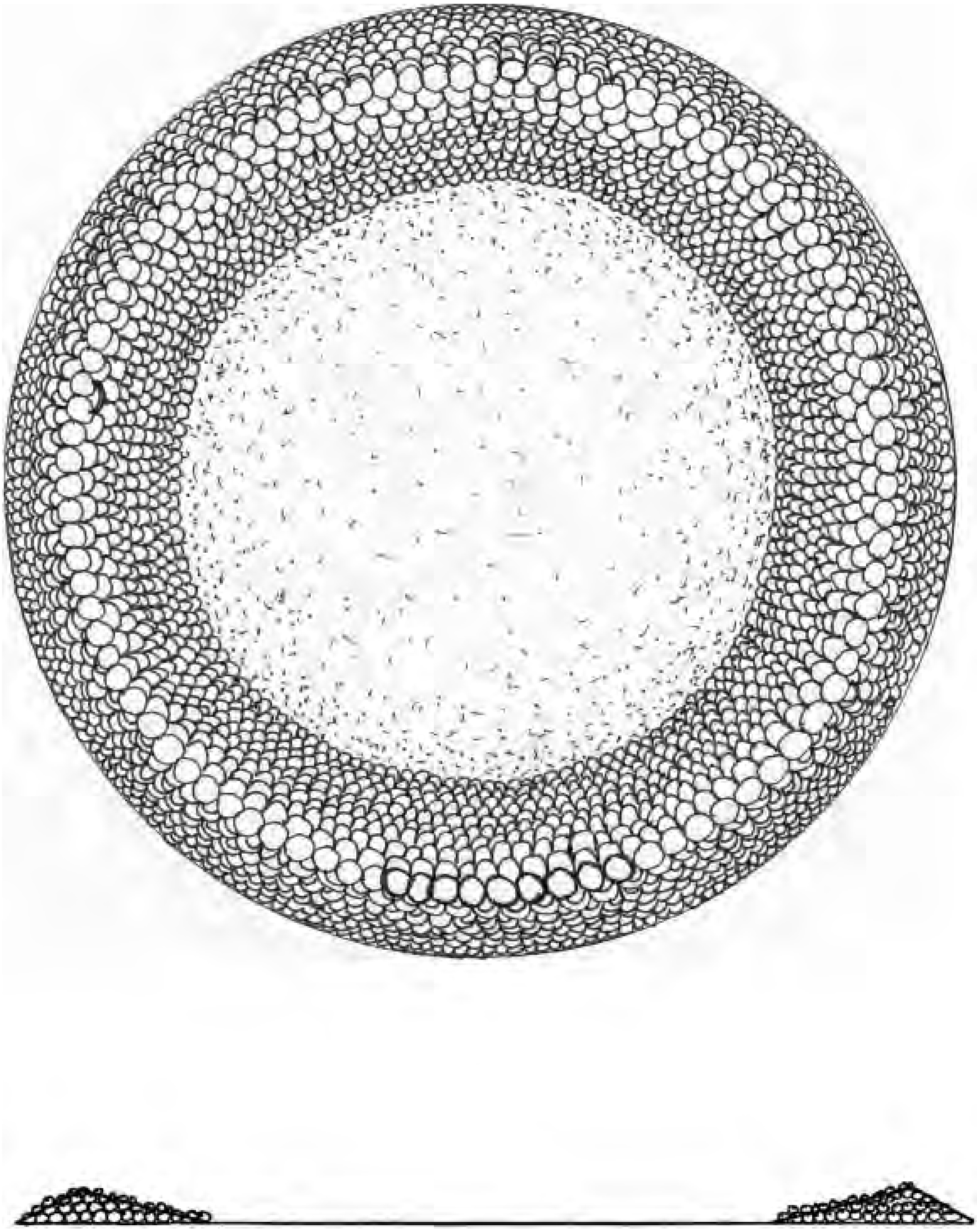


Figure D-4. This illustration is a representation of "Barrier Option 3," discussed by the SMEs during elicitation. This option sets approximately 10-ton boulders in a ring around the footprint of the buried waste, but with no further construction of a mound over the waste site.

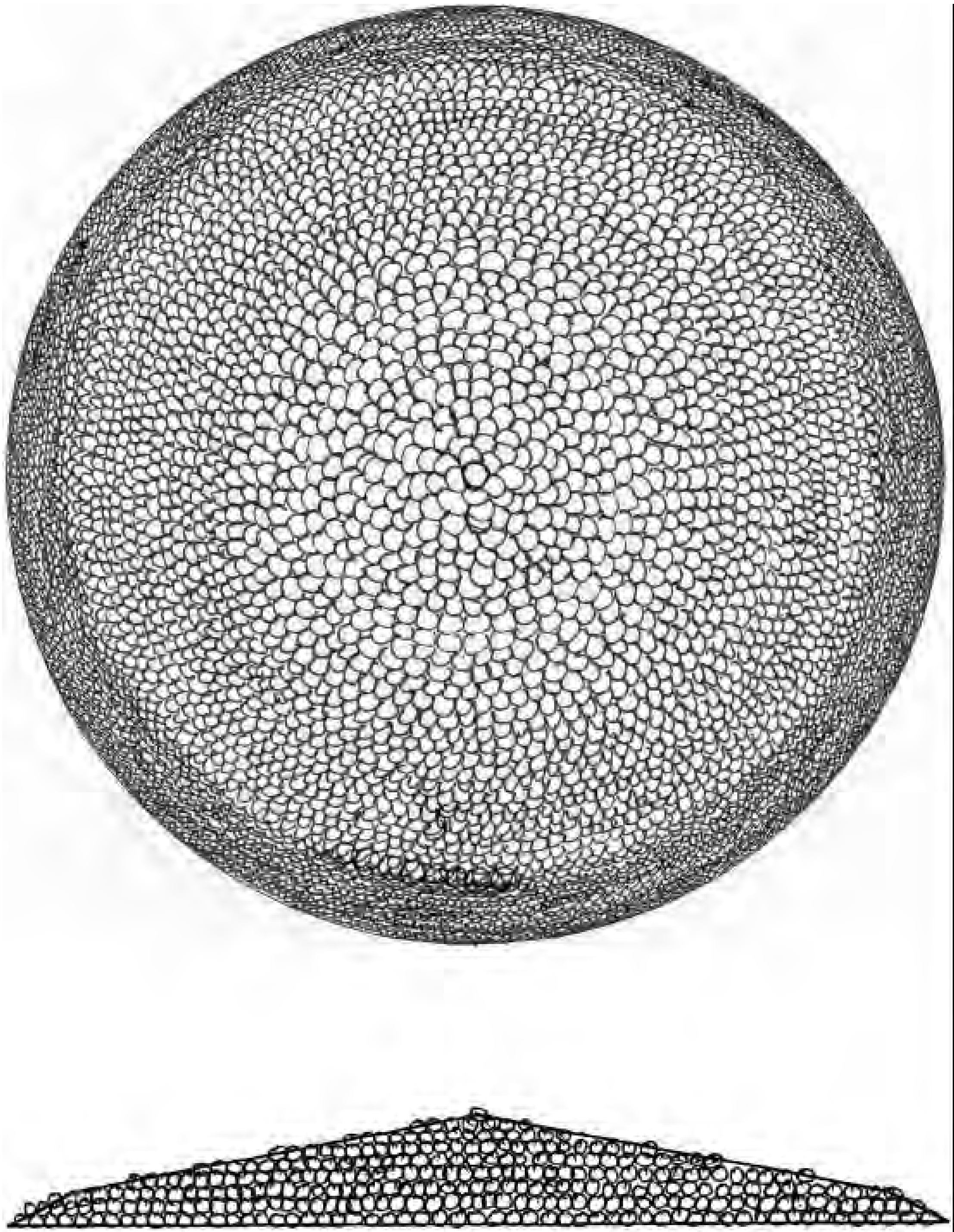


Figure D-5. This illustration is a representation of "Barrier Option 4," discussed by the SMEs during elicitation. This option sets approximately 10-ton boulders in a mountain over the buried waste footprint, with a 2:1 immediate slope up to 10 ft, and a secondary slope with a maximum height of 35 ft.

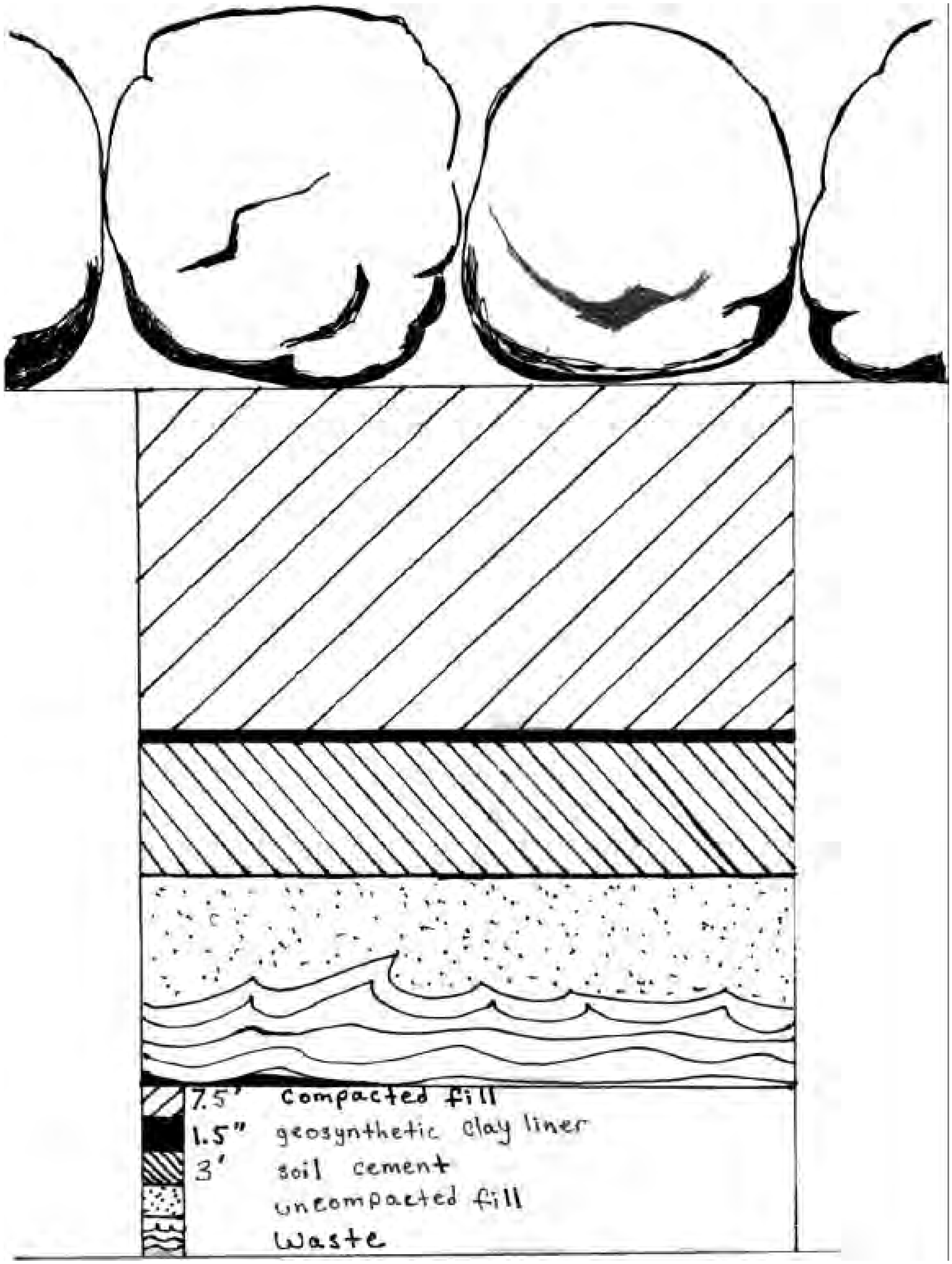


Figure D-6. This illustration represents the subsurface barrier DOE/NV is currently considering for the U3ax/bl Disposal Unit (see Bechtel Nevada 1996).

Subsurface Barriers

Discussion

1) Agreement was again reached that it is easier to consider the probability of efficacy of subsurface barriers, than to consider years of efficacy.
2) The subsurface aspects of the current cap design for the U3ax/bl disposal unit were considered and determined to have no effect on the probability of drilling at the site (see Figure D-6).
3) For a greater confinement disposal (GCD)-type waste disposal site, an angled shield that would deflect a drill bit would deter drilling. This solution is only viable for a waste area with a small footprint.
4) A really effective subsurface barrier was considered cost-prohibitive, so only options put forth by Beth Moore, DOE /NV, were evaluated.
5) One interesting suggestion was made for burying canisters that would emit either a foul-smelling gas or make small explosions to deter drilling.
6) Three suggestions were considered: 30 ft of buried used rubber tires, 30 ft of bailing wire, 5 ft of buried reinforced concrete (with 1-in. rebar inset every 6 in.).

Elicited Inputs

Option 1: Current DOE U3ax/bl cover design

The probability of this barrier deterring drilling is 0.

Option 2: 30 ft of used rubber tires placed 20–30 ft underground.

The probability of this barrier deterring drilling is 0.05–0.10.

Option 3: 30 ft of bailing wire placed 20–30 ft underground.

The probability of this barrier deterring drilling is 0.10.

Option 4: 5 ft of reinforced concrete with 1-in. rebar on 6-in. centers placed 20–30 ft underground.

The probability of this barrier deterring drilling is 0.50.

Rationale

The tires and bailing wire would not physically deter drilling, but may cause a driller to question why those foreign materials are there, and hence move drilling operations to another location. The reinforced concrete was expected to ruin a drill bit every 6 inches, thus leading to a level of frustration over many feet that may cause a driller to be deterred from continuing at that location.

Key SMEs: Bob Gilbert, Terry Katzer, Jerry Kazynski, Beth Scott, John Singer

D.5.2 Homesteader Scenario

<u>Number of Homesteads</u>

Discussion

1) Nobody will homestead on the playas. They are very high in saline, catch and hold unusable water, and are very silty. They also will not be used for commercial purposes because they do not have high concentrations of desirable elements.
2) The cratered area at Yucca Flat would be less likely to be settled than the uncratered area, but will be assumed equal for this scenario, and the population of homesteaders will be so sparse that the differences would be trivial.
3) Homesteaders would not settle on the large natural washes that characterize the flood plains, but the areas are so small that the panel elected not to specify them.
4) Location of natural resources may have a very slight impact on where homesteads will be situated, but the impact is considered negligible and will not be considered further.
5) Homesteaders would not make their living or support themselves from the land in Yucca or Frenchman Flat. Telecommuters, artists, writers, or prospectors were considered potential homesteaders for these sites.
6) Native Americans are not likely to settle in the Flats. Although there is a Native American claim to some or all of the land currently under NTS control, settling would be most likely to occur at or above the tree-line, or near water sources. Therefore, homesteading by Native Americans in different ways than already considered (e.g., artists, commuters, etc.) is of negligible probability.
7) If a community existed nearby, more homesteading would occur. This will be considered under the community scenario.

Elicited Inputs

The probability of there being 0 homesteads in the Frenchman and Yucca Flats area (without any nearby community) at any given time was assessed as 0.98.

The probability of exactly 1 homestead existing at any given time was estimated to be about twice the probability of 2 homesteads existing simultaneously.

The probability of exactly one homestead existing at any given time was estimated to be 100 times greater than the probability of 5 homesteads.

The probability of more than 5 homesteads was considered to be 0.

Rationale

Frenchman and Yucca Flats are desolate areas with great depth to groundwater. The costs of well drilling are high, and it is not economically viable to ground-water irrigate. There are no substantial natural resources available at these sites. Several areas of similar aesthetic appeal across the desert southwest would be expected to be developed prior to these areas due primarily to easier access to water. The combination of these factors led the SMEs to expect very few homesteaders in these areas.

Key SMEs: Don Carns, Terry Katzer, Allan Matthias, Tom Perrigo, Deward Walker

Homestead Lifetime

Discussion

1) Native Americans may be some of the homesteaders at these sites. Increasingly, Native Americans have been drilling ground-water wells at remote homesteads.
2) Wells become an investment that will keep homesteaders from moving on a whim.

Elicited Inputs

Seventy-five percent of homesteads will survive longer than 6.25 years.

Fifty percent of homesteads will last longer than 12.5 years.

Five percent of homesteads will last longer than 25 years.

Only one percent of homesteads will last longer than 40–50 years.

Rationale

There are monetary and other costs of establishing a homestead in these areas. The homesteader will be reluctant to leave soon after establishing a homestead, but will balance the investment against the undesirability of the difficult living conditions at either of these sites.

Key SMEs: Don Carns, Terry Katzer, Allan Matthias, Tom Perrigo, Deward Walker

Homestead Size

Discussion

1) Homestead size is considered sufficiently small so as not to be an issue for this scenario. (The only need for this variable was to ensure that the site would not be over-saturated with homesteads.)

Well Lifetime

Discussion

1) The following issues were considered in determining well lifetimes: breakdown of the casing; breaking the PVC when dropping the pump down the well; encrustation; sand; and cave-ins and breaches which could be caused by earthquakes.

Elicited Inputs
Five percent of the wells are expected to fail within 10 years.

Twenty-five percent of the wells are expected to fail within 15–20 years.

The median well lifetime is expected to be 35 years.

Only five percent of the wells are expected to last longer than 50–70 years.

Rationale
The inputs are based on the list of concerns and a great deal of information on lifetimes of local wells.

Key SMEs: Robert Gilbert, Terry Katzer, Jerrold Kazynski, John Singer

Distance Between Replacement Wells

Discussion
1) Replacement wells will usually be placed about as close to existing wells as is possible with a drill rig.

Elicited Inputs
Half of the replacement wells would be expected to be less than 30 ft apart, and half more than 30 ft apart (i.e., the median was assessed as 30 ft).

Ten percent of the replacement wells would be expected to be less than 10 ft from their corresponding original well.

Ten percent of the replacement wells would be expected to be more than 50 ft from their corresponding original well.

Rationale
This is what happens in current practice, and no reason for change is foreseen.

Key SMEs: Terry Katzer, Jerrold Kazynski, John Singer

D.5.3 Community Scenario

A general discussion of the community scenario led to a decision to consider three different types of communities separately.

1. The first type of community to be considered is one sited on either Frenchman or Yucca Flat.

2. The second type is a nearby community that would impact the use of Frenchman or Yucca Flat.

   The SMEs agreed that communities are most likely to exist where there is business. Commercial business was ruled out, but industry was considered a possibility. Two types of industry were considered: mining and a research park. Because mining is not expected to be economically viable, it was eliminated from further consideration. Other potential types of communities that were considered include prisons, military compounds, casinos, or religious groups' headquarters. Of these possibilities, a research park was considered to be by far the most likely.

3. Finally, expansion of Las Vegas to the point that it puts pressures on Frenchman or Yucca Flat is considered as the third part of the community scenario.

D.5.3.1. Base Community Scenario

<u>Number of Communities</u>

Discussion

1) The playas and steep slopes should be excluded from consideration. The area around the craters (which is where the waste would be buried if it is buried at Yucca Flat) will be much less likely to be settled than other areas.
2) Although there is a Native American claim to some or all of the land currently under NTS control, settling would be most likely to occur at or above the tree-line, or near water sources. Therefore, communities of Native Americans are not considered likely to occur in the Flats area except in ways similar to those already considered (e.g., a research park).
3) Characteristics of the area such as areal size, depth to groundwater, distance from existing infrastructures, etc., led the SMEs to the opinion that settling Jackass Flats is much more likely than settling Frenchman or Yucca Flat.
4) The water supply will be through a community water supply rather than individual wells.

Elicited Inputs

The probability of siting a community in Frenchman Flat is twice as likely as that of siting it in Yucca Flat. The number of communities elicited is for Frenchman Flat.

The probability of siting a community on the noncratered area of Yucca Flat would be ten times that of siting one in the cratered area if the areas were of equal size.

The percentage of the compliance period during which the SMEs would expect there to be a community in Frenchman Flat is 0.5 to 1 percent.

Rationale
The likelihood of a community being sited in Frenchman or Yucca Flat rather than in some other locale is very low. The SMEs considered it a "rare event."

Key SMEs: Donald Carns, Thomas Perrigo, Jim Veltman, Deward Walker

Community Lifetime

Discussion
1) The communities that are being discussed are all single-purpose, and therefore their lifetimes are quite easily predicted. For such communities, lifetime is generally (historically) less than a century.

Elicited Inputs
Ninety percent of such communities are expected to last longer than 10 years.

Seventy-five percent of such communities are expected to last longer than 35 years.

Fifty percent of such communities are expected to last longer than 50 years.

Twenty-five percent of such communities are expected to last longer than 65 years.

Less than ten percent of such communities are expected to last longer than 100 years.

Rationale
History has shown that small towns, such as what have been suggested for Frenchman or Yucca Flat, typically have short life spans like those projected for these communities.

Key SMEs: Don Carns, Deward Walker

Number of Wells

Discussion
1) The communities will form in response to the industry, thus they will originate as communities, rather than as a group of homesteads that eventually form a community.
2) Estimated maximum community size is approximately 3,000 jobs, 2,000 households, spread over about 1,000 acres.
3) The communities will use only community wells, not any individual wells.

Elicited Inputs
Assume each community will initially have 4 wells.

Rationale
The most wells that a community the size being considered may need would be two (this is considered conservatively high). A back-up well is allowed for each well (again this is conservative).

Key SMEs: Terry Katzer, Jerrold Kazynski, John Singer, Jim Veltman

<u>Well Lifetimes</u>

Discussion

1) Community wells will not be PVC, as was considered for private wells, because PVC piping is not appropriate for the larger water production necessary from these wells.
2) The potential causes of failure include encrustation, water draw down, local subsidence, and cave-in.
3) These estimates include the expectation that the wells will be rehabilitated occasionally.

Elicited Inputs
Ten percent of these wells are expected to fail within 10 years.

The median length of time these wells are expected to last is 35 years.

About 10 percent of these wells are expected to last longer than 50 years.

Rationale
Most municipal water systems in California plan for 40-year well lifetimes. In Las Vegas, wells have been constructed since 1907 and there are no wells that are still working beyond the upper estimate. The rationale for the lower estimate is that some wells are just drilled poorly. These estimates are slightly less than for homesteader wells because PVC will not be used for community wells.

Key SMEs: Terry Katzer, Jerrold Kazynski, Beth Scott, John Singer

<u>Distance Between Initial Wells</u>

Discussion

1) The wells would be evenly spaced across the community so that water does not have to be piped farther than necessary, and to minimize water-level drawdown, which reduces impacts to other wells.

Elicited Inputs
Wells are expected to be drilled on one-half mile centers in a square pattern.

Rationale
Estimated maximum community size is approximately 3,000 jobs, 2,000 households, spread over about 1,000 acres. The wells would be placed on 4 corners of a 1/4 square mile in the center of such a community.

Key SMEs: Terry Katzer, Jerrold Kazynski, John Singer

Distance Between Replacement Wells

Discussion
The replacement wells would be drilled as close as possible to the original well.

Elicited Inputs
Replacement wells are expected to be within 100 ft of the well they replace.

Rationale
The estimate would be even nearer to the original well, but in communities, the land very near an existing well is not always available for a new well.

Key SMEs: Terry Katzer, Jerrold Kazynski, John Singer

D.5.3.2 Jackass Flats Scenario

Number of Communities

Discussion
1) Characteristics of the area, such as areal size, depth to groundwater, distance from existing infrastructures, and proximity to the main thoroughfare heading north from Las Vegas, etc., led the SMEs to the opinion that settling Jackass Flats, Mercury, or some other nearby area is much more likely than settling Frenchman or Yucca Flat.
2) Research parks are the most likely types of communities. Prisons, casinos, and military or religious compounds are also possibilities that the SMEs considered.

Elicited Inputs
The SMEs would expect to see communities in surrounding areas that impact Yucca and Frenchman Flats approximately half of the compliance period. This estimate is bounded by a range from one-quarter to three-quarters of the compliance period.

Rationale
This probability is much greater than the probability of siting communities in Frenchman or Yucca Flat because those areas are far less desirable for community placement.

Key SMEs: Donald Carns, Thomas Perrigo, Jim Veltman, Deward Walker

Number of Homesteads

Discussion
A community near Frenchman and Yucca Flat will cause those areas to become more desirable for homesteading because services and supplies will be more easily accessible.

Elicited Inputs
The probability of siting a homestead in Frenchman Flat is twice as likely as that of siting one in Yucca Flat. The number of homesteads elicited is for Frenchman Flat.

The probability of siting a homestead on the noncratered area of Yucca Flat would be ten times that of siting one in the cratered area, if the areas were of equal size.

For Frenchman Flat, when there is a community nearby, the SMEs would expect:

One or more homesteads 95 percent of the time.

More than 50 homesteads 50 percent of the time.

More than 100 homesteads 5 percent of the time.

More than 200 homesteads 1 percent of the time.

Rationale
The number of homesteads likely to exist in Frenchman Flat is based on knowledge of current settling patterns on the fringes of the Las Vegas area.

Key SMEs: Donald Carns, Thomas Perrigo, Jim Veltman

Homestead Lifetime

Discussion
1) The homesteads are assumed to exist for the same length of time as the related nearby community. The communities are expected to have the same lifetimes as those considered in the first community scenario.

Well Lifetime

Discussion
1) The well lifetimes for these homesteads are expected to be the same as for those discussed in the homesteader scenario.

<u>Distance Between Replacement Wells</u>

Discussion

1) The distance between replacement wells for these homesteads is expected to be the same as for those discussed in the homesteader scenario.

D.5.3.3 Las Vegas Expansion Scenario

<u>Expansion of Las Vegas</u>

Discussion

1) The population of Las Vegas is currently just over one million people. Predictions are reporting an expectation of about two million people by the year 2010. Under the condition of using only current knowledge, the SMEs discussed how large (in population) Las Vegas is expected to become.
2) The SMEs estimated that a population of approximately three million is minimally sufficient to begin to impact Yucca and Frenchman Flats.
3) The SMEs believe the greatest population that Las Vegas could achieve is about five million.
4) Water is assumed by the SMEs to be available for the projected population of Las Vegas. As water has been needed in the past, there has always been a way to get more. The SMEs assume that water needs will be met similarly in the future.

Elicited Inputs

A probability of 0.20 for Las Vegas expanding to influence homesteading in Frenchman and Yucca Flats was elicited from the SMEs. This estimate was bounded by a 0.10 minimum probability, and a 0.60 upper probability.

Rationale

Current predictions are for Las Vegas to continue to increase in population dramatically for the foreseeable future, but, of course, the future can not be known.

Key SMEs: Donald Carns, Terry Katzer, Thomas Perrigo

<u>Community Lifetime</u>

Discussion

1) Las Vegas is a multifunctional community.
2) If Las Vegas expands to the point that it impacts homesteading in Frenchman and Yucca Flats, then the lifetime of Las Vegas is likely to last at least two times as long as it takes to expand to its maximum population. That is, the time of expansion is approximately one-third of the lifetime of a typical city.

3) These estimates do not consider whether rapid growth continues to occur or not. They are instead based only on the existence of the city, because growth to a center that can not support it will eventually self-correct. Therefore, growth is not an essential issue for consideration of city longevity.
4) The expected lifetime of Las Vegas is generally past that of institutional control and site knowledge. Many examples of cities that remained while knowledge of specific (and important) aspects was lost were given (e.g., buried structures being found under Mexico City, Middle Eastern cities lost their records during political changes while continuing to grow, etc.). In fact, the trend for knowledge to be lost in the locale of a large city is well documented, and has high probability of occurring.
5) With the estimates provided, it is also possible that site knowledge may outlast the city of Las Vegas. The SMEs see this as less likely to occur, but can imagine it under either the scenario that gambling is made illegal, or that gambling is legalized throughout the U.S.

Elicited Inputs
The probability is about 0.10 that Las Vegas will not last longer than 500 years.

The median length of time that Las Vegas is expected to last is 1,000 years.

The probability that Las Vegas will last longer than 1,500 years is 0.10.

The probability that Las Vegas will last longer than 2,000 years is 0.01.

Rationale
Historically cities have existed no longer than 2,000 years. Although Las Vegas does not have a single purpose, it relies heavily on the gambling industry and proximity to the Nevada Test Site. The lack of great diversity leads to the expectation that it will not be a very long-lived city.

Key SMEs: Don Carns, Terry Katzer, Allan Matthias, Tom Perrigo, Deward Walker

Number of Homesteads

Discussion
1) Homesteading in Yucca and Frenchman Flats is likely to increase as pressures from the expansion of Las Vegas make the outlying areas more attractive. As the Las Vegas infrastructure expands to the north, the reasonably available services for homesteaders in the areas of interest increase, making homesteading in these areas more attractive.

Elicited Inputs
Frenchman Flat:
One or more homesteads 90 percent of the time.
More than 30 homesteads 50 percent of the time.

More than 75 homesteads 10 percent of the time.

Yucca Flat:
One or more homesteads 90 percent of the time.

More than 20 homesteads 50 percent of the time.

More than 75 homesteads 10 percent of the time.

Rationale
The number of homesteads likely to exist in Frenchman or Yucca Flat is based on knowledge of current settling patterns on the fringes of the Las Vegas area. Yucca Flat is considered less desirable mainly based on depth to groundwater.

Key SMEs: Don Carns, Terry Katzer, Allan Matthias, Tom Perrigo, Deward Walker

Homestead Lifetime

Discussion
The homesteads are expected to have the same lifetimes as those discussed in the homesteader scenario. Homesteading (under this scenario) will only occur as long as Las Vegas exists at a size of three million or more people.

Well Lifetime

Discussion
The well lifetimes for these homesteads are expected to be the same as for those discussed in the homesteader scenario.

Distance Between Replacement Wells

Discussion
The distance between replacement wells for these homesteads is expected to be the same as for those discussed in the homesteader scenario.

D.6 EVALUATION BY THE SUBJECT MATTER EXPERTS

Subsequent to completion of the elicitation sessions, a package was prepared for the SMEs to ensure that their input had been properly captured, and to obtain their objective evaluations of the elicitation process. The package consisted of a cover letter (Attachment D.14), a summary report (Attachment D.15), a certification page (Attachment D.16), and an evaluation questionnaire (Attachment D.17).

The main purpose of the summary report and certification process was to obtain SME concurrence that their inputs had been properly captured. These inputs, with very few adjustments from the SMEs, were then used in the final report. The report summarized the inputs provided by the SMEs during both elicitation sessions. The SMEs were asked to review and indicate where their input either required clarification or was incorrectly recorded and summarized. Some of the SMEs requested clarification of several important points, all of which are addressed in the final report. Documentation of a follow-up telephone conversation with one of the SMEs is also included in Attachment D.16. Copies of the signed certification pages for all ten SMEs are included in Attachment D.16. The SMEs will be provided the draft final report for their final review and concurrence in accordance with the quality assurance program established for this study.

The purposes of the evaluation questionnaire were to request open feedback on the elicitation sessions, the purpose of the study, its objectives, and its structure. The responses from the SMEs were very encouraging. Most of the SMEs felt that the background material provided was on target. A few indicated that some further information might have been useful, such as more information on demography of the area, or information about similar expert panel studies. One SME also indicated that more time to look up references in between the two sessions would have been helpful. Overall, however, the SMEs expressed their comfort with the level and appropriateness of the background material, that the elicitation process adequately explored the issue of IHI, that the desired objectives were met, and that the elicitation process was credible. They also strongly indicated that they were comfortable with their inputs and that the results are credible, although there was recognition of the complexity of the problem and the difficulty of dealing with the potential for events in the future. They indicated, however, that the results provide a reasonable or credible measure of the probability of inadvertent human intrusion given current knowledge.

One SME noted that the elicitation was credible only “within the framework dictated by DOE,” and that there was a bias by the Project Team and DOE to “sort of steer the panel in a certain direction.” The Project Team requested clarification of this response, documentation of which is also included in Attachment D.17. The clarification indicated that this SME was referring to the anchoring effect associated with providing preliminary influence diagram models from which the SMEs were expected to iterate. The Project Team concurred with the possibility that a bias could have been introduced through this process, but suggested that this could not easily have been overcome without a much lengthier process, considering the SMEs were chosen based, in part, on their lack of association with low-level waste disposal projects (see Appendix C). The SME agreed, and went on to indicate that the bias probably had a negligible effect on the results and conclusions obtained. The SME certified that the documentation of the clarification was recorded accurately.

The overall evaluation, including verbal as well as written responses, indicated that this was a well-received, interesting, and stimulating study. Further, the evaluation responses indicated that the SMEs felt they were provided all the opportunity necessary to fashion the results and conclusions through their objective input, and that the study provided results that are credible.

D.7 ADDITIONAL REFERENCES

Hora, S.G., von Winterfeldt, D., and Trauth, K.M. (1991). *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant*, Sandia National Laboratories, SAND90-3063.

Sen, A.K. (1977). Social Choice Theory: A Re-examination. *Econometrics* 45:53-89.

Wood, D.E., R.U. Curl, T.E. Buhl, J.R. Cook, M.R. Dolenc, D.C. Kocher, B.A. Napier, K.W. Owens, E.P. Regnier, G.W. Roles, R.R. Seitz, D.J. Thorne, and M.I. Wood. (1992). *Performance Assessment Task Team Draft Progress Report.* DOE/LLW-157. U.S. Department of Energy, Office of Environmental Management, under DOE Idaho Operations Office, Idaho Falls, Idaho.

D.8 ATTACHMENTS

D.1 Information Packet (including cover letters)

D.2 Preliminary Influence Diagrams Report

D.3 Agenda for the Field Trip

D.4 Report: Socioeconomic Overview

D.5 Presentation: Performance Assessment and Composite Analysis at Radioactive Waste Management Sites

D.6 Presentation: Introduction and Overview of Elicitation Project

D.7 Presentation: Probability Training Workshop

D.8 Reference list of "data call" requests

D.9 Presentation: Waste Types and Disposal Configurations

D.10 Presentation: Waste Disposal Site Conditions

D.11 Presentation: Integrated Closure Program

D.12 Presentation: Assessing the Probability of IHI: Recap of the First SME Panel Session and Impact on Model Structure

D.13 Presentation: Elicitation Training Workshop

D.14 Cover Letter for SME certification and evaluation

D.15 Report: Summaries of Inputs Received from the Subject Matter Experts

D.16 Certification Page: Original and SME Responses

D.17 Sample Evaluation Questionnaire: Original and SME Responses

D.9 RELATED ARCHIVED DOCUMENTS

- Background information documents
- SME responses to session 1 elicitation questions
- Flip chart notes (session 1 and session 2)
- Written notes (session 1 and session 2)
- Audio tapes of both elicitation sessions
- "Data call" items

APPENDIX E: ALGORITHMS AND CALCULATIONS

CONTENTS

E.1 INTRODUCTION

This appendix provides a technical description of the results presented in Volume I (Black et al. 2001) of a modeling process for the assessment of the probability of inadvertent human intrusion (IHI) based on the inputs provided by subject matter experts (SMEs). This description includes the assumptions made, the reasoning behind those assumptions, algorithms for calculating the probability of IHI, and the outcome of the process. The algorithms correspond to the influence diagrams presented in the main text (Volume I, Black et al. 2001). The influence diagrams provide a qualitative overview of the underlying models. Consequently, the actual algorithms represent the models in greater detail than the influence diagram forms.

The basic structure of the influence diagram models was completed by the SMEs, and the inputs to the models that quantitatively describe the influence diagrams were derived from inputs elicited from the SMEs, as described in the main text. The influence diagrams presented in the main text are more complete, better matching the numerical models, and incorporating some input provided by the SMEs that was not represented directly in the SMEs' last version. Details of specific input provided by the SMEs are provided in Appendix D.

This appendix has four major sections. The first section describes elements of the calculations that occur frequently in the algorithms. The remaining sections describe specific calculations for the Homesteader scenario, the community scenarios, and the management controls module. Each section includes a basic description of the scenario being addressed and assumptions made regarding input to the scenario. A detailed explanation of the modeling process is provided, and propagation of the SME inputs through the influence diagram models follows.

Statistical assumptions and justifications are stated up-front in many cases, but are otherwise presented as the models unfold. All scenario models lead to the calculation of a "scenario probability," that is conditional on the assumptions and conditions of the study, the knowledge base of the SMEs, aspects of the elicitation process, and on an assumption of completely ineffective management controls. After each scenario probability is calculated, the combination of all scenarios is addressed. In the final section, the scenario probabilities are combined with potential outcomes of the management controls module in an exploratory fashion. As explained in the main text, several of the management controls factors were not well defined, and the SME input is regarded as preliminary. However, their input allows preliminary exploration of the impact of management controls on the scenario probabilities of IHI.

This Appendix supports the description and results of the project that are presented in Volume I (Black et al. 2001), and represents part of the quality assurance program maintained during this project to ensure that the inputs and results are well-founded, credible, and defensible.

E.2 COMMONALITIES IN THE CALCULATIONS

The objective of this project is to provide an assessment of the probability that IHI into buried wastes in Frenchman Flat and Yucca Flat will occur during the next 10,000 years (compliance period). Input was obtained from the SMEs for each of the parameters identified as important for estimating this probability. 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 allows calculation of distributions for the final probabilities of interest.

There are a number of assumptions or conditions of the modeling and the results that are described in this section. In addition, there are several components of the simulation routines that occur frequently, and there are a few constants, such as the defined areas of interest, that have been used throughout. This section provides a description of constants that are used in the algorithms, is followed by a discussion of curve fitting techniques used to fit cdfs from SME inputs, then finishes with an overview of the simulation approach.

E.2.1 Assumptions and Conditions

Input to the models was elicited from the SMEs, and hence can be classified as subjective input. All subjective quantities expressed by the SMEs are conditional on their knowledge bases and aspects of the elicitation process. The results of this study are also conditional on some of the mathematical manipulations performed on the SME input. When interpreting the results, the assumptions and conditions established during the course of the study must be considered. For example, the final products are conditional on:

- the SMEs' knowledge (based on their experience, education, and information provided to them throughout the project)
- the influence diagram models
- the actual SME inputs (quantiles of distributions, etc.)
- the methods used to fit cumulative distribution functions (cdfs) to the quantiles provided by the SMEs
- use of the fitted distributions for simulation purposes[1]
- use of constants instead of distributions for some inputs

[1] Sensitivity analysis related to perturbing the fit distributions is presented in Appendix F.

The assumptions and conditions of the study provide the conditions for the results. For example, the structure of the influence diagram models and the numerical methods used in their mathematical representation impose conditional independence constraints. However, the model was developed according to the SMEs' opinions expressed through their inputs regarding the model structure and its quantitative specification. The SMEs attempted to build a model that was tractable and was likely to provide reasonable results, but in some cases, they erred on the side of conservatism for model development and model structure. For example, the SMEs stated that most commuter homesteading would occur near the shaded steeper slopes towards the edge of Frenchman Flat and Yucca Flat, however, they did not want to deal with this level of detail, feeling that this refinement of the model would make the problem less tractable without significant gain in information. Once the model was established, the SMEs provided quantitative input to specify distributions for the parameters. These quantitative inputs are subject to potential elicitation biases (cognitive and motivational biases), which were controlled to the extent possible during the elicitation.

The variability in the final distribution of the probability of IHI is also conditional on these same assumptions and conditions. The spread of the elicited distributions might be more prone to elicitation biases than the centers; a common cognitive bias is over-estimation of rare events. It should also be noted, however, that the type of group or consensus elicitation performed in this study often results in significantly narrower distributions than might be obtained from approaches such as the Dephi method (cf., Morgan and Henrion 1995). The final simulated probability distributions probably overestimate the center of the distributions of the probability of IHI, and might underestimate the spread of the final results. Aspects of the modeling process on which the results, particularly the spread of the output distributions, depend include:

- Different methods could have been used to fit probability distributions to the SME inputs, or a similar method might have resulted in a different choice of "best fit" distributions.

- Use of the fitted distributions in the simulation algorithms does not account for possible uncertainty in these distributions.

- When constants are used, variability or uncertainty is ignored and the constants become conditions of the results. For example, the distance between replacement wells for the Base Community scenario was elicited as a constant (100 ft). The final results are conditional on this input value. As the algorithms are developed, explanations are provided for any constants that were elicited.

Aspects of the algorithms also introduced potential bias or conservatism in the calculations. Some of these adjustments might have affected the overall estimated variability, although this effect has been mitigated to the extent possible. The potential effects of these adjustments are discussed in the following sections as they occur.

As indicated, the final results provide an indication of the spread of the probability of IHI. The SMEs indicated their subjective assessment of uncertainty or variability by providing several quantile estimates to completely specify distributions. All the information provided by the SMEs is used in the modeling process. In so doing, distributions for the probability of IHI are generated as output. If some audiences prefer a single number result, this can be read directly from the simulated distribution results. It should be noted that propagation of single values through the algorithms was performed as a simple quality assurance check on the algorithms. This provided a form of logic check for the more complex simulation algorithms, to ensure that reasonable results were derived.

All programming and calculations reported were done using S-Plus 2000 (1999). The discussion below does not attempt to describe the code or the internal routines of S-Plus 2000, it provides a description of the algorithms and the outputs of each step taken along the way to the final results. The presentation is made as direct as possible while accounting for the important elements of the algorithms.

E.2.2 Constants

Several constants that are generic to the models are used throughout the calculations:

- time frame of interest, evaluation period, or compliance period
- area of the waste footprint for either Frenchman Flat or Yucca Flat
- area of Frenchman Flat (excluding the Frenchman Lake playa)
- area of Yucca Flat (excluding the Yucca Lake playa)
- area of cratered portion of Yucca Flat

Results depend directly on these constants. These are conditions of the model, and are constants that were specified for the SMEs. Occasionally, other constants were used in the algorithms when the SMEs preferred to give a single value rather than a distribution as their input for a particular factor. Their effect on calculations is noted during this presentation on modeling.

E.2.2.1 Evaluation Period

The time frame for this study, or compliance period, of which the SMEs were informed, is 10,000 years. That is, the SMEs were asked to condition their inputs on this compliance period. If a different compliance period had been used, reassessment of the importance of certain variables might have occurred and might have required more detail in the elicitation. For example, the SMEs believed that institutional control would not last very long (median of 250 years), compared with a compliance period of 10,000 years.

Consequently, the effect of institutional control on the overall results was negligible. Had the compliance period instead been 1,000 years, 250 years of institutional control would have had a far more significant effect.

Similar comments can be made for intrusion scenario factors if the compliance period was limited to 1,000 years. For example, the Jackass Flats scenario is by far the dominant scenario when a compliance period of 10,000 years is used, but if the compliance period had been 1,000 years, then the Las Vegas Expansion scenario would have become more important, because the SMEs specified the lifetime of Las Vegas to be relatively short compared with 10,000 years. Also, applying the results to a reduced compliance period requires an assumption for the Jackass Flats scenario that the distribution of community events over time is random. This might not be an unreasonable assumption, but, given the 10,000 year time frame of interest, it was not tested with the SMEs.

Allowing for these concerns, it is possible to use the SME inputs to generate probabilistic estimates for different compliance periods. However, these and other concerns must be recognized if the compliance period becomes relatively small. Some exploration of the effect of changing the compliance period is provided in Appendix F.

E.2.2.2 Areas of Concern

Fixed constants for the areal sizes of interest were used to provide input probabilities (proportions) used in the simulations. The following constant values were generated using defined bounding criteria and GIS techniques (rounded values):

- areal size of Frenchman Flat: 86,000 acres
- areal size of Yucca Flat (excluding cratered area): 70,500 acres
- areal size of cratered portion of Yucca Flat: 24,000 acres

The areas of Frenchman Flat and Yucca Flat were determined based on the change from alluvial basin to mountain slope. This slope generally followed the 4,500 foot contour of the valleys, but went as high as the 6,000 foot contour on the east side of Frenchman Flat. Further details are provided in Attachment E.1. The areal sizes given for Frenchman Flat and Yucca Flat exclude the playas, and the areal size of Yucca Flat excludes the cratered area. The cratered area was initially defined in terms of highly cratered and moderately cratered areas, although both areas were combined for the final analysis. Note that the Area 3 RWMS lies within the cratered area of Yucca Flat.

The area of the waste footprint was set at two acres by the Department of Energy, Nevada Operations Office (DOE/NV) for this study. This was based on the expected areal size of a waste footprint corresponding to disposal of waste from Fernald that satisfies the conditions of 11e(2) by-product materials (see Appendix C). This constant was shared with the SMEs and was established only to provide a reference size to facilitate calculation of the probabilities of interest. There is no reason to expect that selection of this waste footprint size should have influenced the SME inputs. However, as the relative size of the waste footprint to the areas of Frenchman Flat and Yucca Flat increases, then the probability of IHI increases. Further exploration of the effect of changing the areal size of the waste footprint is provided in Appendix F.

E.2.3 Distribution Fitting

The distributions estimated from SME input formed the basis of the probabilistic nature of the simulations. Two main parametric fitting techniques were used. The first was used directly for two factors (institutional control and site knowledge) with the SMEs during the elicitation session, and employs lognormal distributions to fit the elicited quantiles. The lognormal distribution was chosen during the elicitation because of the apparent skew based on the SMEs inputs. The SMEs agreed that the lognormal forms fit their input and opinion appropriately. The second method was applied to each of the scenario inputs for continuous distributions, and employs “shifted” beta distributions to fit the elicited quantiles. These fits were not presented or demonstrated during the elicitation, but have been used to model the SMEs’ input so that calculations could be performed. Beta distributions tend to be very flexible, although the minimum and maximum of beta distributions are finite. Also, a gamma functional form was used to fit the population distribution for the Las Vegas Expansion scenario.

Each simulation involved drawing at random from the fitted cdfs and propagating these realizations through the influence diagram model. The method by which final cdfs are established is not crucial to the overall results (cf. Raiffa 1970). Only gross deviations from the inputs are likely to have any serious consequence for conclusions. For example, the differences between fitting the SME input for institutional control or site knowledge with a lognormal cdf or a beta cdf are likely to be minimal. The objective for each factor was to establish a cdf that reasonably represented the SME inputs. Appendix F provides some discussion of the effect of fitting different distributions.

E.2.3.1 Lognormal Distribution Fitting

A lognormal distribution was used for both the institutional control and site knowledge factors. In both cases, a lognormal curve was estimated during the elicitation session and was presented to the SMEs for their concurrence. A formula for the lognormal cdf is presented in Equation E-1 for a random variable Y. This formula stems from a normal random variable, X with associated mean m and standard deviation s, transformed, via exponentiation, to a lognormal distribution, $Y = \exp(X)$.

$$F_Y\left(y \middle| m, s\right) = \int_0^y \frac{1}{ts\sqrt{2p}} \exp\left[\frac{-\left((\ln t) - \mu\right)^2}{2s^2}\right] dt \qquad \begin{cases} 0 \le y < \infty \\ -\infty < \mu < \infty \\ s > 0 \end{cases} \qquad \text{E-1}$$

The median of a lognormal distribution with this parameterization is $\exp(m)$, the mean is $\exp(m+\frac{1}{2}s^2)$, and the variance is $\{[\exp(2m+s^2)][\exp(s^2)-1]\}$.

Distribution fitting was performed by initially using the median observation to obtain a direct estimate of *m*, then solving for *s* using numerical methods, the other elicited quantiles, and Equation E-1. The best fit was determined graphically and presented to the SMEs for their final input and verification.

E.2.3.2 Beta Distribution Fitting

Parametric distribution fitting was performed using a scaled beta distribution for all continuous scenario variables. These beta distributions nominally have four parameters that can be adjusted to optimize the fit of the distribution. These are the two shape parameters (*v*, *w*), and the two range parameters (*a*, *b*). The range parameters for a standard beta distribution are zero and one, but different values are used for the "scaled" beta distribution. A formula for the "scaled" beta cdf is presented in Equation E-2 for a random variable *Y*.

$$F_Y(y \mid v,w,a,b) = \int_a^y \frac{(t-a)^{v-1}(b-t)^{w-1}}{\mathrm{B}(v,w)(b-a)^{v+w-1}}dt \qquad \begin{cases} v,w > 0 \\ a \le y \le b \\ -\infty < a,b < \infty \end{cases} \qquad \text{E-2}$$

In Equation E-2, $\mathrm{B}(v,w)$ represents the standard beta function for parameters *v*, and *w*. The mean of a scaled beta distribution in the form presented in Equation E-2 is $\left[{(bv+aw)}/{(v+w)}\right]$, and the variance is $\left[{(vw)(b-a)^2}/{(v+w)^2(v+w+1)}\right]$.

The beta distribution is very flexible, allowing reasonable fitting for most types of input. It is also truncated at both ends of the distribution, allowing zero probability for events outside the range of (*a*, *b*). If *v*, *w* are both less than one, then the probability density function takes a "U" shape within the range of (*a*, *b*). If *v*, *w* are both greater than one then the probability density is unimodal.

In general, distribution fitting was performed by optimization across the four parameters of the scaled beta distribution. Optimization was performed by minimizing the sum of squared differences between the quantile input elicited from the SMEs and the fitted distribution. Optimization involved a non-linear search algorithm, which started with initial values for the four parameters and iterated until convergence was achieved. The algorithms worked, in general, by assuming a beta distribution form, constraining each one of the four parameters to reasonable ranges, and then performing an iterative search across the four parameter space until the sum of the squared differences between the elicited and predicted quantiles was minimized. The output was continually checked to make sure that reasonably good fits had been achieved.

The flexibility of this four-parameter family most often allowed good fits to the SME input. Occasionally the optimization was constrained. For example, in reality the elicited distributions can only obtain non-negative values. If the initial optimization resulted in the potential for negative realizations the search on the parameter a was constrained to the positive real line (which usually forced the distribution through $a = 0$).

Starting values for the optimization were chosen near the ends of the ranges for the truncation parameters, and at values a little greater than one for the beta distribution parameters. The constraints on the range, the functional form of the distribution, and the "poetic" license taken to visually find good fits to the quantile input, in general, allowed estimation (or fitting) of distributions fairly directly. In cases for which a single scaled beta distribution did not provide a good visual fit to the data, discrete mixtures of truncated scaled beta distributions were used in combination. That is, different beta distributions were fit to different parts of the distribution, and the join between the parts served as a constraining point on the two adjoining distributions.

The scaled beta distribution was used primarily because of its flexibility. The goal of the fitting routines was to achieve a good visual fit to the elicited quantiles while providing a mathematical formula that could serve as the basis for simulation. The intent was to avoid constraining the SME input to prescribed distributional forms, but rather to use the flexibility of the beta distribution, or combined beta distributions, to mathematically mimic fitted distributions that might be drawn by hand. Appendix F provides some sensitivity analyses that were performed by examining perturbations of the SME input, and hence refitting of the distributions.

E.2.3.3 Gamma Distribution Fitting

For the factor pertaining to the population through time of Las Vegas under the Las Vegas Expansion scenario, a gamma distribution was used to fit the SME input. This fitted distribution was used to determine the proportion of the time frame of existence of Las Vegas for which population pressure might be placed on Frenchman Flat and Yucca Flat. The general shape of a gamma distribution was more appropriate for the available input. This is the only case for which a gamma distribution was used; consequently, details are provided in the discussion of the Las Vegas Expansion scenario.

E.2.4 Overview of Simulation Approach

This section provides an overview of the algorithms used to generate a distribution of the probability of IHI for each scenario. The focus is on scenario probabilities conditional on ineffective management controls. These are termed the "scenario probabilities" in the main text.

All of the SME inputs were used to fit cumulative distribution functions to each input factor. Monte Carlo simulation techniques were then used to select values from each distribution. These values were propagated through the influence diagram models to derive an estimate of the probability of IHI for each simulation run. Consequently, the many simulation runs produced a distribution of the scenario probability of interest, and, hence, captured the entirety of the SME input. Figure E-1 provides a schematic of the process used to generate a distribution of the probability of IHI for each scenario.

Each simulation involved drawing at random from the fitted cdfs and propagating these realizations through the influence diagram model. For each of the scenario-specific influence diagram models, an intermediate step was to calculate the total number of wells drilled in Frenchman Flat or Yucca Flat during the evaluation period. The final step in the propagation was to calculate the probability that at least one well intersects the waste footprint. These final distributions represent the variability generated through randomly sampling from the SME inputs after distributions (cdfs) were fitted to their input, but conditional on the study conditions and assumptions. This process was repeated 10,000 times, resulting in simulated distributions for the final probabilities of interest (e.g., scenario probability of IHI).

The simulated data distributions are displayed in several ways in this appendix and in the main text. The first types of figures presented are relative frequency diagrams of the 10,000 simulated scenario probabilities. Relative frequency diagrams are normalized histograms. These diagrams often exhibit some multimodality. This is partly an artifact of the simulations and the size of the histogram “bins”, particularly in the extremes of the distributions; however, another reason is that some of the calculations involve discrete components (e.g., number of homesteads, number of wells), which limit the number of possible results. These figures are overlaid by a probability density function. The overlain probability density functions are kernel-smoothed density estimates based on a Gaussian kernel and the simulated data. The density estimates tend to smooth the noise in the histogram. Density estimation is a subjective process, depending on criteria such as bin size and number of bins (bins are permitted to overlap when performing density estimation). Density estimates were selected based on their similarity with the relative frequency diagrams while finding a set of criteria that minimally achieved a unimodal distribution. The second set of figures presented in this appendix portrays cumulative distribution functions that correspond to the histograms and density estimates presented in the first set of figures. The first set of figures is also presented in the main text.

To facilitate discussion of some details that are common to many of the algorithms, the remainder of this section focuses on a summary of the simulation algorithms for the Homesteader scenario. Although the inputs are different for each scenario, the basic approach is the same, as suggested above. Details are provided in the following sections.

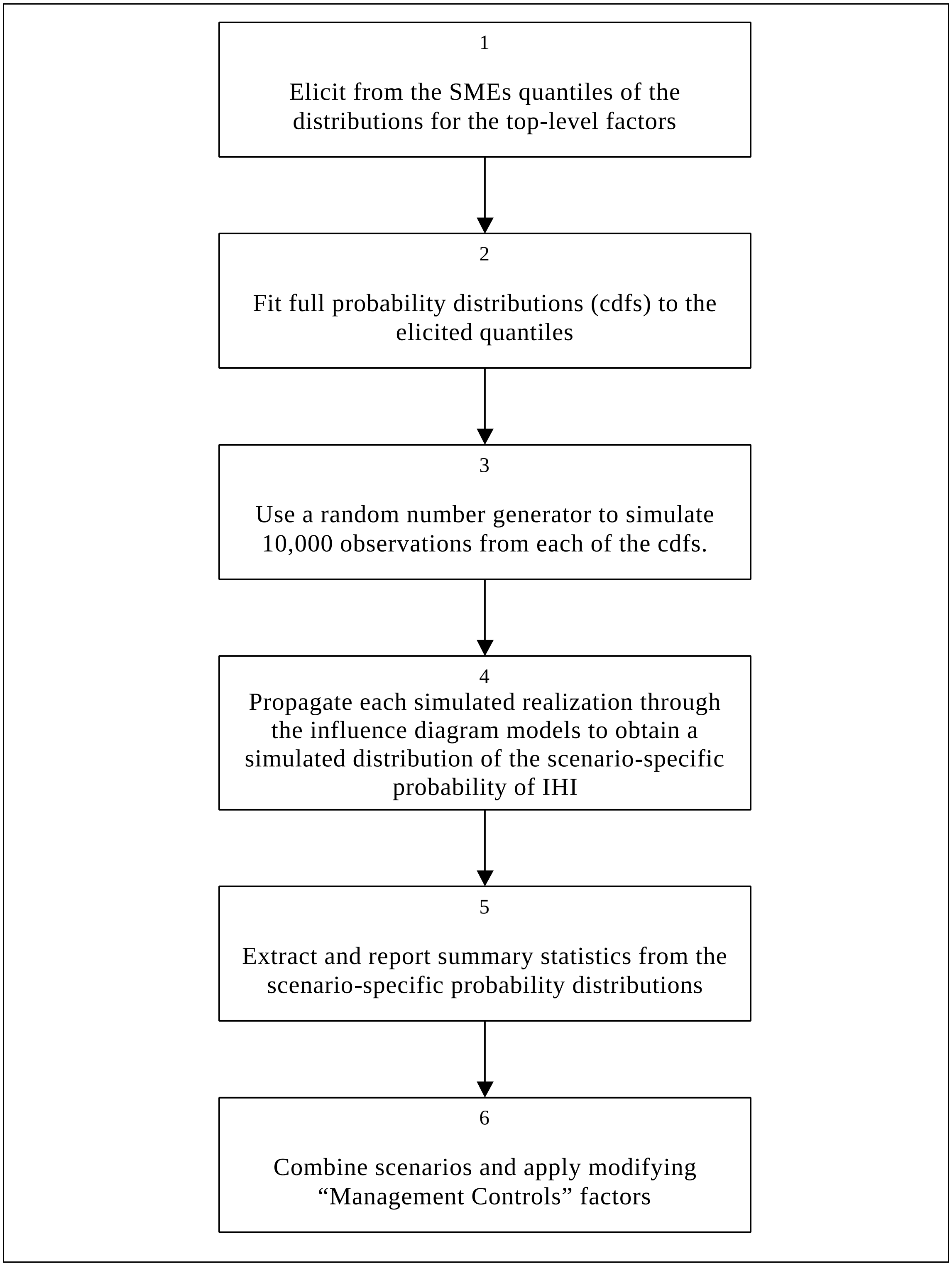


Figure E-1 Computational steps for generating the probability of inadvertent human intrusion

For the Homesteader scenario the SMEs provided input for the following variables:

- homestead density (distribution of number of homesteads)
- homestead lifetime (number of years a homestead remains viable)
- well lifetime (number of years a well remains viable)
- number of wells per homestead
- distance between replacement wells

The type of input provided by the SMEs for the first variable corresponded to a discrete distribution with 98% probability assigned to zero, 2% to more than zero (with a small positive probability assigned across 1 to 5 homesteads). Details are provided in Appendix D. Homestead lifetimes had a slightly positively skewed distribution with a median of 12.5 years, and well lifetimes had a slightly positively skewed distribution with a median of 35 years. These last two distributions were fit with beta distributions, as described in Section E.2.3.2. It should be noted that single values were chosen to facilitate fitting of the beta probability distributions when a range of values was provided for some input quantiles by the SMEs, however, the fit was then visually compared to the range provided.

For each simulation a series of random numbers was drawn from the distribution of homestead lifetime until their sum first met or exceeded 200 years (the total portion of the compliance period for which the SMEs thought that at least one homestead would be present). For example, suppose for one simulation run the following series of numbers was drawn from the homestead lifetime distribution (years): 15, 10, 25, 20, 15, 12, 16, 21, 30, 7, 9, 25 (sum = 205). The two sequential sums of interest are 180 and 205. The number 205 was chosen because it is the first sum to meet or exceed 200. Hence, 12 homesteading events were realized in this simulation.

It should be noted that the SMEs did not provide information about their uncertainty in the elicited value of 200 years. The modeling process has, however, introduced some variability, but has maintained an average of 200 years in a manner that introduced as little variability as possible. The modeling process has introduced a small bias by using a “floor” of 200 years. The bias is likely to be negligible, especially when considering the overall probability of IHI from all the scenarios.

For each one of the homestead lifetimes, a random number was drawn from the positive portion of the homestead density cdf and the total number of homesteads was summed. For example, suppose the 12 (corresponding) numbers were drawn from the homestead density distribution: 1, 2, 1, 1, 1, 1, 3, 1, 1, 1, 2, and 1. This combination would provide a total of 16 primary wells, 1 per homestead, to be drilled during the compliance period.

The next step was to determine if any replacement wells should be included. Random draws were made for each primary well from the well lifetime distribution. This process was repeated until the sum of well lifetimes was greater than the homestead lifetime. The average well lifetime is considerably greater than the homestead lifetime for this scenario, in which case replacement wells were not simulated very often.

Several models were then considered to simulate the output distributions. These included models that directly calculated the probability of at least one primary well intersecting the waste footprint (using a combination of Poisson, binomial or hypergeometric probability calculations), followed by an additional probability of a replacement well intersecting the waste footprint if the primary wells “missed”. The final choice of simulation method hinged on the difficulty of assessing the probability component regarding the impact of replacement wells. Consequently, the final modeling proceeded, for each simulation, by randomly locating each primary well spatially in Frenchman Flat and Yucca Flat, and then randomly choosing an angle and a replacement well distance to assign a location to a replacement well, if necessary. The area of Frenchman Flat and Yucca Flat was modeled as one-foot squares to facilitate the random placement of wells. This process was repeated within each simulation to provide a single estimate of the probability that a (primary or replacement) well intersects the waste footprint. Each repetition provided either an intersection with the waste footprint (a success) or a miss (a failure). The repetitions used exactly the same simulated input, but repeated the random placement of primary and replacement wells in Frenchman Flat and Yucca Flat so that the total number of successes could be counted. This repetition allowed, for each simulation, estimation of the probability that at least one well intersects the waste footprint.

10,000 simulations were performed for each scenario, but the number of repetitions within each simulation varied according to the scenario (for the Homesteader scenario the number was, effectively, 1,000,000 because of the small probability of intersection). This direct approach eliminated the need for dealing with replacement wells purely using analytic approximations, and resulted in better estimates of the output probability distributions. The double simulation (repetition within simulation) provides more reliable results because it avoids the need for analytical approximations and a minimum number of statistical assumptions needed to be made in the algorithms.

The simulation process was repeated 10,000 times to provide many estimates of the probability that at least one well intersects the waste footprint. These probability estimates generate a simulated distribution. Conceptually, the same process was used for each of the intrusion scenarios, although the algorithms differed in detail because of the differing structures of the influence diagram models and the input elicited from the SMEs. For the community scenarios, the algorithms for Yucca Flat differed because of the impact of the cratered area. After simulating the number of homesteads or communities in Yucca Flat, a proportional calculation was made to accommodate the comparative size of the cratered area and the comparative likelihood of settling in the cratered area as opposed to the remainder of Yucca Flat. The proportion used for the adjustment is approximately 0.13. For example, if, for one of the community scenarios, a single simulation for the entirety of Yucca Flat resulted in an initial scenario probability of IHI of 0.02, then this proportional adjustment resulted in a final scenario probability of IHI of 0.0026.

The simulation process followed standard Monte Carlo techniques. The outcome of each Monte Carlo realization was a probability and the final outcome of all realizations was a distribution of the probability of IHI. The final distributions of the probability of IHI represent the variability found in randomly sampling the SME input subsequent to fitting the distributions. Once the scenario probabilities were obtained, the four sets of results were combined by simple addition of the distributions to arrive at an overall probability of IHI (the addition was performed by summing the ordered results of the four simulated scenario distributions of the probability of IHI). The dominance of one of the scenarios indicated that the method used for their combination was not important.

The modifying management controls factor was applied to each scenario probability distribution to obtain a modified probability of IHI for each scenario. However, it should be recognized that the management controls factors were not as well defined as the intrusion scenario factors, in which case these modifications were highly dependent on the conditions of the input and should be regarded as preliminary and exploratory. The following sections show the simulations and results for the scenarios followed by simulations and results for the management controls factors.

E.3 HOMESTEADER SCENARIO

The Homesteader scenario, like the three community scenarios described later, is conditioned on ineffective management controls. This condition exists because effective management controls preclude IHI. The Homesteader scenario is described in the main text. Factors that play a significant role in this scenario include effective time period for independent homesteading (i.e., proportion of the 10,000-year compliance period for which homesteading might occur), number of homesteads expected in the effective time period, and homestead lifetime. SMEs also provided input on well lifetime and distance between replacement wells. These factors are included in the algorithms, although they are not sensitive factors for this scenario.

The model employed can be regarded as including an approximation to Poisson (Markov) processes that consider “birth and death” of primary wells and replacement wells. For this problem, such a Poisson process involves a (potentially infinite) discrete state space and a continuous time space. The state space consists of the number of wells at any one point in time, and the time space is continuous for the duration of the compliance period. The same is true of each of the scenarios considered. If a Poisson process had been used explicitly, then the number of well events could be counted from the assessed process itself, and the probability of drilling through a waste site determined from that count and the comparative areas of the waste and the encompassing area (Frenchman Flat or Yucca Flat).

The approach taken to approximating these Poisson processes was to count the number of homesteads and homestead elicited from the SMEs, and then determine the potential for a well to intersect a two-acre waste footprint. The SMEs preferred to deal with the number of homesteads and primary wells at any given point in time, rather than to deal with transition probabilities for a Poisson process. Using information from the SMEs, the intensity of well drilling can be estimated, and the problem can be set up as a Poisson process. However, replacement wells are not easy to deal with in this setting, requiring modeling of a Poisson cluster process. Consequently, a more direct approach was taken that models random placement of wells, and replacement wells, that are expected to be drilled in Frenchman Flat and Yucca Flat during the course of the next 10,000 years.

Once a count of the number of primary wells expected to be drilled has been derived from the SME assessments and some spatial information has been obtained, particularly for replacement wells, the final step is to determine the probability that one of these wells will intersect the waste area. This final probability calculation for this scenario can be performed in one of many ways (e.g., Poisson, hypergeometric, binomial, equal spacing, spatial distribution), all of which give very similar results because the number of homesteads assessed by the SMEs is so small. The process of counting the number of wells and applying the final probabilistic calculation was repeated many times by simulation of the fitted distributions that are based on the input elicited from the SMEs.

Based on the model structure developed by the SMEs, there are seven required inputs to the calculation of the probability of IHI into the waste areas on NTS for this scenario:

1. the total amount of time that homesteads would be found on Frenchman Flat or Yucca Flat

2. the number of homesteads that could be found on the total area at any one time

3. the lifetime of a homestead in the area

4. the lifetime of a well

5. the distance of a primary well from a replacement well

6. the areal size of the waste footprint

7. the areal sizes of Frenchman Flat and Yucca Flat, subdivided into the playas, cratered areas, and other (habitable) areas.

The SMEs indicated that well lifetimes are considerably greater than homestead lifetimes, so an assumption of one well per homesteading event would not have been unreasonable. The median homestead lifetime for this independent homesteading scenario was assessed at 12.5 years, whereas the median well lifetime was assessed at 35 years. The results presented show the effect of including replacement wells in the calculations, and demonstrate the lack of sensitivity to replacement wells for this scenario.

E.3.1 Fitting the Cumulative Distribution Functions

The number of homesteads that could be found on the total area at any one time is a discrete variable, and was modeled directly from the SME inputs. The remaining factors were subjected to curve fitting to form scaled beta cdfs on which the simulations could be based. The following discussion indicates how the SME inputs were used in the final calculation of a distribution for the probability of IHI for the Homesteader scenario. The discussion focuses on underlying assumptions, numerical input, probabilistic associations, and simulations performed.

E.3.1.1 Number of Homesteads

The SMEs felt that independent homesteading was extremely unlikely. In fact, they indicated that they expected the type of independent homesteading envisioned to occur for only 200 years of the 10,000-year evaluation period. The SMEs provided some guidelines for a distribution of number of homesteads that might be present at any point in time:

- Pr(0 homesteads at any point in time) is approximately 0.98
- Pr(at least one homestead at any point in time) is approximately 0.02
- Pr(2 homesteads) is approximately 1/2 the Pr(1 homestead)
- Pr(5 homesteads) is approximately 1/100 the Pr(1 homestead)

Using these rules, the following discrete probability density function was developed (Table E-1).

Table E-1

SME Input on Number of Homesteads

Number of Homesteads	Probability
0	0.98
1	0.012
2	0.006
3	0.0012
4	0.0006
5	0.00012
6 or more	essentially 0

The probability of obtaining six or more homesteads was small enough that it did not occur during the simulation. Random numbers were drawn from this distribution to determine number of homesteads at a given point in time to be used to calculate the total number of homesteads that might occur during the compliance period. Note that the SMEs did not choose to further refine their inputs by, for example, expressing uncertainty about the probability that zero homesteads would be present at a given point in time. They chose not to refine their inputs because they regarded this as a very unlikely scenario that did not warrant further assessment.

E.3.1.2 Homestead Lifetimes

For this particular scenario the SMEs felt that homesteads were not likely to last for very long. The median lifetime assessed was only 12.5 years. Table E-2 provides a summary of points on the distribution that were used to formally establish a cdf for this factor. A scaled beta distribution was fit to the input quantiles. Note that the value of 50 years was used for the 0.99 quantile, although the fitted curve passes between the points in the elicited range. This approach might introduce a slight conservatism in the results for this scenario, but considering the small probability of IHI for this scenario, the effect is negligible overall.

Table E-2

SME Input on Homestead Lifetime

Homestead Lifetime (years)	Cumulative Probability
6.25	0.25
12.5	0.5
25	0.95
40 - 50	0.99

The cdf is presented in Figure E-2. Note that optimization was constrained to pass through a = 0. The approximate fitted values for the remaining parameters are b = 55 years[2], v = 1.8, and w = 5.9, resulting in a unimodal probability density function[3]. The mean of the distribution is approximately 13 years, and the variance is approximately 63. This distribution was used to simulate homestead lifetimes to generate realizations of the number of homesteads that might be sited in the areas of interest in the next 10,000 years.

[2] The shape and scale of the cdf portrayed in Figure E-2 does not allow the value of *b* to be clearly depicted.
[3] Values given for parameters of the scaled beta distributions are usually rounded to two significant digits.

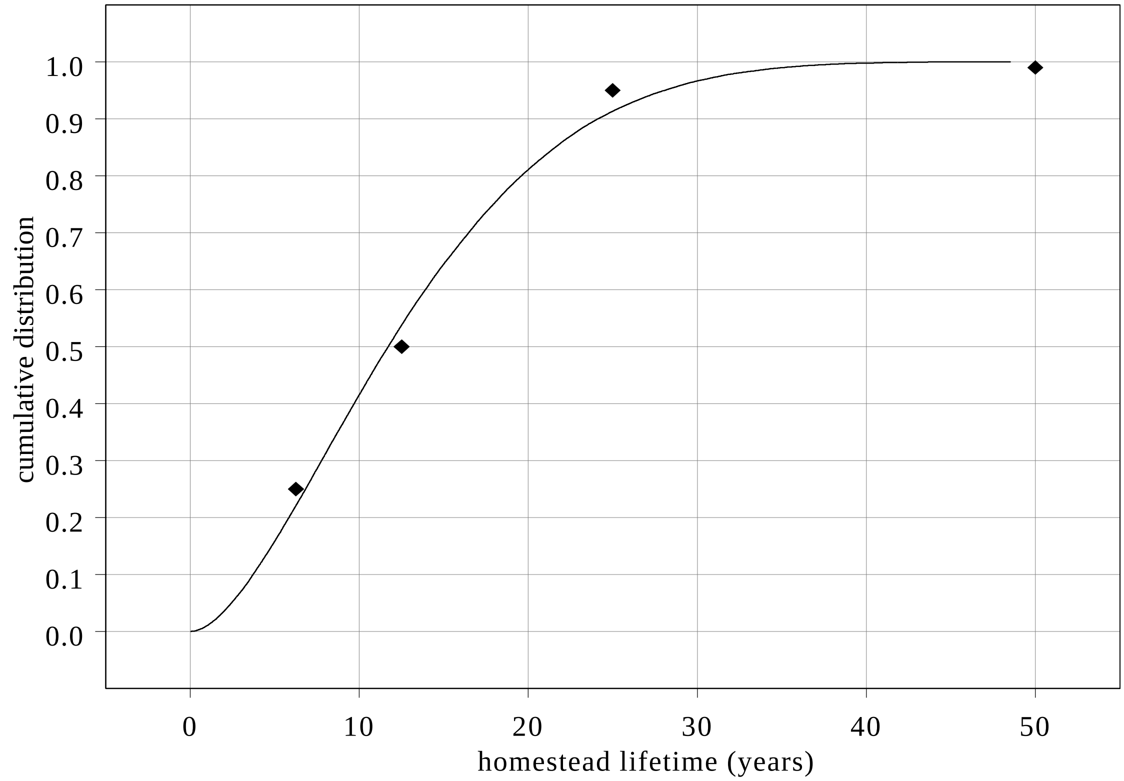


Figure E-2 Cumulative distribution function for homestead lifetimes

E.3.1.3 Well Lifetimes

Table E-3 provides a summary of the elicited input used to generate a cdf for this factor. A value of 20 years was used from the range provided for the 0.25 quantile, and a value of 60 years was used from the range provided for the 0.95 quantile. The cdf is presented in Figure E-3.

Note that optimization was constrained to pass through a = 0. The approximate fitted values for the remaining parameters are b = 220 years, v = 3.0, and w = 16, resulting in a unimodal probability density function with a mean of approximately 35 years and a variance of approximately 260. Using the upper end of the range for the 0.25 quantile provided a better fit for the distribution, and introduces a slight conservatism (e.g., because the probability of a well lasting longer than 20 years is greater). The middle of the range was used for the 0.95 quantile, although the fitted distribution fits that quantile closer to 70 years for a well lifetime. This distribution was used to obtain well lifetimes during the simulations to determine if replacement wells would be needed for the homestead events.

Table E-3

SME Input on Well Lifetimes

Well Lifetime (years)	Cumulative Probability
10	0.05
15 - 20	0.25
35	0.5
50 - 70	0.95

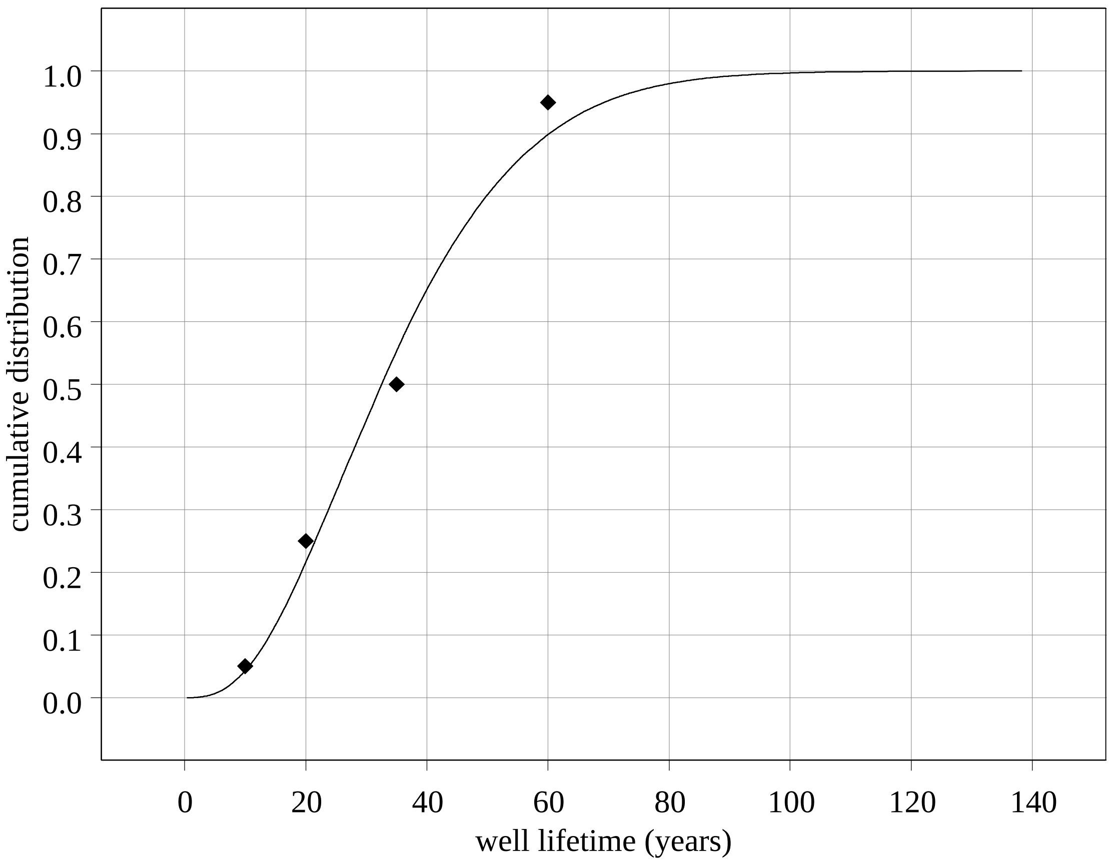


Figure E-3 Fitted cumulative distribution function for well lifetimes

E.3.1.4 Distance Between Replacement Wells

The expected distances between replacement wells, as elicited from the SMEs, are reported in Table E-4. Figure E-4 displays the fitted beta distribution cdf. The median distance between replacement wells provided by the SMEs was 30 ft as shown in Table E-4, with the distance ranging from roughly 10 ft to 50 ft.

The optimization was not constrained and resulted in approximate parameter values for this unimodal beta distribution of: *a* = 1.4 feet, *b* = 59 feet, *v* = 1.4, and *w* = 1.4. This limited the minimum distance between replacement wells to one or two feet in the fitted distribution, but also limited the maximum distance to just less than 60 feet. The distribution is unimodal with a mean of approximately 30 feet and a variance of approximately 210.

Table E-4

Replacement Well Distance for Homestead Wells

Replacement Well Distance (feet)	Cumulative probability
10	0.1
30	0.5
50	0.9

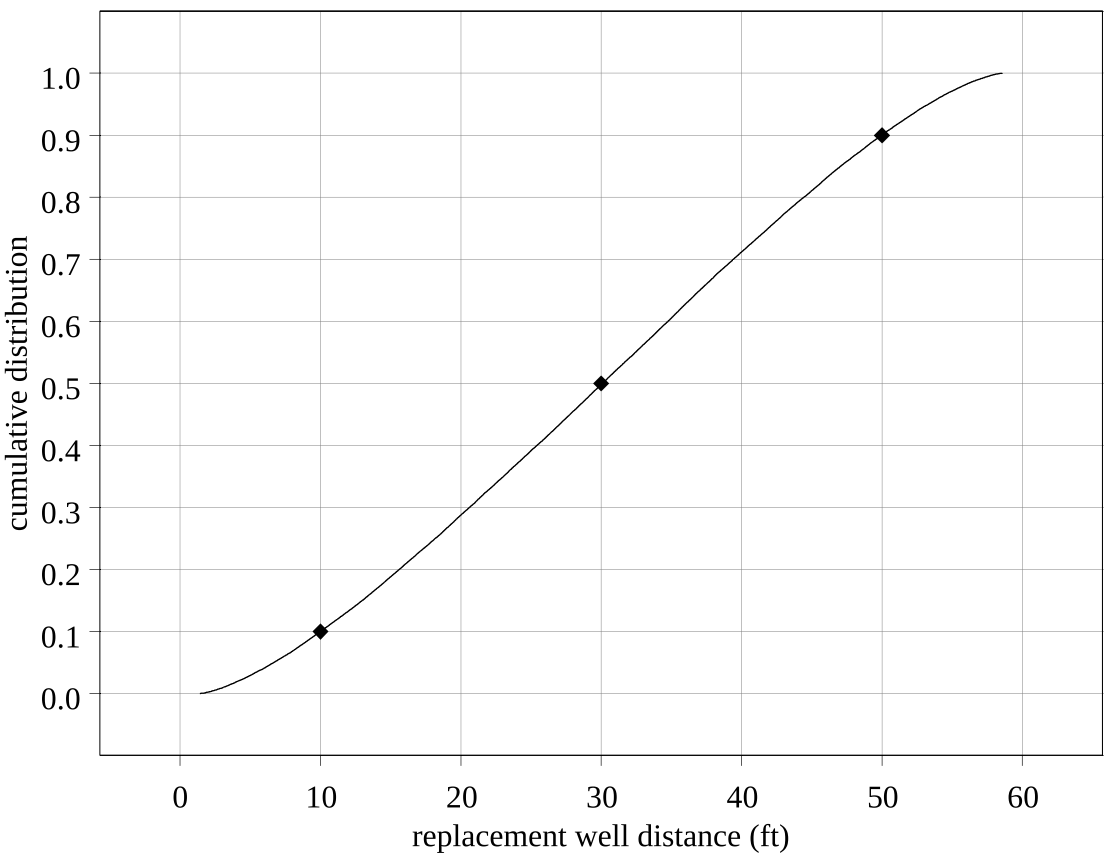


Figure E-4 Fitted cumulative distribution function for replacement well distance for homestead wells.

E.3.2 Simulations and Calculations

The first step in the calculation was to draw a random number from the distribution of number of homesteads. Most often this number was zero. When a positive number was drawn, a random draw from the homestead lifetime distribution was made. This process was repeated until the sum of homestead lifetimes was at least 200 years. The number of homesteads was then summed to generate an estimate of the total number of homesteads expected during the compliance period. This process was illustrated in the example in Section E.2.4. Using a "floor" of 200 years introduces a small positive bias, causing a slight overestimation of the scenario probability of IHI. The impact of this scenario is so small on the overall results that a small bias is considered negligible.

One concern that can be raised for this approach is that when two or more homesteads were drawn from the distribution of number of homesteads, then each homestead was given the same lifetime drawn (randomly) from the homestead lifetime distribution. This raises questions of adequate accounting of variability in the simulation process, and of potentially biasing the probability calculations. The problem could have been approached, instead, by drawing different lifetimes for each homestead in these cases. However, this method creates a further computational complexity that does not seem warranted, given the small probabilities of IHI for this scenario.

It should be realized that, although the homesteads may have the same lifetimes, they do not necessarily overlap completely in time: they might only partially overlap. If they partially overlap, then the time frames in which they occur separately should already be accounted for by the random chance of drawing fewer homesteads from the number of homesteads distribution. This means that the time frame for two homesteads to occur together is maximized if they overlap completely in time, and drawing a single homestead lifetime for concurrent homesteads might introduce a positive bias in the results. If homesteads that occur at the same time, by random draw, are assigned the same homestead lifetime, then the length of time that these homesteads might be present is minimized (because each homestead could also exist alone for some period of time). This increases the expectation of the number of homesteads that are counted towards the target value of 200 years. This artificial increase probably results in increased variability, although the effect is likely to be minuscule.

The net effect of the simplification employed is suspected to be a positive bias for each simulated probability, and a very small positive bias in the variability component. These potential biases were mitigated to some extent by the infrequent occurrence of a draw of two or more homesteads (see Table E-1). Again, any slight effect was regarded as unimportant, considering the small scenario probability for the Homesteader scenario.

Using the target value of 200 years, based on SME input, provided a rule for counting the number of homesteads expected in Frenchman Flat and Yucca Flat under this scenario. Each simulation run provides a different number of homesteads; and the 10,000 runs provide a simulated distribution. This is the distribution of the number of original, or primary, wells that are expected to be drilled in these areas during the evaluation period. Comparison of a simulated homestead lifetime and a simulated well lifetime revealed the need for a replacement well. The 10,000 simulations, hence, also provide a distribution of the number of replacement wells expected to be drilled.

Once the distribution of total number of wells expected during the compliance period was established, the next step was to incorporate this information in calculations of the probability that a well would intersect the waste footprint. A number of observations, or assumptions, are relevant: the total area under consideration (for this scenario this is the combined area of Frenchman Flat and Yucca Flat, including the cratered areas, but without the playas); the area of the waste footprint; and the area of a well. The waste footprint size is much smaller than the size of Frenchman Flat and Yucca Flat (i.e., four or five orders of magnitude different), and the area occupied by a well is much smaller than the waste footprint (the area occupied by a well is usually less than a one-foot diameter circle). Because of these large differences in sizes, and because of the small number of homesteads (thus wells) expected in the compliance period for this scenario, some simplifying assumptions can be made. Spatial units of one-foot squares were established and used to randomly locate primary wells in Frenchman Flat and Yucca Flat. Only one well was permitted per one-foot square. The probabilistic problem becomes one of assessing the potential for selecting a one-foot square from within the two-acre waste footprint from among the many one-foot squares in Frenchman Flat and Yucca Flat, with the number of possible selections being the number of homesteads (primary wells), followed by replacement wells as necessary.

Many choices are available for calculating the probability of IHI from the primary and replacement well distributions, however, the issue of replacement wells does not lend itself to a simple calculation because their placement cannot be assumed to be random with respect to the primary wells. The final simulations were performed spatially using a direct approach. This involved locating primary wells at random in Frenchman Flat and Yucca Flat, and, if necessary, selecting a random angle and a random distance (from the distribution of replacement well distance) to locate replacement wells. This process was repeated many times for each simulation. That is, the random placement of primary wells, and random angles for replacement wells were redrawn for each repetition. The number of primary wells and replacement wells was not changed for each repetition, but was changed for each simulation. Each repetition resulted in either an intersection of at least one well with the waste footprint, or no intersection. The repetition allowed the probability of intersecting the waste footprint to be estimated for each simulation by counting the total number of repetitions for which at least one well intersected the waste footprint. For the Homesteader scenario, the probability of intersection is so small that effectively 1,000,000 repetitions had to be performed for each of the 10,000 simulations[4].

[4] For this scenario, 10,000 repetitions were actually performed using an area 100 times smaller than Frenchman Flat and Yucca Flat. The probabilities were adjusted by a factor of 100 to realize the corresponding effect. This saved considerable time in the simulations, and, because the probabilities of interest are very small and, hence, nearly linear in the number of wells, it has insignificant effect on the results.

Each simulation provides a single estimate of the probability of IHI. Consequently, 10,000 estimates of the probability of IHI were obtained for this scenario, resulting in a distribution that reflects the conditions described in Section E.2.1 and the potential range of the probability of interest.

Table E-5 shows the results for the distributions of the probability of IHI, the total number of primary wells, and the total number of replacement wells. On average the Homesteader scenario realizes about 24 homesteads over the course of 10,000 years, 3 of which might be expected to need replacement wells, resulting in a probability of IHI of approximately 0.00026. The maximum probability simulated was 0.0005, generated from 46 primary wells and 12 replacement wells. The final distribution of Homesteader scenario probabilities is depicted in Figures E-5 and E-6. Figure E-5 depicts an estimated probability density function overlaid on a relative frequency diagram; Figure E-6 translates the estimated density and the histogram into a cdf for the scenario probability of IHI. The conditions or constraints described in Section E.2.1 should be recognized when interpreting the measure of variability or uncertainty inherent to these extreme values.

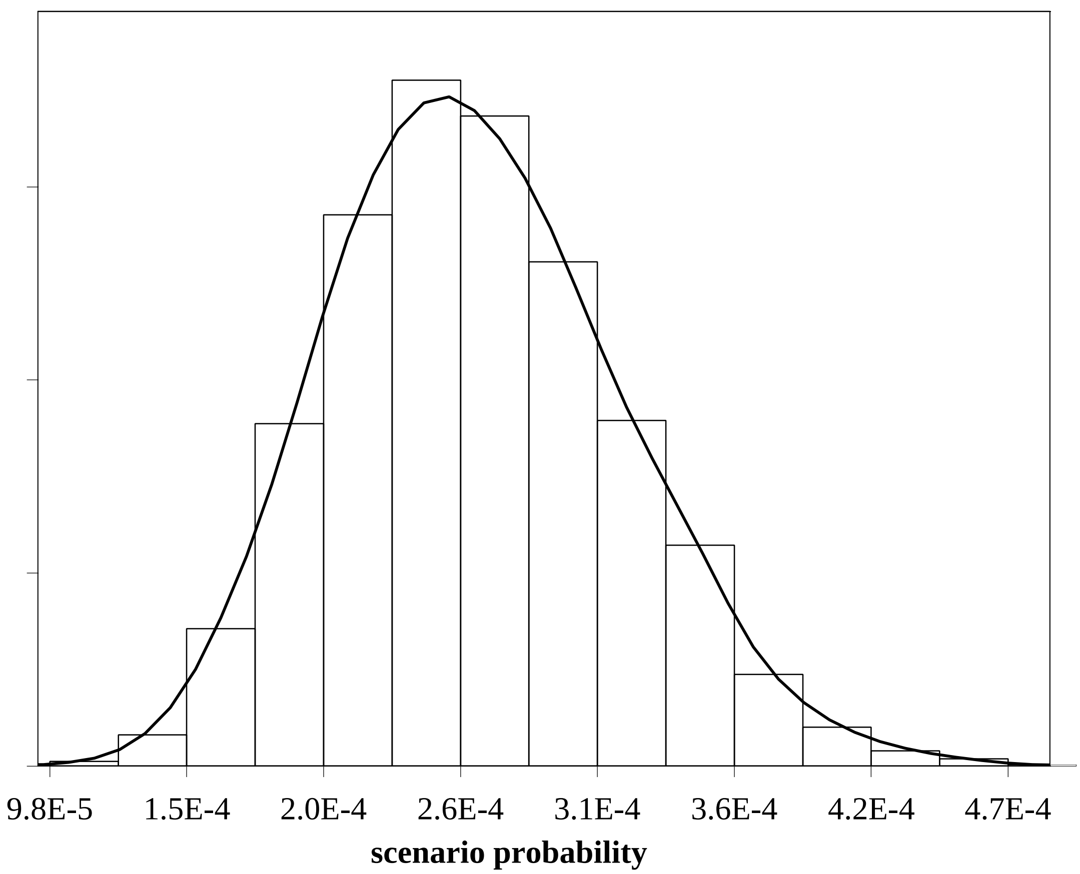


Figure E-5 Estimated distribution of the probability of inadvertent human intrusion overlaid on the simulated relative frequency distribution for the Homesteader scenario.

Table E-5 Summary statistics for the propagated probability distributions of the total number of wells and the probability of inadvertent human intrusion for the Homesteader scenario

Summary Statistic	Total Number of Wells		Probability of IHI
	Primary	Replacement	
Minimum	10	0	0.000098
5%	17	1	0.00018
25%	21	2	0.00022
Median	24	3	0.00026
Average	**24**	**3**	**0.00026**
75%	27	4	0.00030
95%	33	6	0.00036
Maximum	46	12	0.00050

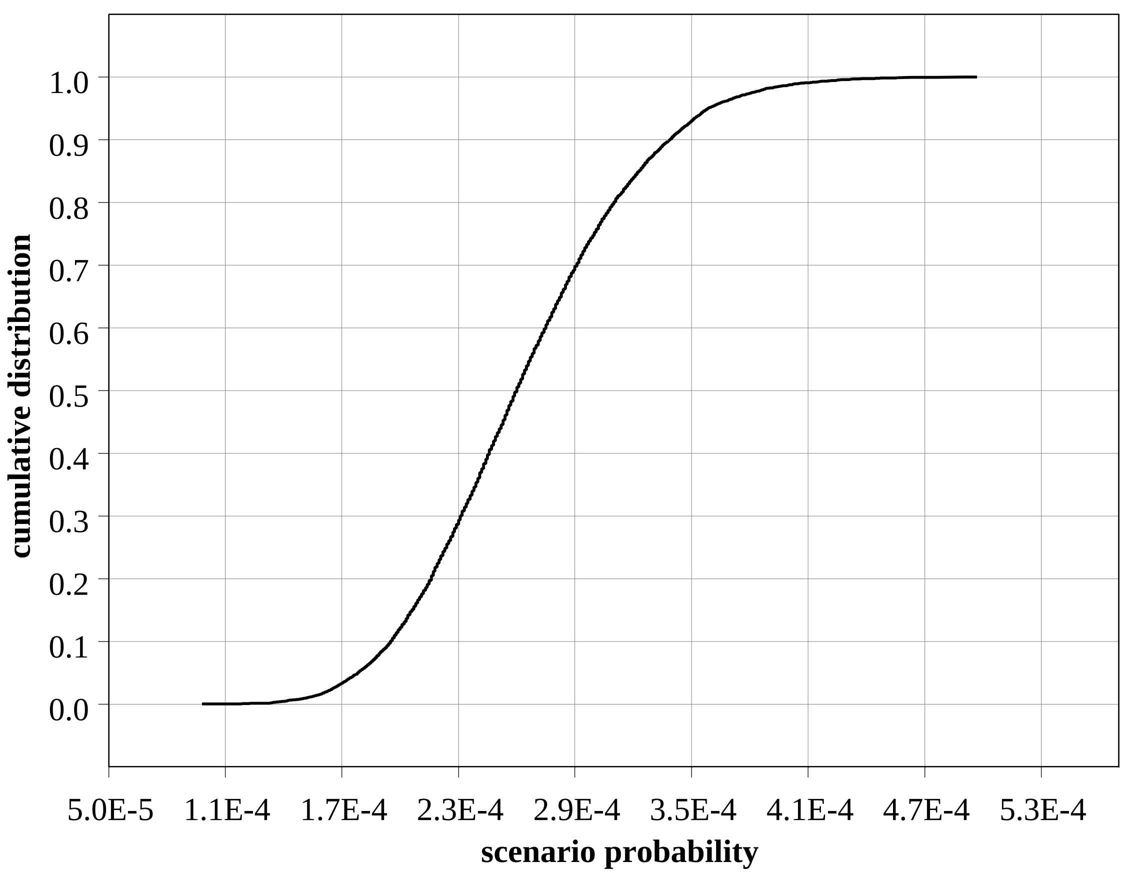


Figure E-6 Estimated cumulative distribution function of the probability of inadvertent human intrusion for the Homesteader scenario.

The impact of replacement wells is very small. Using binomial probability calculations as an approximation, the probability of at least one out of 23 primary wells intersecting the waste footprint is approximately 0.00025, compared with the simulated average of 0.00026 when the impact of replacement wells is added. For the Jackass Flats and Las Vegas Expansion scenarios (described below) the geometry of the problem is sufficiently different that replacement wells are more important in the calculations.

E.4 COMMUNITY SCENARIOS

As indicated in the main text (Volume I, Black et al. 2001), there are three community scenarios that need to be considered. The basic approach to calculating the final probability distributions of interest is the same as that for the Homesteader scenario. That is, find the total number of wells that might be drilled in the evaluation period, and determine the probability that at least one will intersect the waste footprint. The following sections deal with the three community scenarios in turn: the Base Community scenario, the Jackass Flats scenario, and the Las Vegas Expansion scenario.

E.4.1 Base Community Scenario

As with the Homesteader scenario, the overall probability of IHI for this scenario is very small. The main differences for this scenario include separate calculations for Frenchman Flat and Yucca Flat, and a community water supply system without private wells. Based on the model structure developed by the SMEs, there are nine required inputs to the calculation of the probability of IHI into the waste areas on NTS for this scenario:

1. the time frame for existence of communities on Frenchman Flat and Yucca Flat
2. the number of communities that could be found on the total area at any one time
3. the lifetime of a community in Frenchman Flat or Yucca Flat
4. the number of primary community supply wells
5. the spatial allocation of community supply wells
6. the lifetime of a community supply well
7. the distance of a primary well from a replacement well
8. the areal size of the waste footprint
9. the areal sizes of Frenchman Flat and Yucca Flat, subdivided into the playas, cratered areas, and other (habitable) areas.

E.4.1.1 Fitting the Cumulative Distribution Functions

Similar to the Homesteader scenario, the first factor to be considered is the effective number of years that a base community might exist in Frenchman Flat or Yucca Flat. For Frenchman Flat this was assessed as 50-100 years, and for Yucca Flat 25-50 years. Quantiles were not elicited for the distributions for these factors because the effect of using any value within these ranges would not have any significant impact on the results, and because the SMEs considered the probability of IHI for this scenario to be very small.

The SMEs indicated that only one community could exist in Frenchman Flat or Yucca Flat at any point in time, and that the community would be supported by no more than four initial, or primary, community supply wells. The SMEs indicated that a community developed in Frenchman Flat or Yucca Flat was likely to be small, with a population of no more than 5,000 people, occupying an area of less than one square mile. Within that community the SMEs indicated that the four primary wells would be spatially distributed on approximately ½ mile centers in a square pattern. The SMEs also decided to simplify the model by providing a single input, of 100 feet for the distance between replacement wells. The inputs to several of the variables in this section were, hence, constants, although the SMEs provided quantile input for the distributions of community lifetime and well lifetimes, both of which are described in the next section.

E.4.1.1.1 Community Lifetime

Potential community lifetime was established as a discrete mixture distribution, consisting of a truncated scaled beta distribution after 50 years (50% probability), a different truncated scaled beta distribution between 10 and 50 years, and a truncated uniform distribution between 0 and 10 years (10% probability). Each relevant incomplete part of the mixture was included in the complete cdf. The reason for this discontinuity is that a single scaled beta distribution, or any other standard statistical distribution, cannot adequately fit all the SME input and truncate at or near zero years. The mixture of three truncated scaled beta distributions was used to find a good fit to the SME input, which is summarized in Table E-6.

The fitted mixture distribution is presented in Figure E-7. The optimization for the first scaled beta distribution component was constrained through the 0.5 quantile, which was used as a truncation point[5]. The parameters of the first scaled beta distribution (greater than 50 years) were estimated as: a = 45 years; b = 600 years; v = 0.3; and, w = 9. The value of a does not affect the calculations directly, but does have an impact on the adequacy of the fit. The parameters of the second scaled beta distribution (10 –50 years) were estimated as: a = -500; b = 53 years; v = 14; and, w = 0.4. The values of a and b for this part do not affect the calculations directly, but do have an impact on the adequacy of the fit. The final part of the cdf (0 – 10 years) was fit as a uniform distribution with a minimum of zero and a maximum of 100. The value of the maximum simply facilitates

[5] Each component of the mixture distribution is, effectively, an incomplete scaled beta distribution.

the fit between 0 and 10 years. The maximum community lifetime that can be simulated is 600 years[6]. Figure E-7 demonstrates that the choice of mixture distribution provides a good fit for the elicited input. The fitted mixture distribution formed the basis for determining the number of communities that might exist in Frenchman Flat or Yucca Flat during the next 10,000 years.

Table E-6

SME Input for Community Lifetime

Community Lifetime (years)	Cumulative Probability
10	0.1
35	0.25
50	0.5
65	0.75
100	0.9

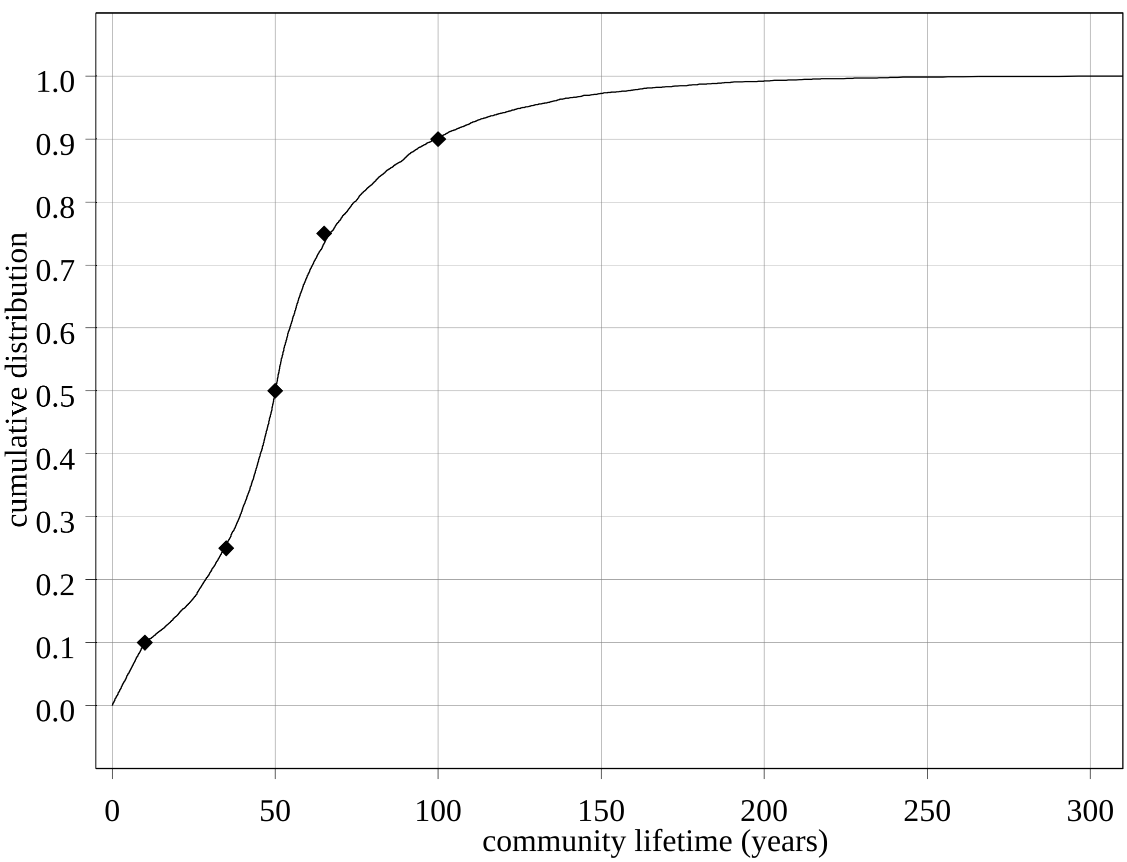


Figure E-7 Fitted cumulative distribution function for community lifetime.

[6] The shape and scale of the cdf portrayed in Figure E-7 does not allow the value of *b* to be clearly depicted.

E.4.1.1.2 Community Well Lifetime

A mixture of truncated scaled beta distributions was also fit to the elicited quantiles for community well lifetimes. Only community water system supply wells were considered in this scenario. The SME input is summarized in Table E-7. For the first truncated scaled beta distribution, the fit passed through a = 0. The remaining parameters were estimated as: *b* = 39 years; *v* = 0.87; and, *w* = 0.27. The value of *b* for this part does not affect the calculations directly, but does have an impact on the adequacy of the fit. The parameters of the second truncated scaled beta distribution (greater than 35 years) were estimated as: *a* = 20; *b* = 65 years; *v* = 1.4; and, *w* = 2.6. The value of *a* for this part does not affect the calculations directly, but does have an impact on the adequacy of the fit. The maximum community well lifetime that can be simulated is 65 years[7]. Figure E-8 demonstrates that the choice of mixture model provides a good fit for the elicited input.

Table E-7

SME Input for Community Well Lifetime

Well Lifetime (years)	Cumulative Probability
10	0.1
35	0.5
50	0.9

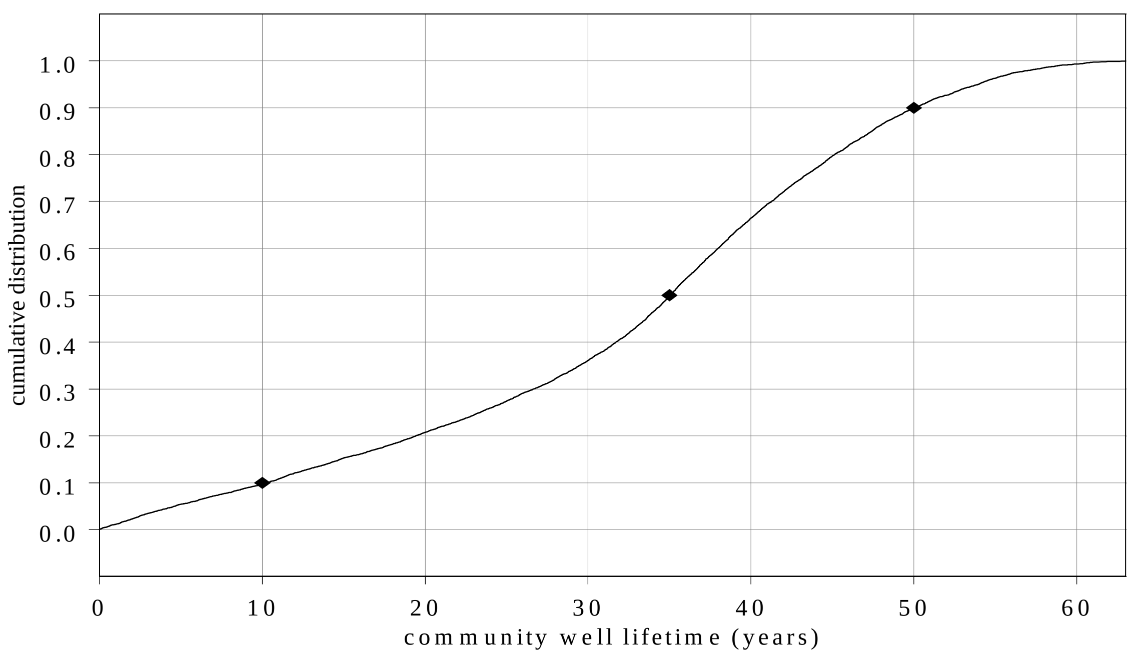


Figure E-8 Fitted cumulative distribution function for community well lifetime.

[7] The shape and scale of the cdf portrayed in Figure E-8 does not allow the value of *b* to be clearly depicted.

E.4.1.2 Base Community Analysis

Given the input variables, it was possible to generate distributions for the total number of communities and number of wells that may exist in Frenchman Flat and, separately, Yucca Flat during the next 10,000 years. The first steps of the simulations were the same for each area. For a single simulation, random draws were made from the community lifetime distribution until values drawn summed to at least the minimum number of years that the SMEs expected a community to exist in the respective area (i.e., 50 years for Frenchman Flat and 25 years for Yucca Flat). Whereas these values may appear to be non-conservative, they actually provide a reasonable basis because of the short lifetime expectancy of a community. The minimum values from the ranges provided by the SMEs were used to balance the effect of always surpassing this number given the distribution of community lifetime. This approach arrived at numbers of years for each simulation run that averaged near the middle of the range provided for Frenchman Flat (50-100 years), and at the high end of the range for Yucca Flat (25-50 years).

For each scenario, this method provided a reasonably natural way of determining the number of communities for these areas. Based on this approach, the number of communities simulated is often only one (especially for Yucca Flat), and is very rarely more than two. When more than one community was simulated, an assumption was made that the communities could be sited anywhere in Frenchman Flat or Yucca Flat. There was no requirement for, or any prohibition against, communities being sited in the same place as a previous community.

A community was assigned four initial, or primary, water supply wells. The SMEs indicated that this is probably conservative for the type of community considered, but were reluctant to provide more specific information, again because they expected this scenario to be very unlikely. Replacement wells were also considered based on a comparison of the community lifetime and community well lifetime distributions. Each well was considered separately, and a random draw from the well lifetime distribution was made to determine when a replacement well was needed. Well lifetimes were drawn for each well until the total lifetime met or exceeded the lifetime of the community.

From this point, for Frenchman Flat the algorithm proceeded very similarly to the algorithm for the Homesteader scenario. The biggest difference is the spatial placement of the wells. For each simulation for this scenario, the next step was to select a random location for each community (usually only one community). Four wells were then placed on ½ mile centers based on the central location that was drawn. For each replacement well a random angle was drawn, and the replacement well was placed 100 feet from the preceding well. This process of placement of the wells was, effectively, repeated 1,000,000 times for each of the 10,000 simulations to provide a distribution for the probability of IHI[8]. Distributions for the intermediary variables relating to number of primary wells and number of replacement wells are also available from the simulations.

[8] See Footnote 2.

As mentioned, the analysis for a Base Community scenario on Yucca Flat was more complex than for Frenchman Flat. In Yucca Flat, the Area 3 RWMS waste disposal area is located in the cratered area. The SMEs suggested that the probability of locating a community or homestead in the cratered area would be 1/10th that of locating it outside of the cratered area of Yucca Flat if the areas were the same size (note that the SMEs indicated that they felt it was unnecessary to use this information for the Homesteader scenario). This means that the calculation of landing a community on the waste footprint must be considered in terms of choosing the cratered area as the place for the community. The resulting probabilities of IHI for Yucca Flat scenarios are always about one order of magnitude less than those for Frenchman Flat because of the reduced probability of placing a well in the cratered sub-area.

As noted, the SMEs indicated that the probability of choosing the cratered area of Yucca Flat for a community would be 1/10 the probability of choosing the non-cratered area if the two areas are of equal size. An adjustment needs to be made to account for the relative difference in their size because the cratered area is only a small portion of the Flat. Calculation of the probability of choosing the cratered area for a community was performed by using the 1/10 ratio and the ratio of the size of the cratered area to the size of the remainder of Yucca Flat (excluding the playa area that is uninhabitable). In the following formulation, the probability of choosing the cratered area is denoted p, r represents the preference ratio for choosing the non-cratered area over the cratered area (i.e., $r = 10$), c represents the areal size of the cratered area, and n represents the size of the non-cratered area:

$$p = \left[\frac{\frac{1}{r}\frac{c}{n}}{1 + \frac{1}{r}\frac{c}{n}} \right] \left[\frac{c+n}{c} \right] = \frac{c+n}{c+rn} \qquad \text{E-3}$$

Section 2.1.2 summarizes the information needed to complete the calculation presented in Equation E-3. The two ratios in Equation E-3 possibly require some explanation. It is easier to think about them in terms of integer values. Given the actual areal sizes of the areas of interest, $c = 1$, and $n = 3$ provides a useful working example (because the ratio of the sizes of the cratered and non-cratered areas is approximately 1:3).

The first component in Equation E-3 represents the ratio of the proportion of primary wells that might be expected in the cratered area. Using the example, for every one well in the cratered area, 30 wells are expected in the non-cratered area, hence, 31 wells are expected in the total area.

In this example, the area of the non-cratered area is three times the area of the cratered area, in which case, probabilistically, there are four possible choices of area for the non-cratered area. This provides the second ratio in Equation E-3, which represents the choices available for the cratered area. Using Equation E-3 with the actual areal sizes of the cratered and non-cratered areas, the resultant probability, π, is approximately 0.13.

This constant is used in all the community scenarios as a modifier that affects the Yucca Flat scenario only. This is a constant because the SMEs did not provide input for the uncertainty in the 10:1 preference ratio. This preference ratio becomes a condition of the results for the Yucca Flat scenarios.

For all of the community scenarios, this modifier was used after the algorithm had first been run to obtain the distribution of the probability of IHI without consideration of the cratered area. The modifier was used to multiply each simulated probability to arrive at the final distribution of the probability of IHI for these scenarios.

Summary statistics for the distributions of the total number of wells and the probability of IHI for this scenario in Frenchman Flat and Yucca Flat are provided in Table E-8 and Table E-9, respectively. Figures E-9 through E-12 provide graphical representations of the final simulated distributions. The average scenario probability of IHI for Frenchman Flat was calculated as approximately 0.00017, whereas for Yucca Flat this value is about one order of magnitude less. These probabilities are very small and, like the Homesteader scenario, are dwarfed by the probability of IHI for the remaining scenarios. The same caveats also apply for interpretation of the conditional variability and uncertainty indicated by the simulated distribution. It should be recalled that the results presented are conservative because of the SME inputs (e.g., starting with at least four community wells). The bimodality evident in the Figures is also a consequence of the four primary wells per community, and is caused by the existence of one, two, or more communities. Given the small probability, however, the bias effects can largely be ignored because the Jackass Flats scenario results in substantially larger scenario probabilities of IHI.

Table E-8 Summary statistics for the propagated probability distributions of the total number of wells and the probability of inadvertent human intrusion for the Base Community scenario: Frenchman Flat

FRENCHMAN FLAT			
	Number of Wells		
Summary Statistic	Primary	Replacement	Probability of IHI
Minimum	4	0	0.000052
5%	4	3	0.000086
25%	4	5	0.00011
Median	8	7	0.00015
Average	**4**	**8**	**0.00017**
75%	8	10	0.00021
95%	12	18	0.00030
Maximum	20	52	0.00058

Table E-9 Summary statistics for the propagated probability distributions of the total number of wells and the probability of inadvertent human intrusion for the Base Community scenario: Yucca Flat

YUCCA FLAT			
	Number of Wells		
Summary Statistic	**Primary**	**Replacement**	**Probability of IHI**
Minimum	4	0	0.0000060
5%	4	3	0.000010
25%	4	5	0.000013
Median	8	7	0.000018
Average	**4**	**8**	**0.000020**
75%	8	10	0.000025
95%	12	18	0.000036
Maximum	24	49	0.000076

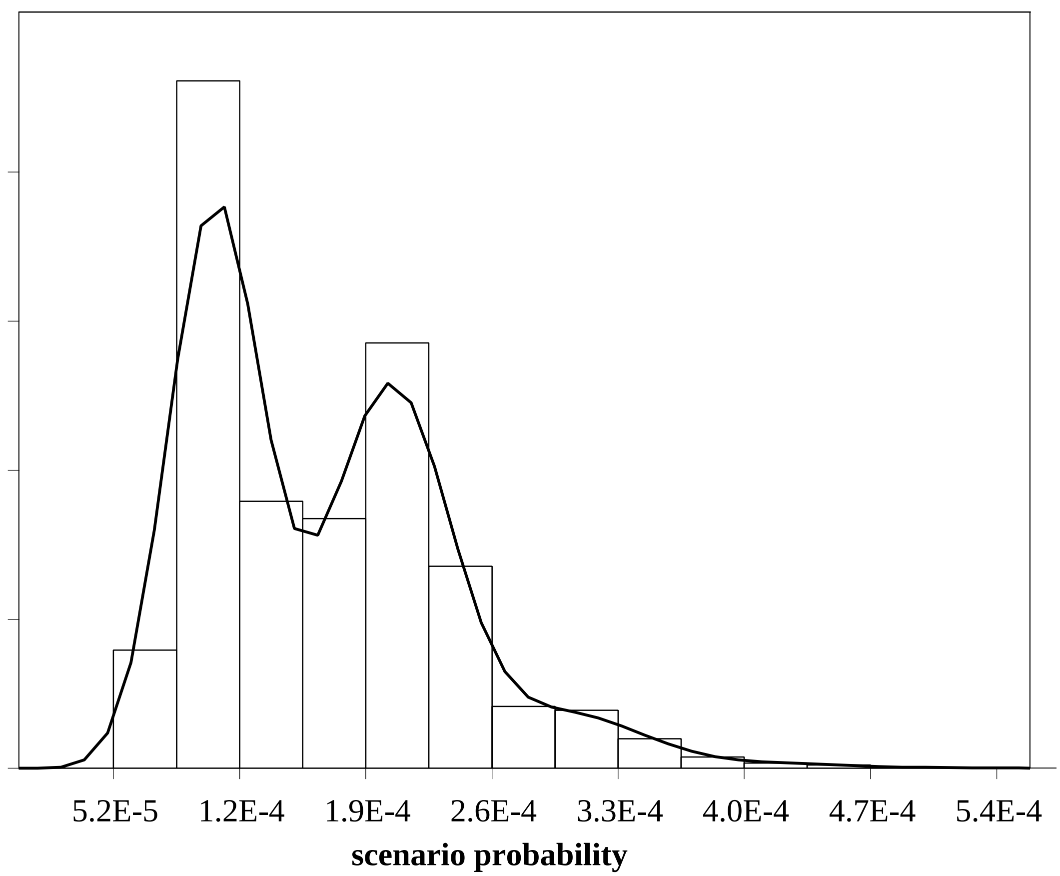


Figure E-9 Estimated distribution of the probability of inadvertent human intrusion overlaid on the simulated relative frequency distribution for the Base Community scenario: Frenchman Flat

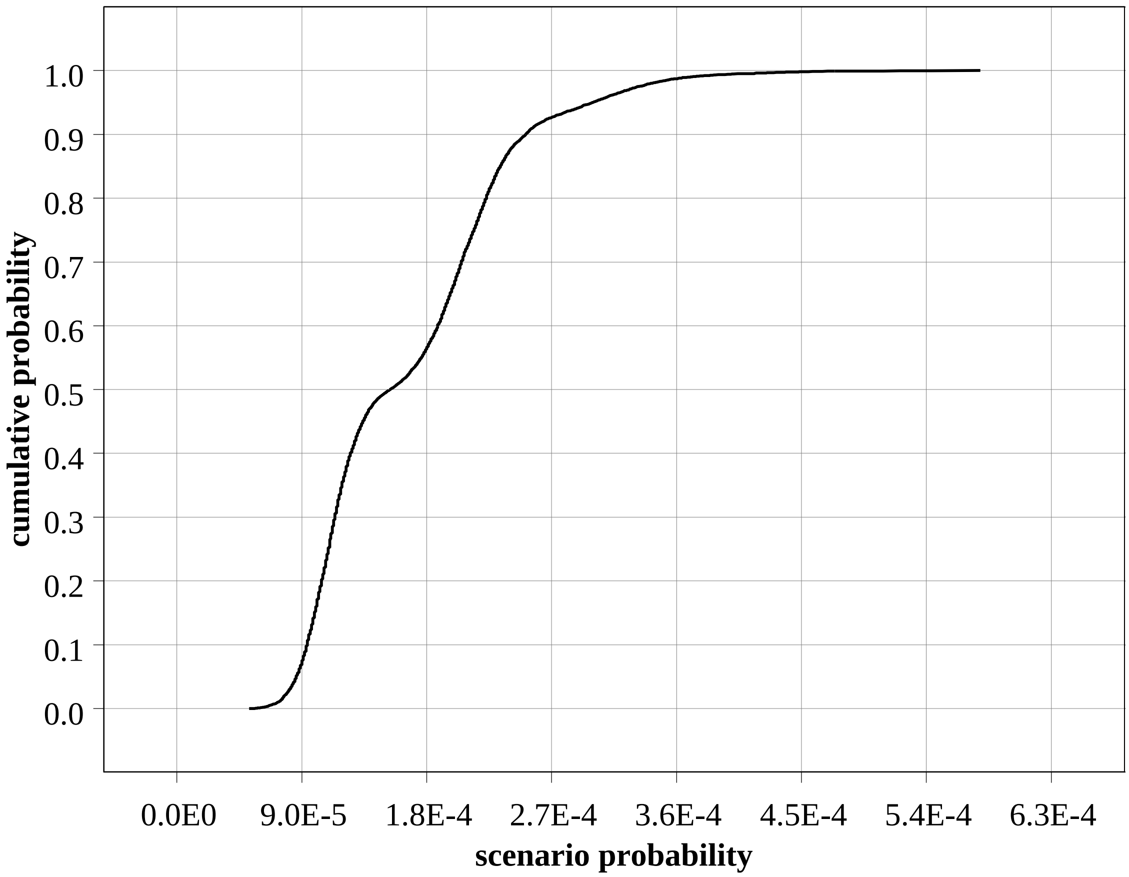


Figure E-10 Estimated cumulative distribution function for the probability of inadvertent human intrusion for the Base Community scenario: Frenchman Flat

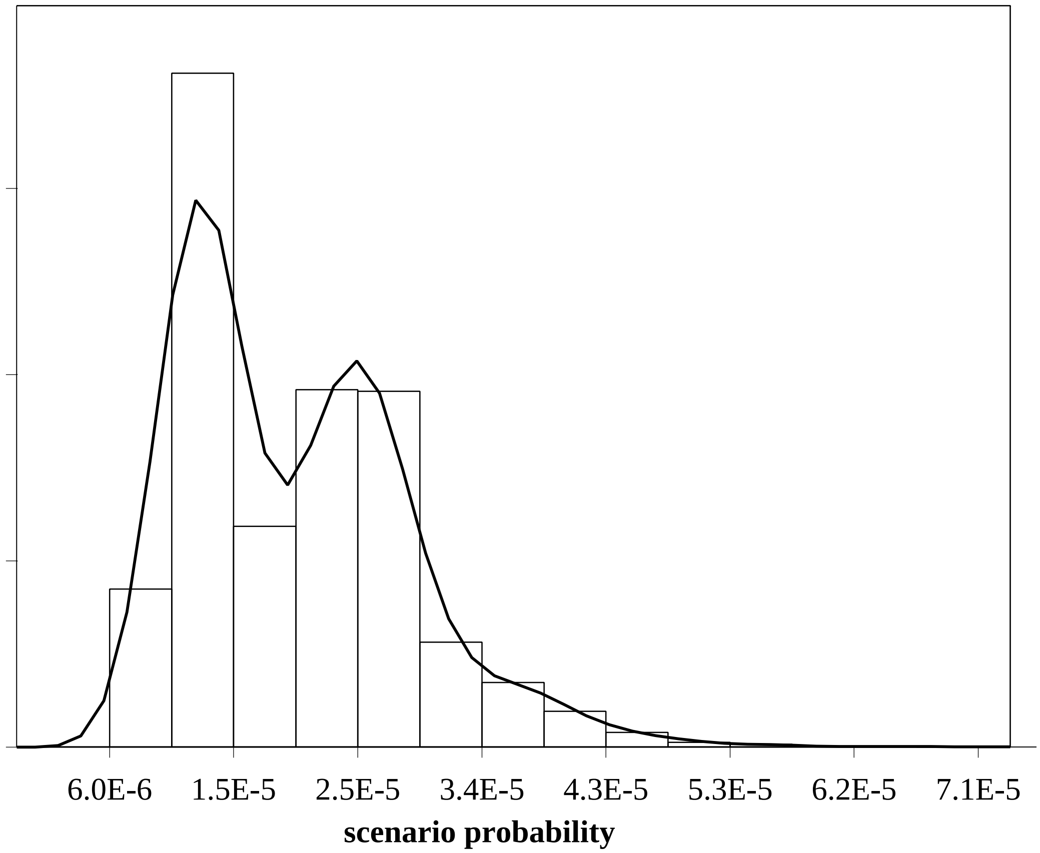


Figure E-11 Estimated distribution of the probability of inadvertent human intrusion overlaid on the simulated relative frequency distribution for the Yucca Flat Base Community scenario: Yucca Flat

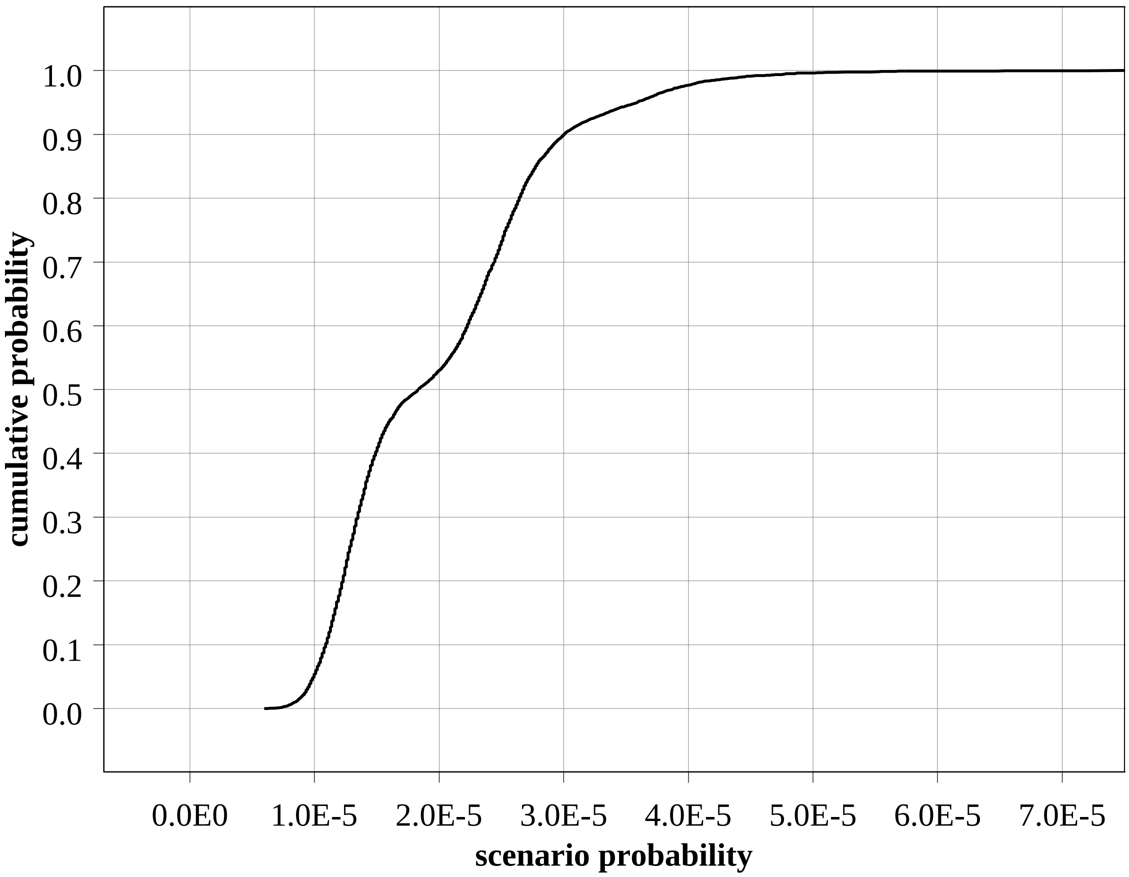


Figure E-12 Estimated cumulative distribution function for the probability of IHI for the Yucca Flat Base Community scenario.

E.4.2 Jackass Flats Community Scenario

The Jackass Flats community scenario involves a community located in the vicinity of, but not directly in, Frenchman Flat or Yucca Flat that places population pressure on these two areas of interest. The type of settlement assumed for Frenchman Flat and Yucca Flat under this scenario is commuter homesteading. This is to be distinguished from the independent homesteading of the Homesteader scenario for which attachment to a community is not involved, and from the Base Community scenario for which a community is settled in Frenchman Flat or Yucca Flat. The factors that enter the calculations for this scenario are:

1. the proportion of time in the next 10,000 years that a community will develop in the vicinity of Frenchman Flat or Yucca Flat, such that population pressure in the form of commuter homesteading might occur in these areas

2. the number of commuter homesteads associated with the extant community

3. the lifetime of a community in the vicinity of Frenchman Flat or Yucca Flat

4. the lifetime of a commuter homestead in Frenchman Flat or Yucca Flat that is associated with a nearby community

5. the lifetime of a commuter homesteader's well

6. the distance of a primary well from a replacement well

7. the areal size of the waste footprint

8. the areal sizes of Frenchman Flat and Yucca Flat, subdivided into the playas, cratered areas, and other (habitable) areas

E.4.2.1 Fitting the Cumulative Distribution Functions

The basic approach is the same as that for the Homesteader scenario. That is, determine the number of wells in Frenchman Flat or Yucca Flat during the compliance period based on the SME assessments, and calculate the probability that at least one of these wells intersects the waste site. Calculations are performed separately for Frenchman Flat and Yucca Flat. Before describing the calculations, the inputs to the Jackass Flats scenario are presented, and assumptions are explained.

E.4.2.1.1 Proportion of the Evaluation Period for which a Community Exists in the Vicinity of Frenchman Flat or Yucca Flat

The first factor to be considered is the effective number of years a community might exist in the vicinity of Frenchman Flat or Yucca Flat that could cause commuter homesteads to be sited in these two areas. The SMEs assessed the proportion of the 10,000-year compliance period for which this type of homesteading would be present in these areas to be 50%. This corresponds to 5,000 years, and was offered as a median of the distribution. The SMEs further indicated that this proportion could lie uniformly between 25% and 75%, which seemed to reflect the uncertainty in their response. Random numbers were drawn from this interval to establish a baseline for the number of communities that might exist during the compliance period.

E.4.2.1.2 Community and Commuter Homestead Lifetimes

The distribution of community lifetimes for this scenario is the same as for the Base Community scenario, and is presented in Table E-6 and Figure E-7. Also, the SMEs indicated that commuter homesteads could be assumed to last the same length of time as the corresponding communities. Consequently, the distribution for homestead lifetimes for this scenario is also provided in Table E-6 and Figure E-7.

E.4.2.1.3 Number of Commuter Homesteads

Tables E-10 and E-11 provide a brief summary of the SME input for the distribution of number of homesteads per community. In general, the SMEs indicated that Frenchman Flat would have about twice as many commuter homesteads as Yucca Flat. This was interpreted as, for example, a median of 25 commuter homesteads as opposed to 50 for Frenchman Flat. However, this caused a slight problem for the 0.05 quantile, which was handled by applying the same probability for one or more commuter homesteads for both Frenchman Flat and Yucca Flat. This introduces a small positive bias to the Yucca Flat results, although the effect is difficult to measure. Some sensitivity analyses on different fits to the quantile input is provided in Appendix F.

Table E-10

SME Input for Number of Commuter Homesteads per Extant Community for Frenchman Flat

Number of homesteads	Cumulative Probability
0	0.05
50	0.5
100	0.95
200	0.99

Table E-11

SME Input for Number of Commuter Homesteads per Extant Community for Yucca Flat

Number of homesteads	Cumulative Probability
0	0.05
25	0.5
50	0.95
100	0.99

Note that the SMEs indicated that population pressure might not be placed on Frenchman Flat or Yucca Flat under this scenario. In particular, they indicated that the probability of one or more homesteads in Frenchman Flat was 95%. This allowed a 5% probability that commuter homesteads would not be developed in Frenchman Flat or Yucca Flat even if a community existed in the vicinity of Frenchman Flat or Yucca Flat. The beta distributions fit to the SME input accommodate this by constraining the fit to pass through the point on the cdf corresponding to 1 homestead and 5% probability. During the simulation, any random number drawn that was less than 0.05 was associated with zero commuter homesteads.

The beta cdf for Frenchman Flat was fit with the following parameter values: a = -100; b = 220 commuter homesteads; v = 13; and, w = 15. The value of a does not impact the calculations directly, but does have an impact on the adequacy of the fit. The value of b establishes a maximum value that can be drawn for the simulations. The probability density is unimodal, and the distribution has a mean of approximately 50, and a variance of approximately 900. However, the simulated mean and variance will be slightly different because any random number drawn that is less than 0.05 is assigned zero commuter homesteads. Figure E-13 shows the fitted cdf. The shape and scale of the figure do not allow the maximum value to be clearly shown, otherwise, the fit closely matches the SME input.

Figure E-14 shows the fitted cdf for the number of commuter homesteads per community in Yucca Flat. This beta cdf was fit with the following parameter values: a = -45; b = 110 commuter homesteads; v = 12; and, w = 14. Again, the value of a does not impact the calculations directly, but does have an impact on the adequacy of the fit. The value of b establishes a maximum value that can be drawn for the simulations. The probability density is unimodal, and the distribution has a mean of approximately 25, and a variance of approximately 220, although the simulated mean and variance will, again, be slightly different. Again, the shape and the scale of the fitted cdf do not clearly show the maximum for this distribution, otherwise, the fit closely matches the SME input. The lack of visual definition in the upper tail of the fitted cdf demonstrates the very small probability of values near the maximum of the distribution.

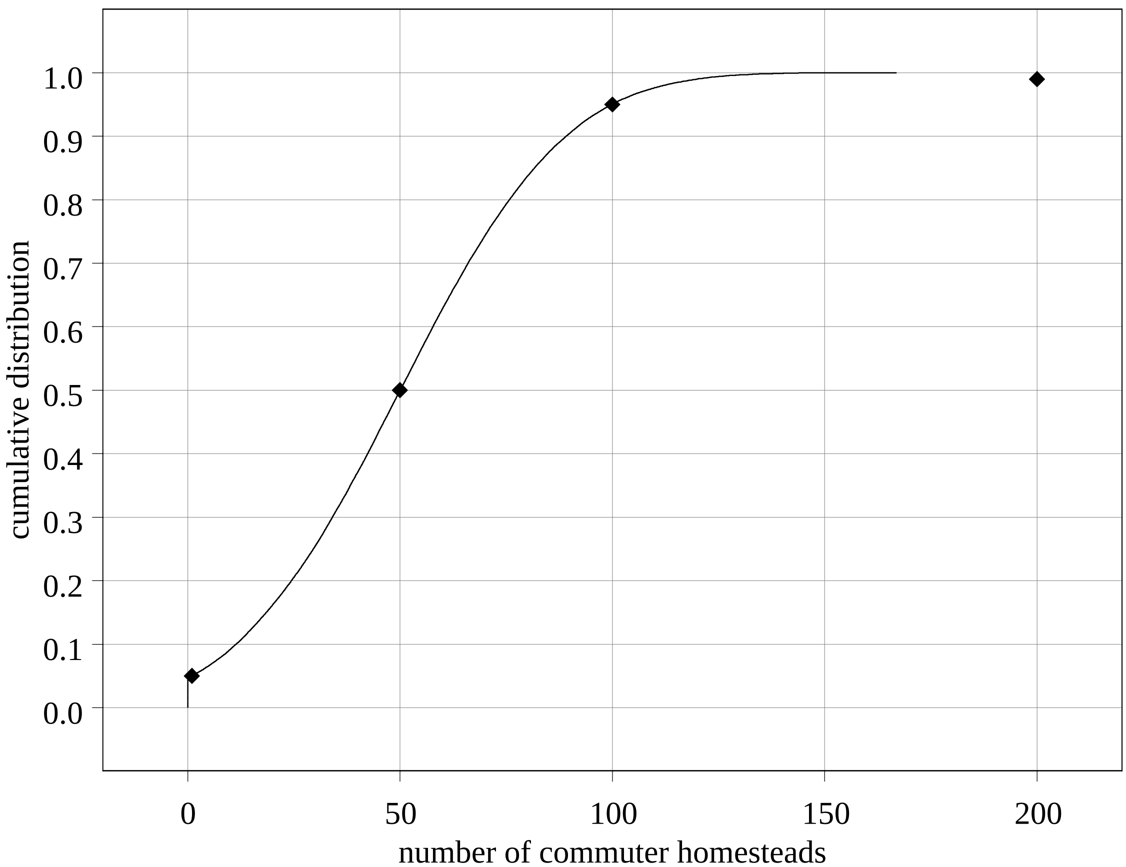


Figure E-13 Fitted cumulative distribution function for number of homesteads in Frenchman Flat for the Jackass Flats scenario.

E.4.2.1.4 Well Lifetimes

The SMEs decided that the distribution of well lifetimes is the same for this scenario as it is for the Homesteader scenario. Table E-3 (Homesteader scenario) provides a summary of the points used to generate a cdf for this factor. Section E.3.1.3 provides the estimated parameter values for the fitted beta distribution, and Figure E-3 displays the corresponding cdf.

E.4.2.1.5 Distance Between Replacement Wells

The SMEs also decided that the distribution of distance between replacement wells is the same for this scenario as it is for the Homesteader scenario. Table E-4 (Homesteader scenario) provides a summary of the points used to generate a cdf for this factor. Section E.3.1.4 provides the estimated parameter values for the fitted beta distribution, and Figure E-4 displays the corresponding cdf.

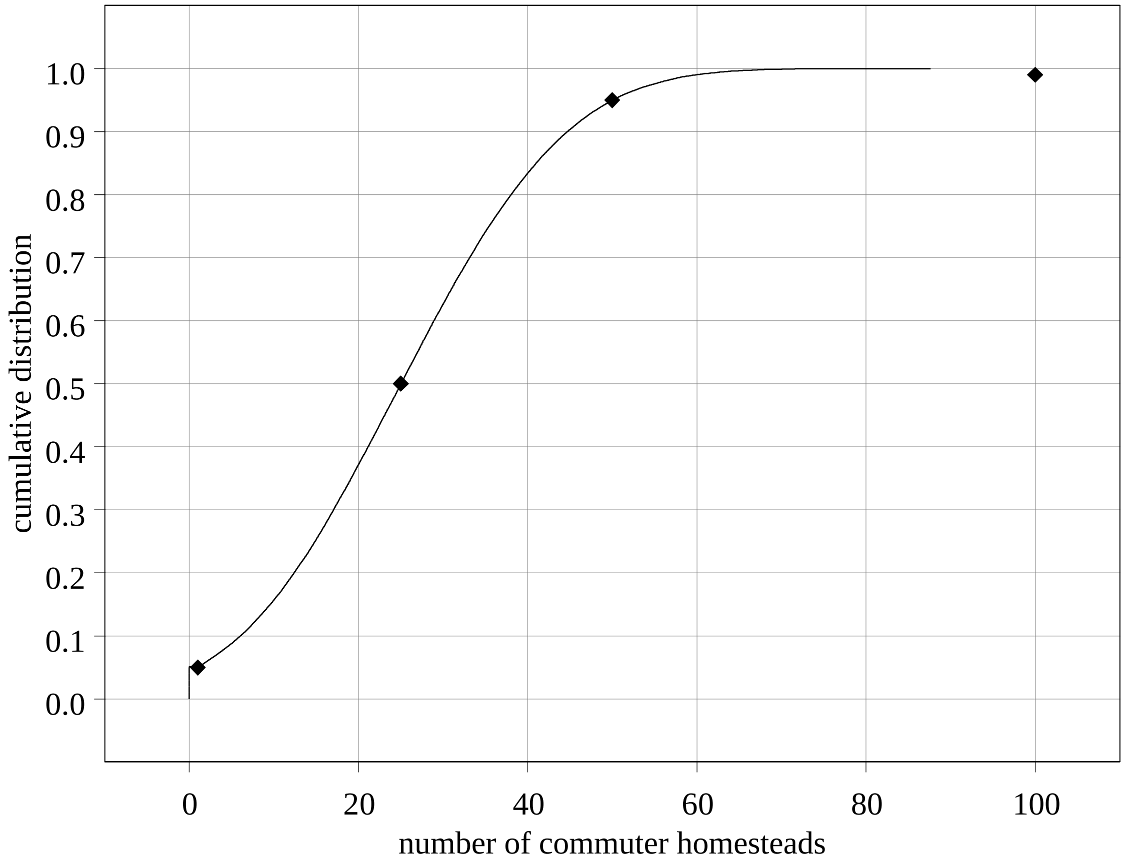


Figure E-14 Fitted cumulative distribution function for number of homesteads in Yucca Flat for the Jackass Flats scenario.

E.4.2.2 Jackass Flats Analysis

The simulations and calculations performed for this scenario are very similar to those performed for the Homesteader scenario. For this scenario, the target value used to calculate the total number of homesteads in Frenchman Flat or Yucca Flat during the evaluation period was simulated from the interval 2,500 to 7,500. From this input distribution, the base number of years that communities might exist was simulated.

The next step for each simulation was to determine the number of communities by successive random draws from the distribution of community lifetime presented in Section E.4.1.1.1 (see Figure E-7). These random draws were repeated until the sum of community lifetimes minimally exceeded the randomly drawn target base number of years. At this point either the total number of community lifetime drawn was selected as a count of the number of communities, or one was subtracted from this count. The subtraction was performed at random to eliminate a potential small positive bias, and so that overestimation of the probability of IHI was not expected. Note that this process was not applied to the Homesteader scenario, which avoided this complication because of the very small probability of IHI for that scenario.

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. The communities, and hence the homesteads were treated as independent, both in time and in space. Homesteads could occur in the same location as homesteads from previous settlements.

Replacement wells were determined in the same way as for the Homesteader scenario. Each simulation resulted in a total number of primary wells, each of which was associated with some number of replacement wells. The number of replacement wells was often zero or one, although two or more replacement wells were possible.

The algorithms for Frenchman Flat and Yucca Flat deviated at this point. For Frenchman Flat, the primary wells for each simulation were located at random throughout the area of Frenchman Flat. Random angles and random distances from the preceding well were drawn and applied for each replacement well. The placement of wells throughout Frenchman Flat was repeated 1,000 times within each of the 10,000 simulations. It is reasonable to perform fewer repetitions for this scenario because of the comparatively large probability of IHI compared to the other scenarios.

For Yucca Flat, the algorithm was similar initially, and was performed without consideration of the cratered area. However, because of the smaller probability, the number of repetitions performed was 10,000 for each of the 10,000 simulations. Once this step was performed, the resultant, initial probabilities were multiplied by 0.13 to accommodate the impact of the cratered area (as described in Section E.4.1.2)

Summary statistics for the distributions of the total number of wells and the probability of IHI for this scenario in Frenchman Flat and Yucca Flat are provided in Tables E-12 and E-13, respectively. Figures E-15 through E-18 provide graphical representations of the final simulated distributions. The average scenario probability of IHI for Frenchman Flat was calculated as approximately 0.11, whereas for Yucca Flat the scenario probability of IHI is approximately 0.014. These are by far the largest probabilities of all the scenarios, which corresponds to the comparatively large number of wells expected to be drilled in Frenchman Flat and Yucca Flat.

Table E-12 Summary statistics for the propagated probability distributions of the total number of wells and the probability of inadvertent human intrusion for the Jackass Flats scenario: Frenchman Flat

FRENCHMAN FLAT			
Summary Statistic	**Total Number of Wells**		**Probability of IHI**
	Primary	**Replacement**	
Minimum	1500	1800	0.031
5%	2500	3000	0.058
25%	3400	4200	0.082
Median	4600	5600	0.11
Average	**4600**	**5600**	**0.11**
75%	5700	7000	0.13
95%	6800	8300	0.16
Maximum	8500	10000	0.21

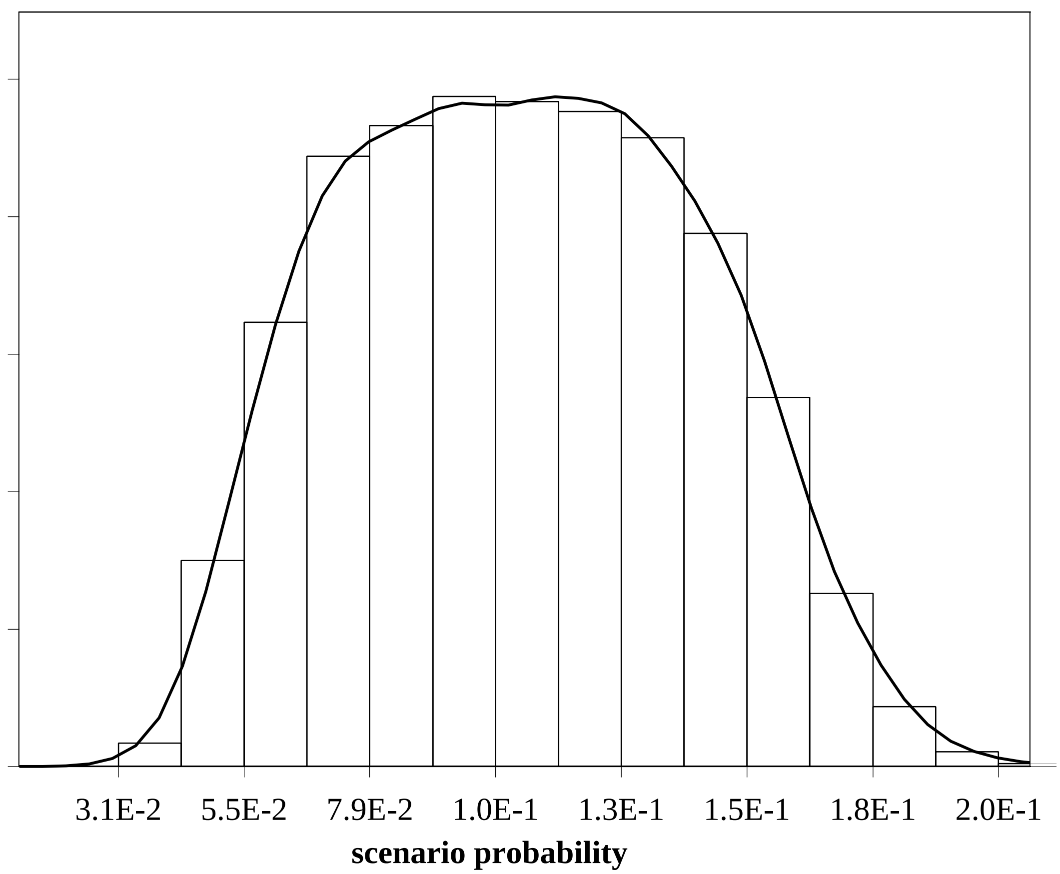


Figure E-15 Estimated distribution of the probability of inadvertent human intrusion overlaid on the simulated relative frequency distribution for the Jackass Flats scenario: Frenchman Flat

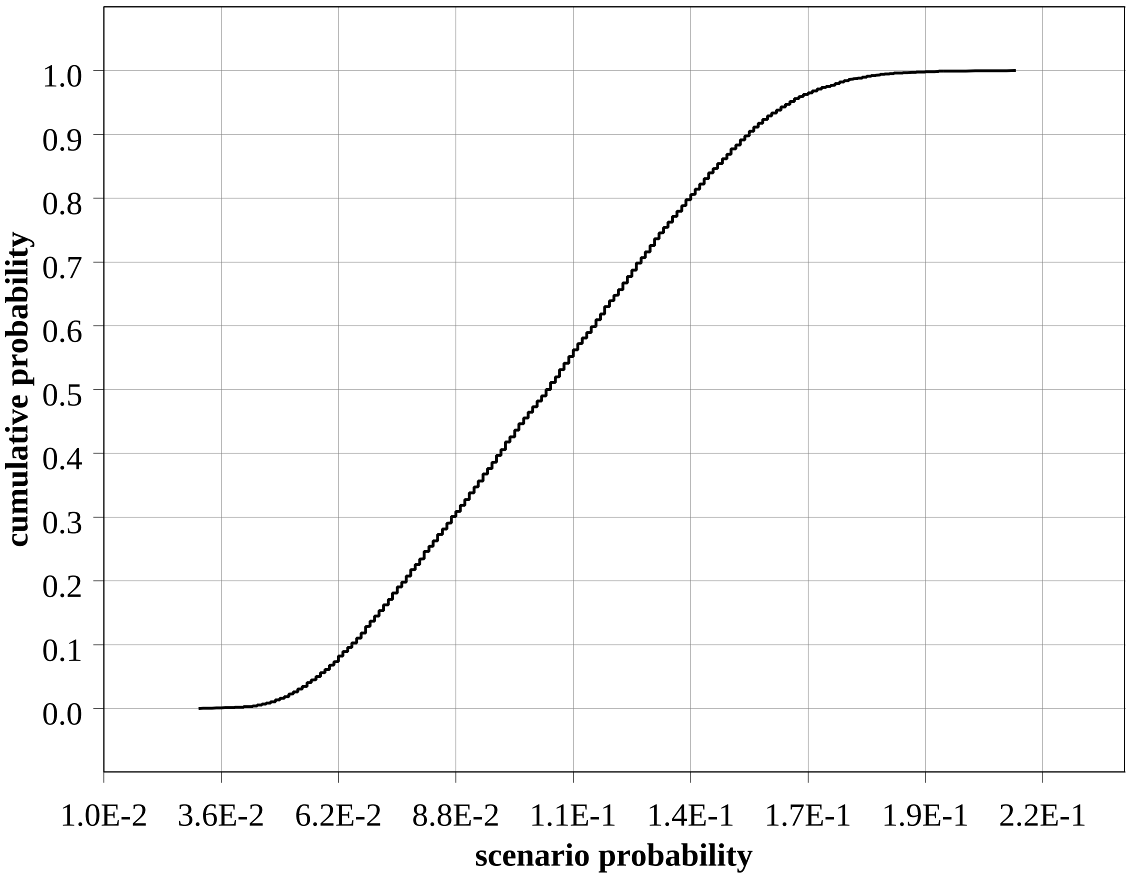


Figure E-16 Estimated cumulative distribution function for the probability of inadvertent human intrusion for the Jackass Flats scenario: Frenchman Flat

Table E-13 Summary statistics for the propagated probability distributions of the total number of wells and the probability of inadvertent human intrusion for the Jackass Flats scenario: Yucca Flat

YUCCA FLAT			
	Total Number of Wells		
Summary Statistic	**Primary**	**Replacement**	**Probability of IHI**
Minimum	800	1100	0.0010
5%	1200	1500	0.0034
25%	1700	2100	0.0048
Median	2200	2700	0.0063
Average	**2300**	**2800**	**0.0065**
75%	2800	3400	0.0080
95%	3400	4100	0.010
Maximum	4400	5000	0.013

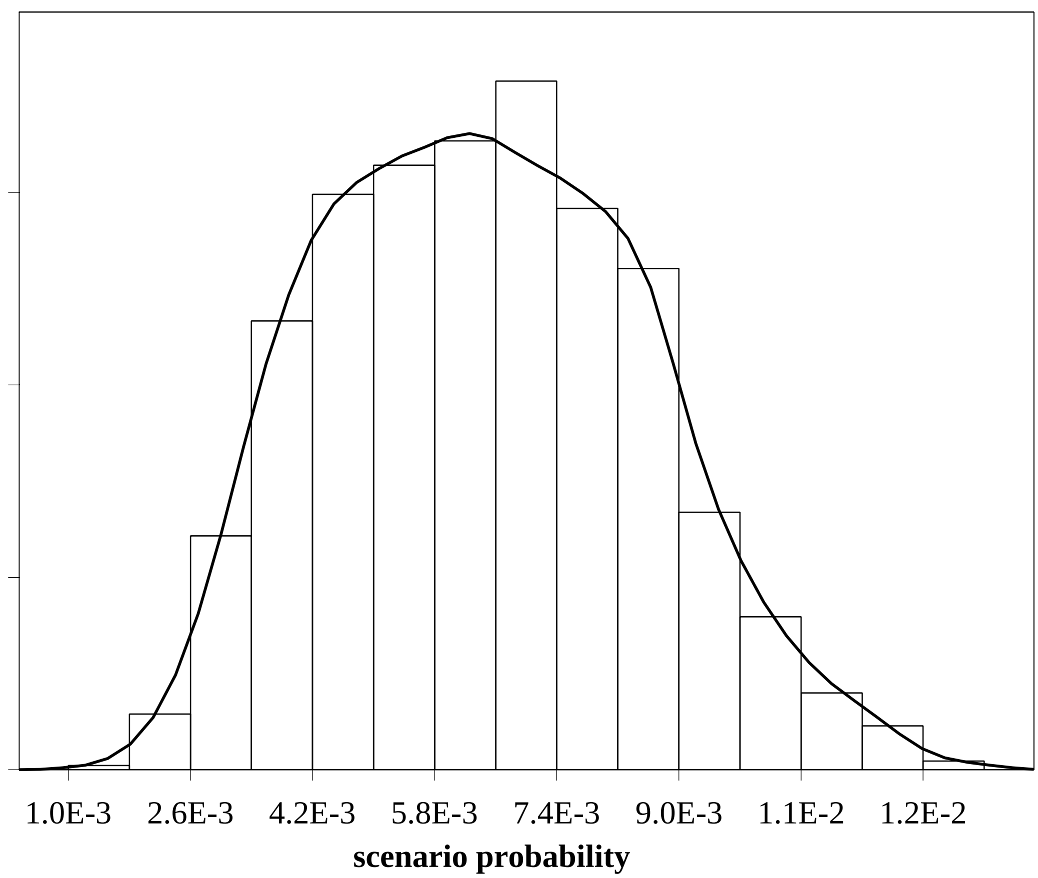


Figure E-17 Estimated distribution of the probability of inadvertent human intrusion overlaid on the simulated relative frequency distribution for the Jackass Flats scenario: Yucca Flat

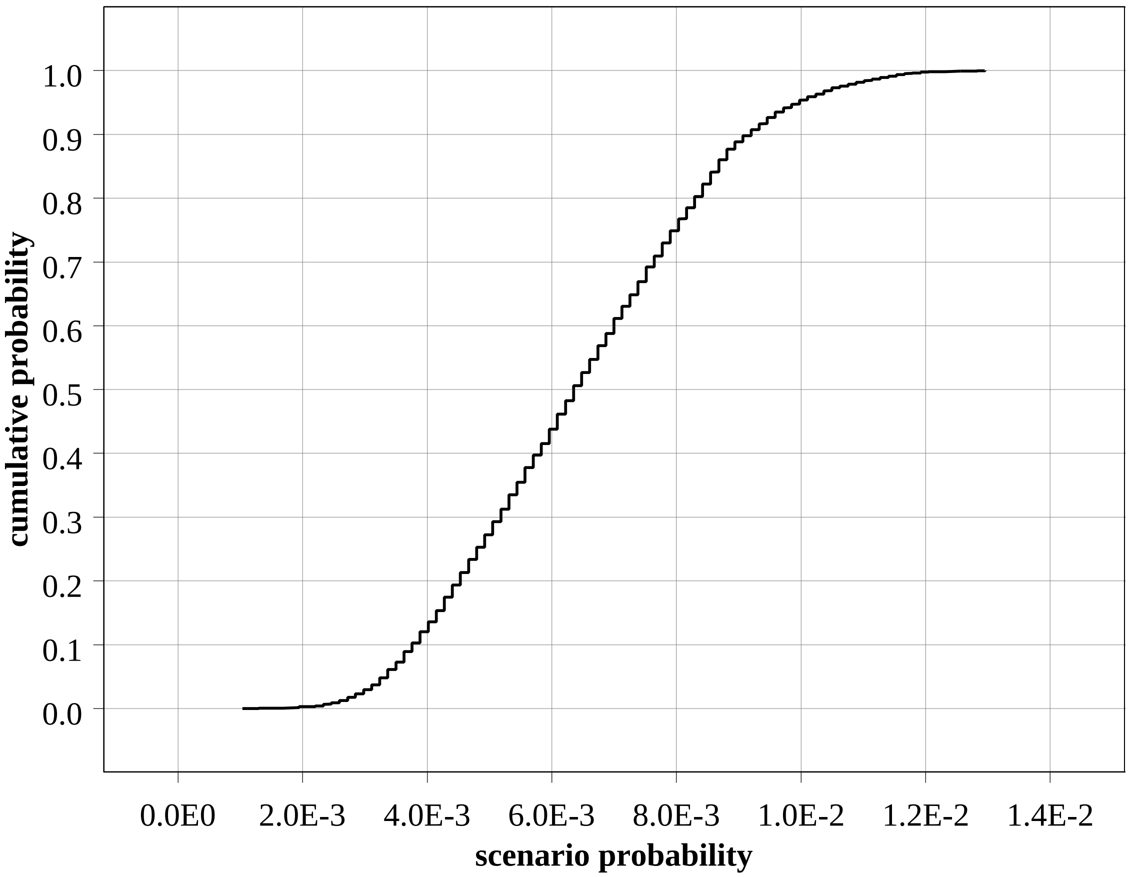


Figure E-18 Estimated cumulative distribution function for the probability of inadvertent human intrusion for the Jackass Flats scenario: Yucca Flat

E.4.3 Las Vegas Expansion Scenario

This scenario considers the influence of expansion of Las Vegas on the potential for commuter homesteading in Frenchman Flat and Yucca Flat. The SMEs indicated that such population pressure is not very likely to occur, and will not occur unless the population of Las Vegas exceeds three million people (the current population of Las Vegas is approximately one million people).

The basic approach is the same as before. That is, determine the number of wells to be drilled in Frenchman Flat and Yucca Flat during the compliance period, and calculate the probability that at least one of these wells intersects the waste footprint. For this scenario, however, replacement wells become more of a concern because commuter homesteads are assumed to be viable for the duration of the period in which population pressure is placed on Frenchman Flat and Yucca Flat, a period of up to several hundred years. Thus, there are potentially several replacement wells associated with each primary well. The previous scenarios, by comparison, have comparatively few instances of replacement wells. In addition, the SMEs indicated that there was only some potential for sufficient expansion of Las Vegas to place population pressure on Frenchman Flat and Yucca Flat. The factors that enter the calculations for this scenario are:

1. the lifetime of Las Vegas as a viable city
2. the probability that the population of Las Vegas will reach three million people
3. the proportion of the lifetime of Las Vegas for which the population exceeds three million people and, hence, has the potential for placing commuter homesteading population pressure on Frenchman Flat and Yucca Flat
4. the number of commuter homesteads that might be associated with the expansion of Las Vegas to more than three million people
5. the lifetime of a commuter homestead in Frenchman Flat or Yucca Flat
6. the lifetime of a well
7. the distance of a primary well from a replacement well
8. the areal size of the waste footprint
9. the areal sizes of Frenchman Flat and Yucca Flat, subdivided into the playas, cratered areas, and other (habitable) areas.

E.4.3.1 Fitting the Cumulative Distribution Functions

For several of the factors in this scenario scaled beta distributions were fit to the elicited SME input. The inputs provided for the proportion of the lifetime of Las Vegas for which the population might exceed three million people did not have the same type of input as other factors. A gamma functional form was used to model the input provided so that the numerical model could be completed and the distribution of the probability of IHI for this scenario could be generated. Before describing the calculations, the inputs to the Las Vegas Expansion scenario are presented, and assumptions are explained.

E.4.3.1.1 Las Vegas Lifetime

The first factor to be addressed concerns the lifetime of the city of Las Vegas. Table E-14 provides a summary of the SME input. There were two reasons provided by the SMEs that the lifetime of Las Vegas should be considerably shorter than the 10,000-year compliance period. First, the SMEs recognized that Las Vegas relies primarily on one commercial industry, gambling, that could rise and fall at the whim of a government. The SMEs recognized DOE's presence and the management of NTS, but did not regard that as a long-term prospect, and also indicated that erosional changes in government policy could easily change the importance of the NTS to Las Vegas. Second, the SMEs considered lifetimes of historical cities and indicated that cities that are centers for shipping activities generally survive for longer than other cities. They classified Las Vegas as a "secondary" city in the sense that it is not a shipping center, and consequently decided that the expected lifetime of Las Vegas as a large city should be more in line with historical lifetimes of past "secondary" cities.

The fitted scaled beta cdf is displayed in Figure E-19. The optimization did not require mathematical constraints, indicating that the minimum lifetime of Las Vegas in the fitted distribution is greater than zero. The parameter representing the minimum of the range was estimated as $a = 0.01$ years, fixing this value as the smallest lifetime of Las Vegas that could be simulated. Figure E-19 shows that the lower tail probability is very small for lifetimes of 100 years or less, suggesting that very small lifetimes are unlikely to be simulated. The remaining scaled beta distribution parameters were estimated as: $b =$ 2,200 years; $v = 3.4$; and, $w = 4.1$. Consequently, the distribution is unimodal with a mean of approximately 1,000 years and a variance of approximately 140,000.

Table E-14

SME Inputs for Las Vegas Lifetime

Lifetime (years)	Cumulative probability
500	0.1
1,000	0.5
1,500	0.9
2,000	0.99

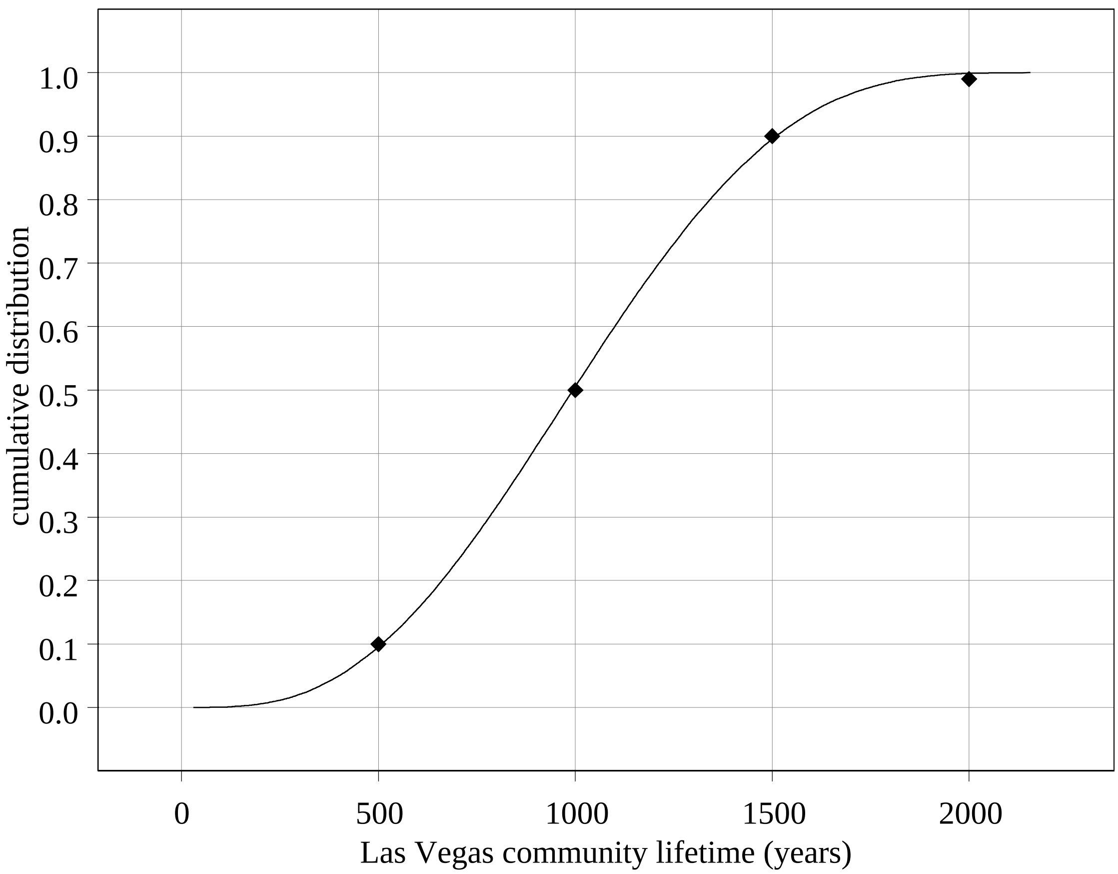


Figure E-19 Fitted cumulative distribution function for Las Vegas lifetime.

E.4.3.1.2 Population Distribution of Las Vegas

As discussed in Chapter 3, one of the base assumptions of this study concerned conditioning on current knowledge of society and technology. The SMEs were particularly concerned that current knowledge of population trends be included. The SMEs indicated that current knowledge was sufficient to be able to make determinations about some aspects of population growth of Las Vegas. Although demographic planning for the city of Las Vegas does not extend beyond about 20 years into the future, the SMEs decided that historical information was sufficient to be able to more generally forecast population trends under current conditions of society. The SMEs did not consider water supply as a major obstacle to population expansion. They took the view that if population and economic pressure were sufficient, then sufficient water would be found to accommodate the increased population.

The SMEs then considered the geography of the area, and recognized that population expansion is most likely to occur down the main transport corridors around Las Vegas. These areas include the corridor to the northwest of Las Vegas, that passes directly by

Jackass Flats on the south side of the NTS. The SMEs decided that sufficient population expansion of the city of Las Vegas could occur along this corridor such that population pressure might be exerted on Frenchman Flat and Yucca Flat in the form of commuter homesteading. After consideration of the geography and the potential for population expansion, the SMEs indicated that the population of Las Vegas would have to expand to at least 3,000,000 people before any population pressure would be exerted on Frenchman Flat or Yucca Flat.

The SMEs indicated that the distribution of the life of “secondary” cities should reflect a faster rise than decline, with a relatively drawn-out decay to the point where they are no longer viable large cities (e.g., less than 10,000 people), and that the city will reach its maximum population at about one-third of its lifetime. The SMEs indicated that this information is relatively independent of population size for a city of this stature. The SMEs did, however, consider the rate of population expansion that could be considered in the vicinity of Las Vegas. They recognized that the current rate of population expansion is approximately 10% per year, but decided that this rate probably could not be sustained. They were more inclined to consider an average rate of expansion of 1% per year, which they recognized is more consistent with the national average. At this continuous rate of population expansion, the city of Las Vegas would expand to around 5,000,000 people in about 200 years.

The potential for Las Vegas to exert population pressure on Frenchman Flat and Yucca Flat sometime during the compliance period of 10,000 years requires two sets of input: an assessment of the probability that the Las Vegas population will be sufficient to place population pressure on Frenchman Flat and Yucca Flat (i.e., that the population will expand to more than 3,000,000), and, if this occurs, the length of time that the population of Las Vegas will remain sufficient. More simply, the issues under consideration concern whether the population will ever be large enough, and if so for how long. These two factors are combined to provide an overall picture of population pressure that might be exerted on Frenchman Flat and Yucca Flat during the lifetime of Las Vegas (or during the compliance period).

The SMEs indicated that the lifetime of Las Vegas as a city is, to some extent, independent of the population size. The SMEs assigned a value of 0.2 to the probability that the population of Las Vegas will reach 3,000,000 people, but indicated that this factor could have a probability as high as 0.6 or as low as 0.1. This distribution portrays the uncertainty the SMEs had in their prediction of future Las Vegas population increases. Figure E-20 displays the scaled beta cdf that was fit to this input. The optimization was constrained by parameters a = 0.1, and b = 0.6. There are infinite possible solutions because only one other quantile (the median) was elicited from the SMEs, consequently, the fitting procedure also required some subjective assessment to generate an appealing fitted beta cdf. The remaining beta distribution parameters were estimated to be: v = 0.5; and, w = 1.1. Consequently, the fitted beta distribution has a mean of 0.25, and a variance of 0.021. The fit distribution is unimodal, although the mode is at the minimum value of 0.1.

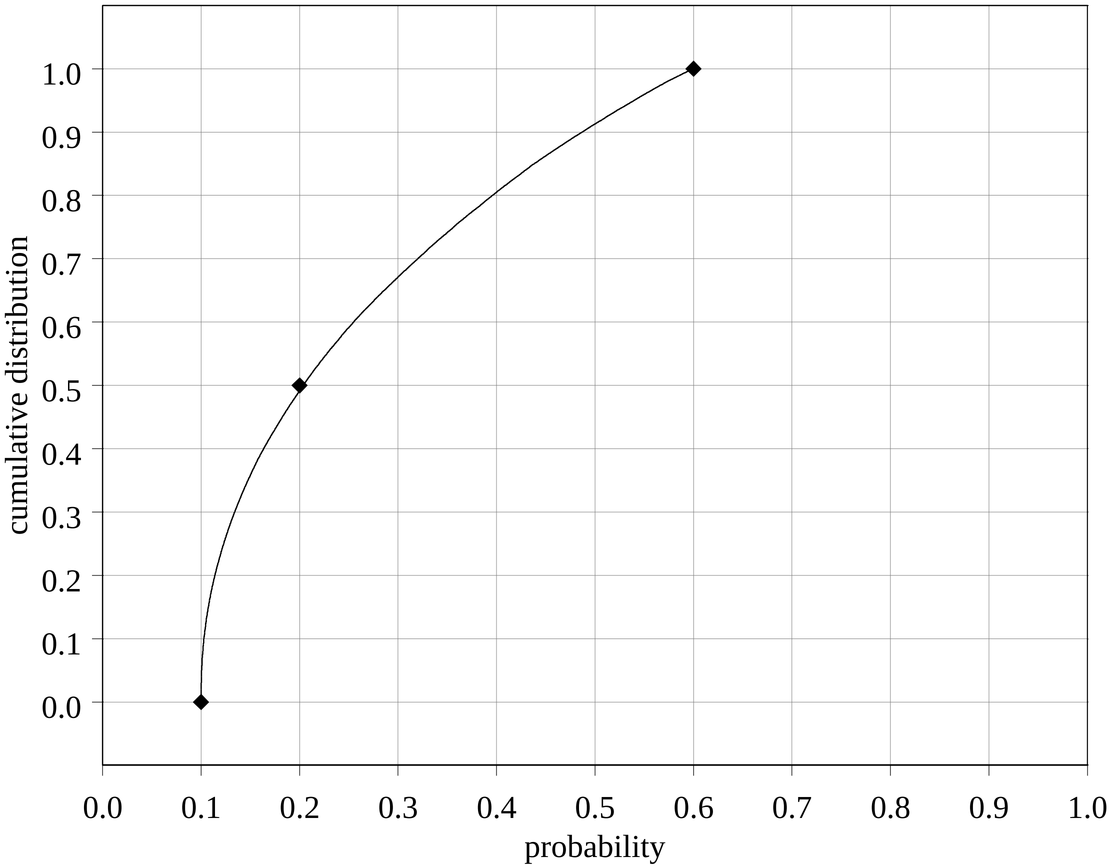


Figure E-20 Fitted cumulative distribution function for the probability that Las Vegas will expand to a population size of 3,000,000 people.

The SMEs were also asked to address the issue of the length of time for which the population of Las Vegas would continue to exert population pressure on Frenchman Flat and Yucca Flat. They indicated that the population of Las Vegas would peak at about one third of the lifetime of the city, and that a population size that would signify the final decline of Las Vegas corresponds to 10,000 or fewer people. The SMEs further indicated that the population of Las Vegas was very unlikely to exceed 5,000,000 people. These SME inputs were used to construct a model to estimate the proportion of the Las Vegas lifetime for which population pressure might be placed on Frenchman Flat and Yucca Flat.

A functional form was sought to model the rise and fall of Las Vegas and to assess the proportion of the lifetime of Las Vegas for which population pressure might be exerted on Frenchman Flat and Yucca Flat. The function's mode was assumed to be approximately one-third of the effective lifetime of Las Vegas, with the vertical peak, or mode, representing 5,000,000 people, tailing off to less than 10,000 people at the far right of the horizontal axis. Thus, the distribution would rise more steeply than it would decline. Using this information a function proportional to a gamma distribution was proposed to model the rise and fall of Las Vegas over time.

A gamma distribution was chosen to fit the above criteria, due to its relative flexibility of shape and scale and its ability to effectively model positive skewness. The gamma distribution that seemed to best fit the requirements had a shape parameter (k) of 7 and a scale parameter (q) of 0.5 (this distribution has a mean of 3.5 and a variance of 1.75). Equation E-3 provides the form of the gamma distribution used (where X represents a gamma distribution random variable). Figure E-21 provides an illustration of the shape of this distribution.

$$f_X(x|q,k) = \frac{1}{q^k\,\Gamma(k)}\,x^{k-1}e^{-x/q} \qquad \text{E-3}$$

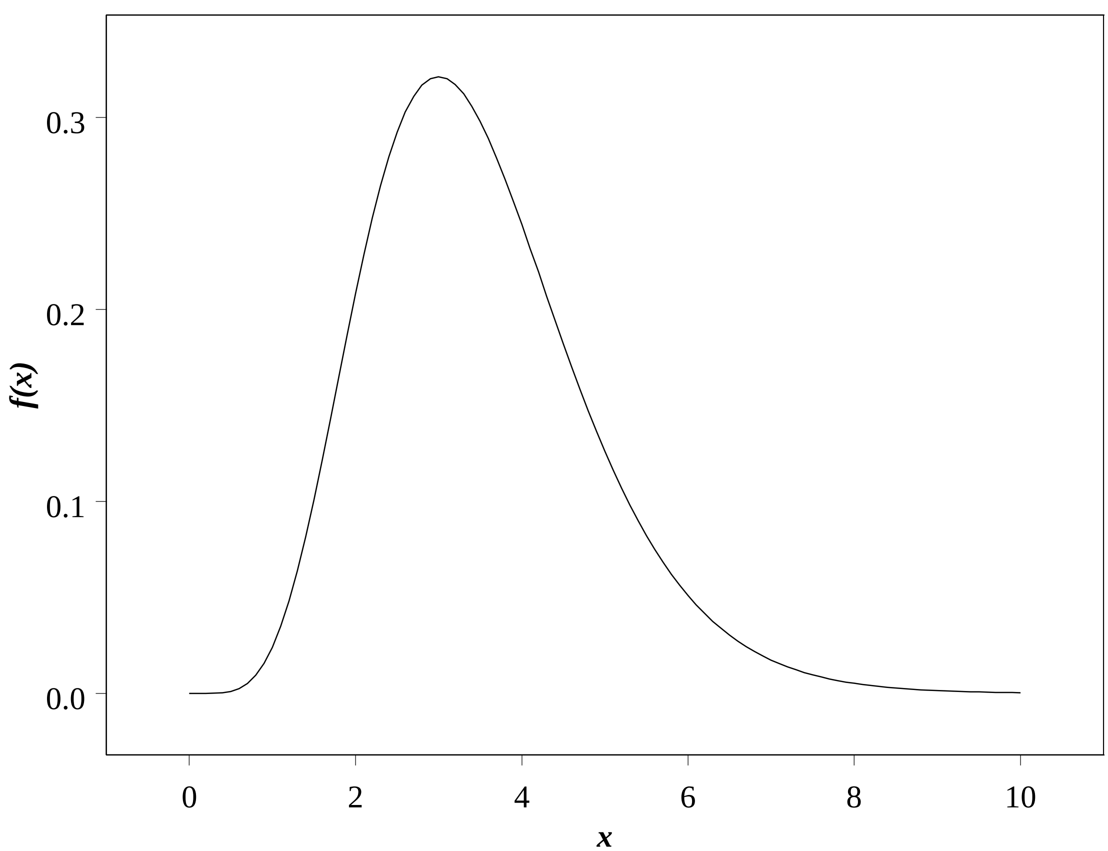


Figure E-21 Base functional form used to model population growth and decline of Las Vegas [gamma distribution (0.5,7)].

According to the SMEs, Las Vegas would put population pressure on Frenchman Flat or Yucca Flat when it reaches a population of 3,000,000 or more. The gamma distribution can be used as an effective basis for determining the proportion of Las Vegas lifetime during which the population might exceed 3,000,000 people. By scaling the vertical axis of the gamma distribution to a maximum of 5,000,000, the approximate proportion of a Las Vegas lifetime that the population would exceed 3,000,000 can be determined. The distribution tail was cut off at 10,000 people to provide a workable bound. Given these constraints, the proportion of Las Vegas lifetime that population pressure is sufficient to realize commuter homesteading is the proportion of the scaled gamma functional form that exceeds 3,000,000. This proportion is approximately 0.25, or ¼. The scaled gamma functional form for this determination is depicted in Figure E-22. This provides a conservative estimate for the length of time that Las Vegas could be of sufficient size to put population pressure on Frenchman or Yucca Flat because the largest plausible population was assumed in these calculations.

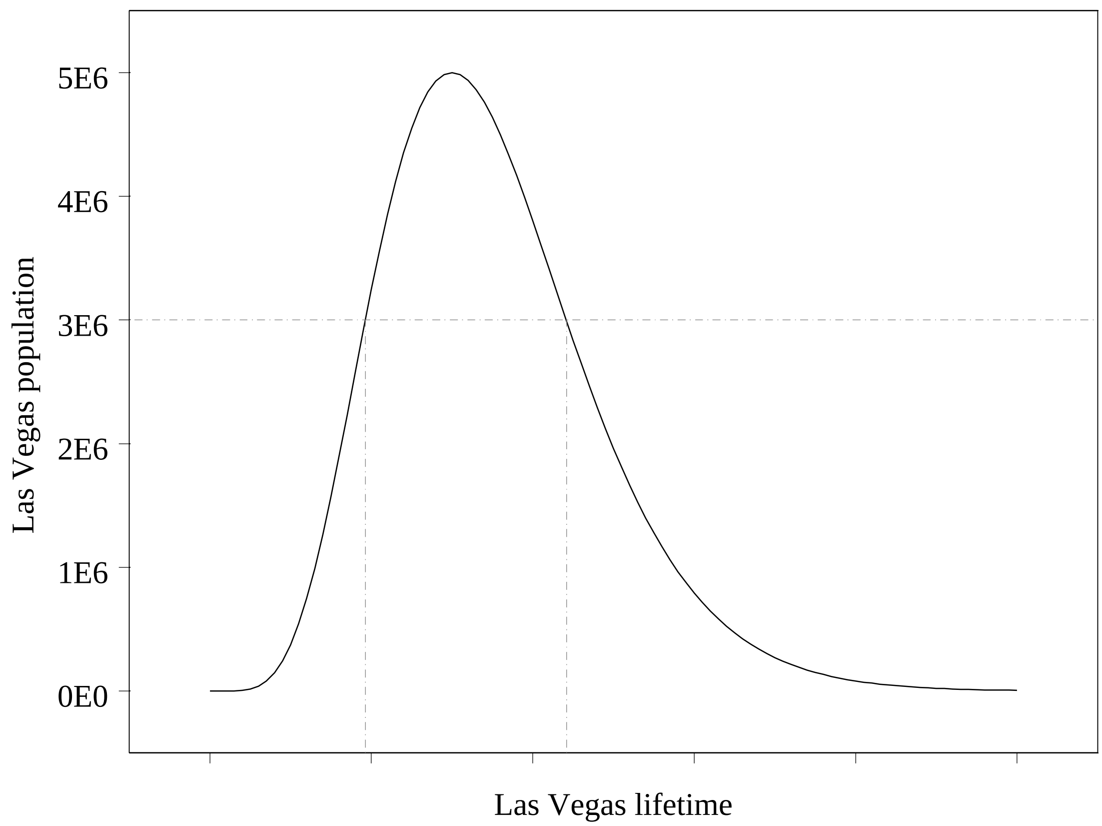


Figure E-22 Function used to model population growth and decline of Las Vegas [scaled gamma functional form (0.5,7)].

It was noted above that the SMEs indicated that independence of the population growth of Las Vegas and the lifetime of Las Vegas was a reasonable working assumption. However, the modeling performed further assumes that, independent of the lifetime of Las Vegas and the population growth of Las Vegas, population pressure will be placed on Frenchman Flat and Yucca Flat for ¼ of the lifetime of Las Vegas. Sufficient information is not available from the SMEs for refinement of this factor. Using a value of ¼ is probably conservative because it is based on the greatest population expansion envisioned by the SMEs (i.e., five million people). Clearly, the proportion of time cannot be greater than zero if the population of Las Vegas only reaches three million people. However, the effect of the proportion is subject to independent modification through the variable that represents the probability that Las Vegas will expand to a population of at least three million people. This does not directly tie the probability of sufficient expansion to the lifetime or population expansion of Las Vegas, but probably serves as a reasonable surrogate. Like the Homesteader and Base Community scenarios, this scenario does not provide nearly the opportunity for wells to intersect a waste footprint in Frenchman Flat or Yucca Flat as does the Jackass Flats scenario. Consequently, further refinement is probably unnecessary.

E.4.3.1.3 Homestead Lifetimes

Commuter homesteads were assumed by the SMEs to be present for the duration of the time period for which Las Vegas exerts population pressure on Frenchman Flat and Yucca Flat. The median lifetime of Las Vegas, modified by the proportion of time that homesteads might be located in Yucca Flat and Frenchman Flat using the methods described above, is approximately 250 years. Consequently, this is also the median homestead lifetime. The SMEs recognized the somewhat conservative nature of this assumption (i.e., all commuter homesteads are unlikely to start at the same time, and are unlikely to all run the course of the long time frame anticipated), however, the SMEs chose this approach for simplicity and because their inputs for the other scenarios had clearly shown that the probability of IHI is dominated by the Jackass Flats scenario.

E.4.3.1.4 Well Lifetimes

The SMEs indicated that the distribution of well lifetimes is the same for this scenario as it is for the Homesteader and Jackass Flats scenarios. Table E-3 (Homesteader scenario) provides a summary of the points used to generate a cdf for this factor. For example, the median well lifetime is 35 years. Section E.3.1.3 provides the estimated parameter values for the fitted beta distribution, and Figure E-3 displays the corresponding cdf.

E.4.3.1.5 Number of Homesteads

The number of homesteads expected by the SMEs in Frenchman Flat during the time frame of sufficient Las Vegas expansion is reported in Table E-13. Figure E-23 displays the fitted scaled beta cdf. Table E-14 and Figure E-24 provide similar information for

Yucca Flat. The input provided by the SMEs was more qualitative than indicated, the more extreme quantiles being provided as reasonable minima and maxima. When asked to translate these statements, the SMEs indicated correspondence to any quantile less than 0.1 or greater than 0.9. The SMEs did, however, also indicate that Frenchman Flat can support more homesteads than Yucca Flat. Given that the Jackass Flats scenario would clearly dominate the probability of IHI, further efforts to refine the SME input for these factors were not attempted. The cumulative probabilities presented in Tables E-15 and E-16 were set to approximate the SME input described, and to adhere to the constraint that the number of homesteads in Yucca Flat should in general be less than the number expected in Frenchman Flat.

The optimization procedure for fitting the scaled beta cdfs was constrained to pass through the 0.1 quantile, so that zero homesteads could be realized for some of the simulations. This was consistent with the SME input, and recognizes that even if the population of Las Vegas exceeds three million people, that did not guarantee that commuter homesteading would occur in Frenchman Flat or Yucca Flat. Consequently, when a random number less than 0.1 was drawn, zero homesteads were simulated.

The fitted scaled beta cdfs are displayed in Figure E-23 and E-24 for Frenchman Flat and Yucca Flat, respectively. For Frenchman Flat the following scaled beta distribution parameters were estimated: a = -5.9.; b = 110 years; v = 1.1; and, w = 2.1. The value of a is not used directly, but does affect the fit of the distribution. This distribution is unimodal with a mean of approximately 34 years and a variance of approximately 760. However, the simulated mean and variance are slightly different because of the effect of assigning zero homesteads when a random number of less than 0.1 is drawn.

For Yucca Flat the following scaled beta distribution parameters were estimated: a = 0.23 years; b = 105 years; v = 0.5; and, w = 1.3. Again, the value of a is not used directly, but does affect the fit of the distribution. This distribution is unimodal with a mean of approximately 29 years and a variance of approximately 780. For both Frenchman Flat and Yucca Flat, the simulated mean and variance are slightly different than these estimates because of the effect of drawing zero homesteads. The simulated mean and variance are, again, slightly different because of the effect of assigning zero homesteads when a random number of less than 0.1 is drawn.

Table E-15

SME Input on Number of Homesteads in Frenchman Flat

Number of homesteads	Cumulative probability
0	0.1
30	0.5
75	0.9

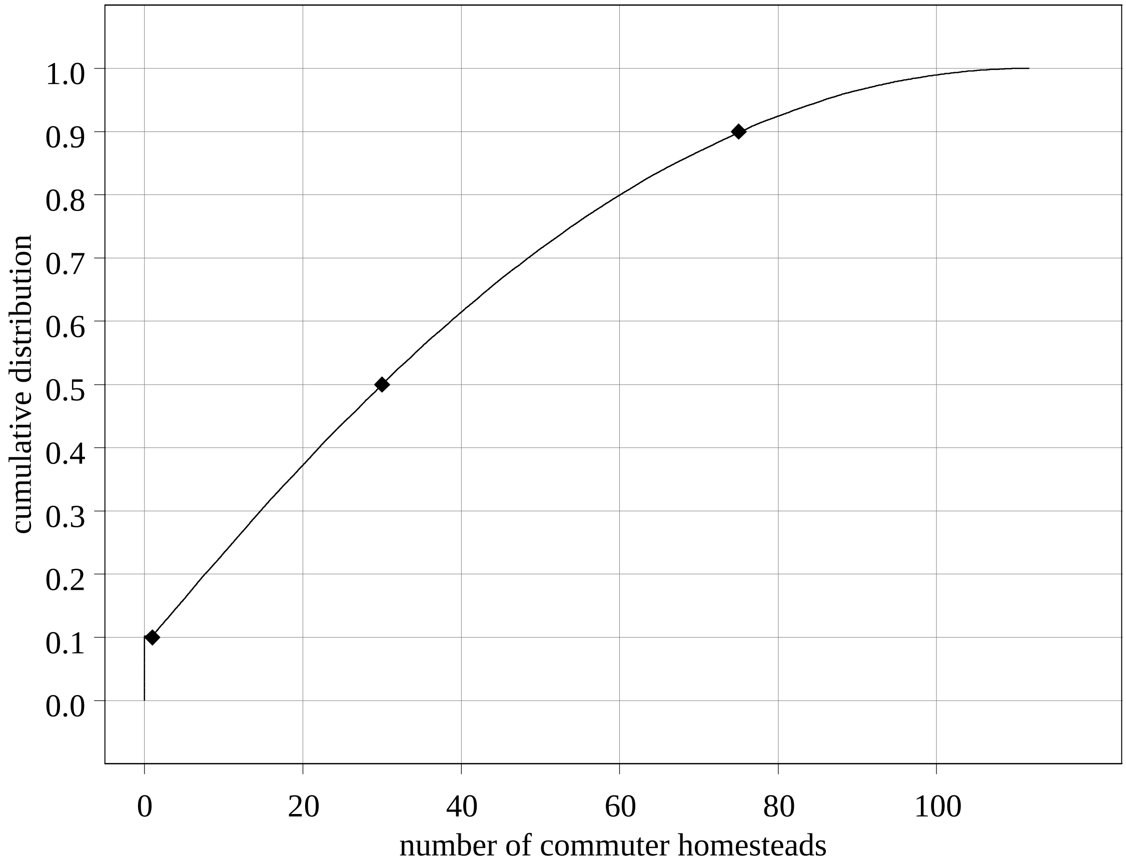


Figure E-23 Fitted cumulative distribution function for number of homesteads in Frenchman Flat for the Las Vegas Expansion scenario.

Table E-16

SME Input on Number of Homesteads in Yucca Flat

Number of homesteads	Cumulative probability
0	0.1
20	0.5
75	0.9

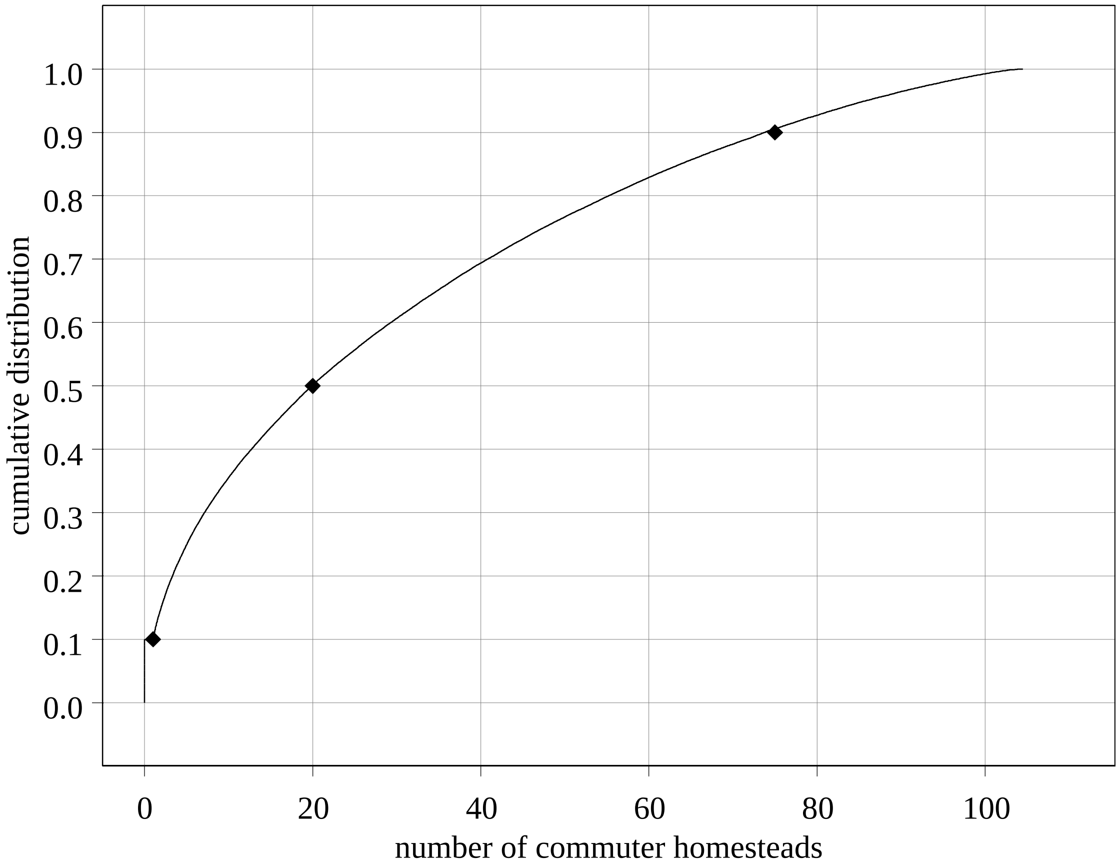


Figure E-24 Cumulative distribution function for number of homesteads in Yucca Flat for the Las Vegas Expansion scenario.

E.4.3.1.6 Distance Between Replacement Wells

The SMEs decided that the distribution of the distance between replacement wells is the same for this scenario as it is for the Homesteader and Jackass Flats scenarios. Table E-4 (Homesteader scenario) provides a summary of the points used to generate a cdf for this factor. Section E.3.1.4 provides the estimated parameter values for the fitted beta distribution, and Figure E-4 displays the corresponding cdf.

E.4.3.2 Simulation and Calculations for Las Vegas Expansion

The algorithms for this scenario take a similar approach to those for the previously described scenarios. Again, the probability of IHI is based on the number of wells drilled in Frenchman Flat and Yucca Flat during the 10,000 year time frame. The one important difference for this scenario concerns application of the probability that the population of Las Vegas will reach three million people, and, hence, place population pressure in the form of commuter homesteading on Frenchman Flat and Yucca Flat. This probability was used as a modifying factor for this scenario, and was applied by multiplying the (initial) probability of IHI that is conditional on sufficient population expansion.

Simulation began by selecting, from the above fitted distributions, Las Vegas lifetimes and the number of homesteads in Frenchman Flat and Yucca Flat. For each distribution, this process was repeated 10,000 times. For each draw on Las Vegas lifetime, the outcome was multiplied by the proportion of time, ¼, that Las Vegas might effect homesteading on Frenchman Flat and Yucca Flat, yielding simulated modified Las Vegas lifetimes. The number of homesteads provided the number of initial, or primary, wells for this scenario. Replacement wells were assigned to each primary well by repeatedly drawing at random from the well lifetime distribution, until the sum of the randomly drawn well lifetimes met or exceeded the modified Las Vegas lifetime.

For Frenchman Flat the simulation proceeded in much the same way as it did for the Homesteader scenario. For a given simulation, the primary wells were placed at random throughout Frenchman Flat, random angles and replacement well distances were drawn to site the replacement wells, and the process was, effectively, repeated 1,000,000 times[9]. Each simulation resulted in an estimated probability of IHI in Frenchman Flat conditional on the population of Las Vegas reaching three million people. The 10,000 simulations provided a distribution for this probability. Each simulated result was then multiplied by a random draw from the probability distribution that reflected the chance that the scenario would occur (i.e., that the population of Las Vegas reaches three million people). This provided the final distribution of the probability of IHI for this scenario[10].

The algorithm for Yucca Flat was again modified to reflect the preferential difference between the cratered and non-cratered sub-areas. The same basic algorithm was applied initially to the entirety of Yucca Flat, without considering the effect of the cratered area. This included the first modification, drawn at random for each simulation, for the probability that Las Vegas reaches a population of three million people. Finally, for each simulation, the initial probability of IHI generated was modified using the 0.13 factor described in Section E.4.1.2.

The complete simulations resulted in 10,000 estimates of the scenario probabilities that generated simulated distributions. Summary statistics for the distributions of the total number of wells and the probability of IHI for this scenario in Frenchman Flat and Yucca Flat are provided in Tables E-17 and E-18. Figures E-25 through E-28 provide graphical representations of the final simulated distributions. The average scenario probability of IHI for Frenchman Flat was calculated as approximately 0.0003, whereas for Yucca Flat the scenario probability of IHI is approximately one order of magnitude less. These probabilities are, again, very small compared to those generated from the Jackass Flats scenario.

[9] See footnote 2.
[10] This is the probability of IHI for this scenario because IHI can only occur for this scenario if the population of Las Vegas reaches three million people

Table E-17 Summary statistics for the propagated probability distribution of the total number of wells and the probability of inadvertent human intrusion for the Las Vegas Expansion scenario: Frenchman Flat

FRENCHMAN FLAT			
	Total Number of Wells		
Summary Statistic	**Primary**	**Replacement**	**Probability of IHI**
Minimum	0	0	0
5%	0	0	0
25%	11	62	0.000068
Median	30	180	0.00019
Mean	**34**	**240**	**0.00029**
75%	54	350	0.00039
95%	85	680	0.00094
Maximum	110	1400	0.0022

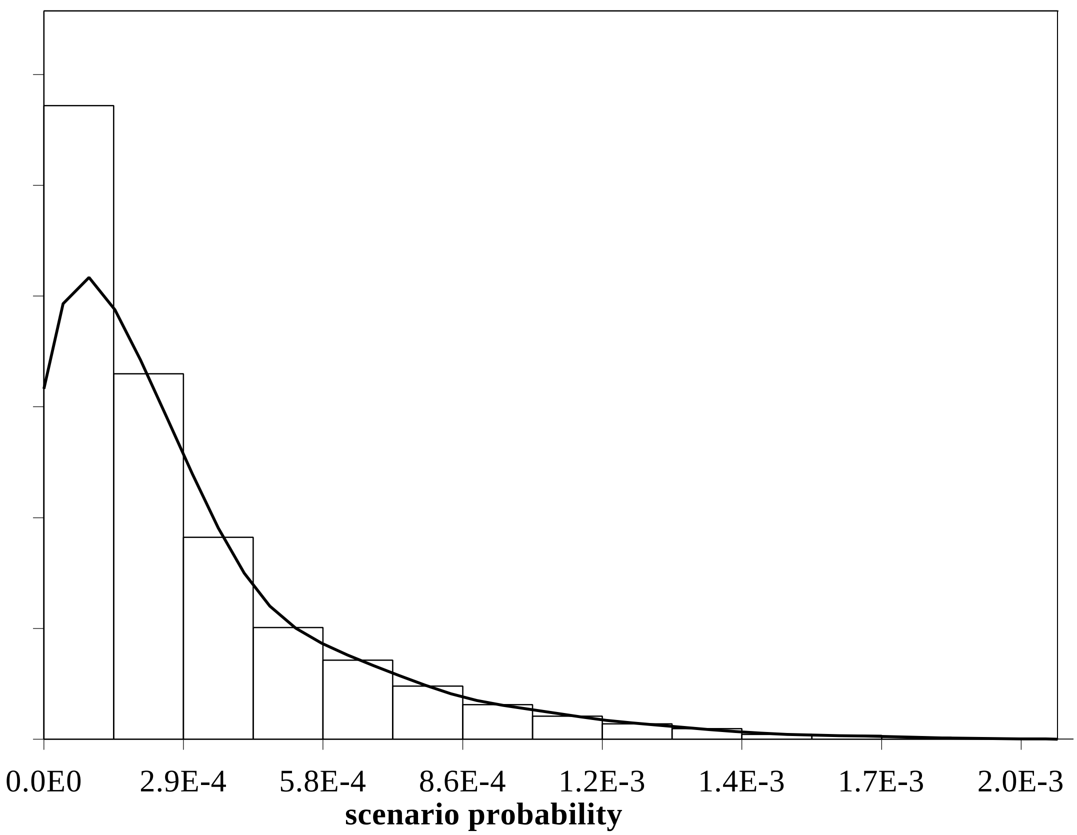


Figure E-25 Estimated distribution of the probability of inadvertent human intrusion overlaid on the simulated relative frequency distribution for the Las Vegas Expansion scenario: Frenchman Flat

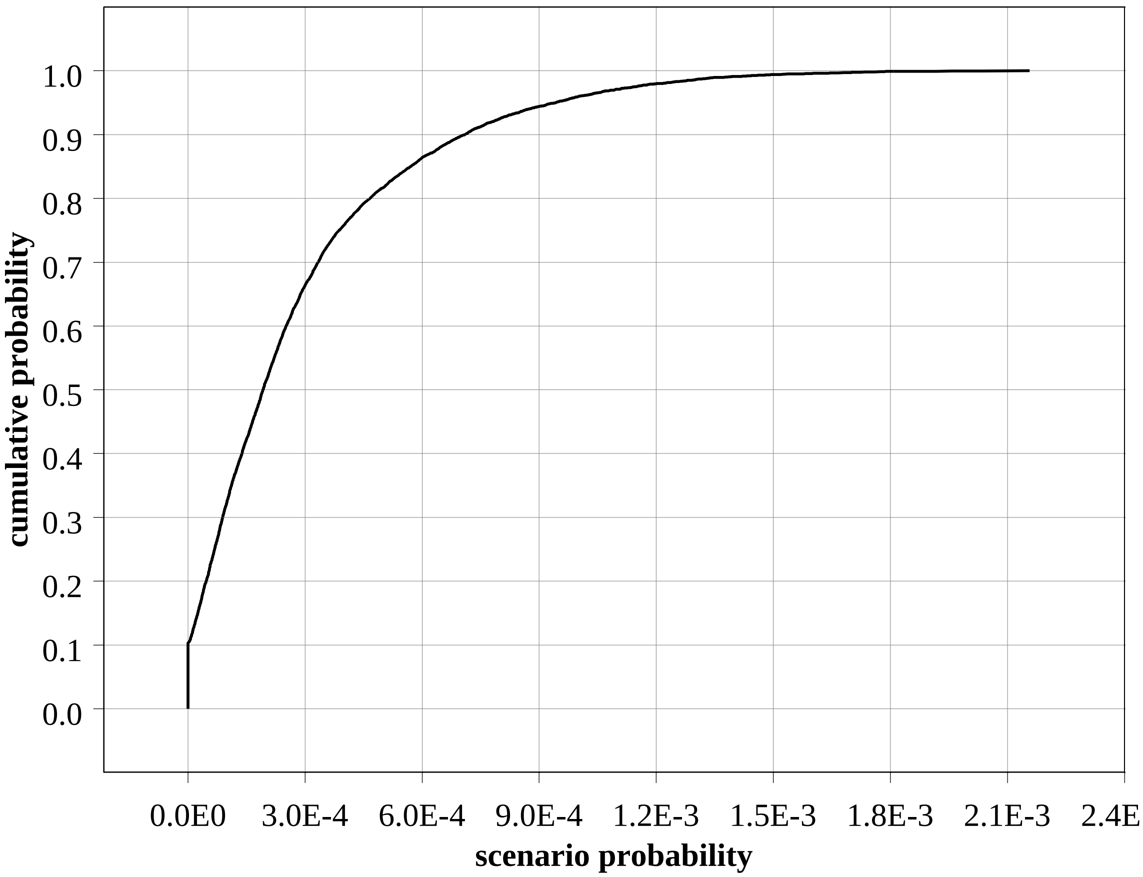


Figure E-26 Estimated cumulative distribution function for the probability of inadvertent human intrusion for the Las Vegas Expansion scenario: Frenchman Flat

Table E-18 Summary statistics for the propagated probability distributions of the total number of wells and the probability of inadvertent human intrusion for the Las Vegas Expansion scenario: Yucca Flat

YUCCA FLAT			
	Total Number of Wells		
Summary Statistic	Primary	Replacement	Probability of IHI
Minimum	0	0	0
5%	0	0	0
25%	5	32	0.0000042
Median	21	120	0.000016
Average	**29**	**200**	**0.000029**
75%	48	300	0.000039
95%	87	680	0.00011
Maximum	100	1400	0.00024

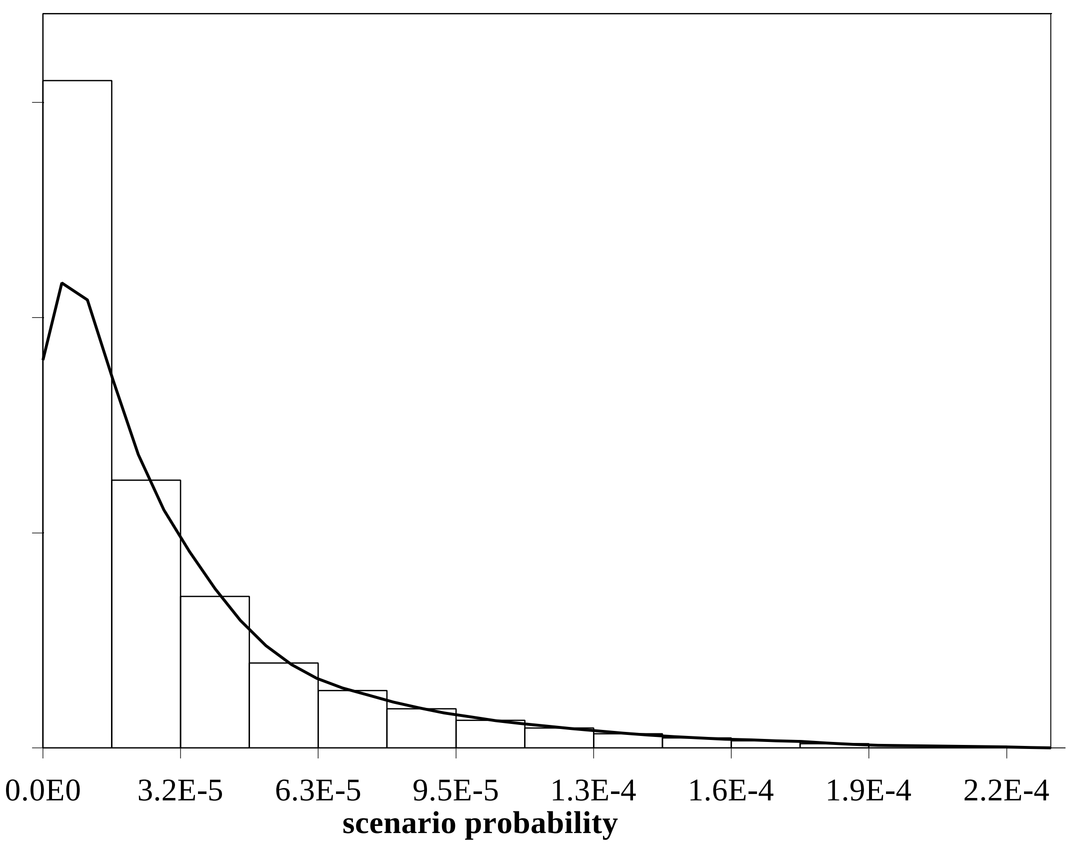


Figure E-27 Estimated distribution of the probability of inadvertent human intrusion overlaid on the simulated relative frequency distribution for the Las Vegas Expansion scenario: Yucca Flat

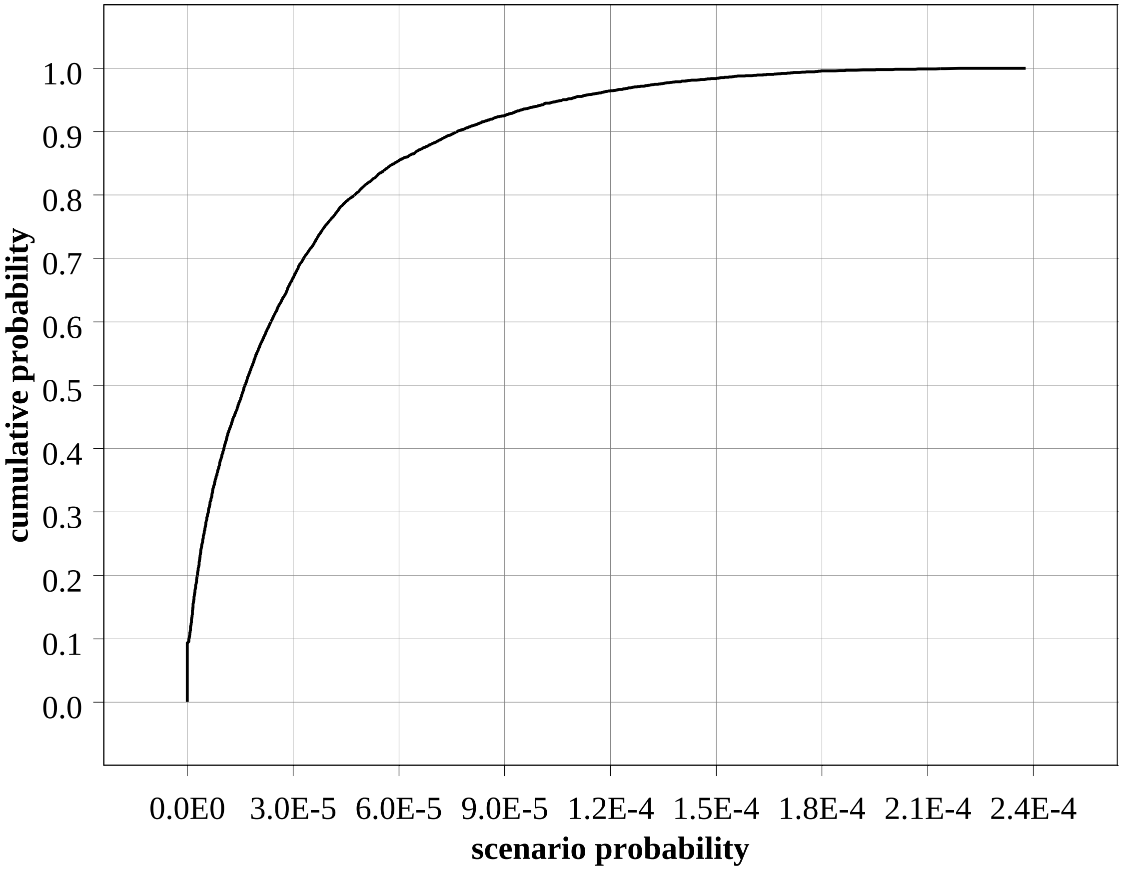


Figure E-28 Estimated cumulative distribution function for the probability of inadvertent human intrusion for the Las Vegas Expansion scenario: Yucca Flat

E.4.4 Overall Probability of Inadvertent Human Intrusion

In the previous sections the probability of IHI was calculated for each of the four scenarios. To obtain an overall probability of IHI, these results need to be combined.

Given the time frames for which the SMEs expected each scenario and institutional control or site knowledge to be in effect (see Section E.5), it is possible that the scenarios would not overlap in time (i.e., the central values for the distributions are approximately 250 years for institutional control, 100 years for site knowledge, 200 years for the Homesteader scenario, 100 years for the Base Community scenario, 5,000 years for the Jackass Flats scenario, and 250 years for the Las Vegas Expansion scenario). However, it may be reasonable for some of these scenarios to overlap in time (e.g., communities could exist in both Frenchman and Jackass Flats at the same time). Hence, it is conservative to merge the four scenarios by simple addition.

Under different circumstances the method of combination should consider the potential for the scenarios to exist at the same time, or, more generally, on the effect that they might have on one another. However, merging of the scenarios is dominated by the Jackass Flats scenario. Because one scenario strongly dominates the others, the actual method for merging scenarios does not greatly impact the final probability distribution. It is reasonable, therefore, to suggest that the probability of IHI, as assessed through input from these SMEs, is approximately 0.11 for Frenchman Flat and 0.0065 for Yucca Flat assuming all management controls are ineffective, and that the range of these probabilities or the characteristics of the uncertainty are expressed in Table E-12 (Frenchman Flat) and Table E-13 (Yucca Flat), and Figures E-15 through E-18. However, the lower tail of the overall distribution is affected by the other scenarios.

Table E-19 shows summary statistics of the overall probability formed by resampling from each of the four scenario probability distributions, and summing each resampled qudruplet. This method most appropriately adds the underlying random variables together to form the sum of effects from each of the scenarios. The Homesteader scenario results are included in the overall probability distributions for both Frenchman Flat and Yucca Flat. Figures E-29 through E-32 show the simulated probability density functions and the simulated cdfs. The results show how close the combined results are to those for the Jackass Flats scenario.

Again, the results are conditional on the assumptions and conditions established in this assessment, including the two-acre waste footprint. The range of values is also conditional on the assumptions and constraints of the data collection process and the numerical methods used. The probability distribution is also conditional on ineffective “management controls” factors. The next section describes some of the information elicited from the SMEs regarding the management controls factors, all of which can be used to reduce the probability of IHI.

Table E-19 Summary statistics for the propagated overall probability of inadvertent human intrusion

Summary Statistic	Frenchman Flat	Yucca Flat
Minimum	0.032	0.0013
5%	0.059	0.0037
25%	0.084	0.0052
Median	0.11	0.0068
Average	**0.11**	**0.0069**
75%	0.14	0.0084
95%	0.16	0.010
Maximum	0.21	0.014

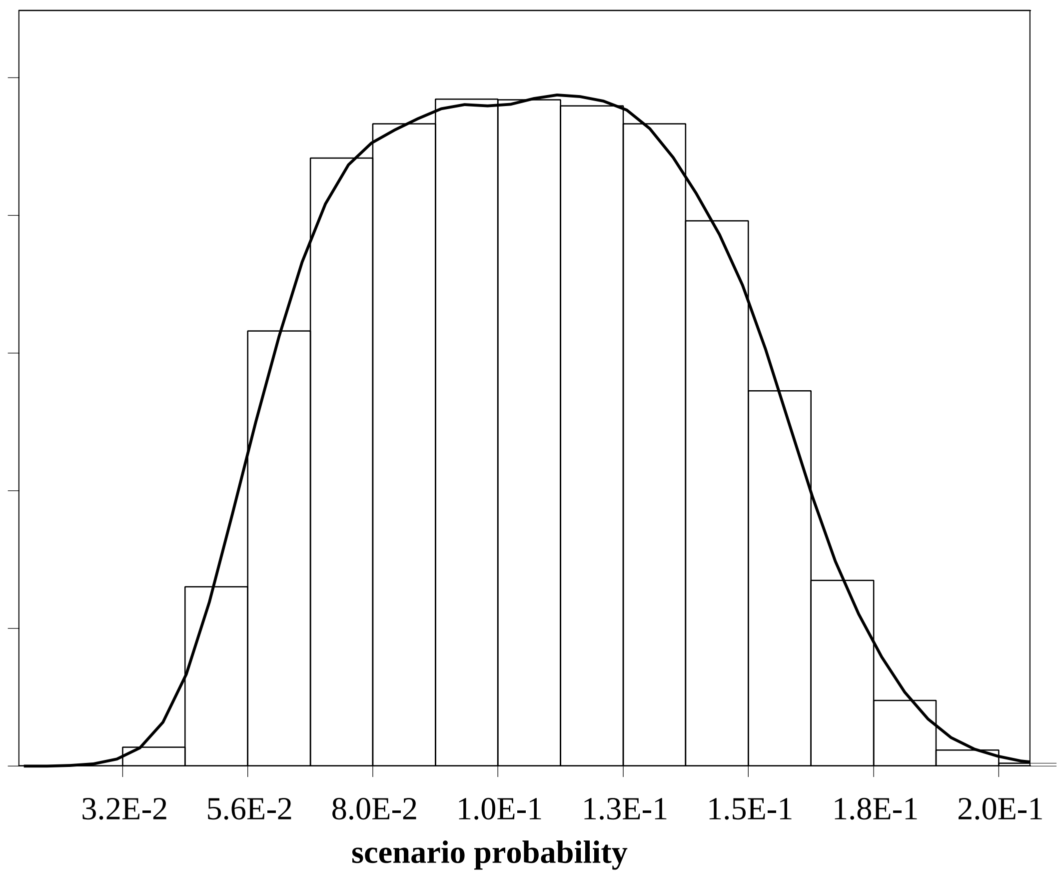


Figure E-29 Estimated distribution of the overall probability of inadvertent human intrusion overlaid on the simulated relative frequency distribution: Frenchman Flat

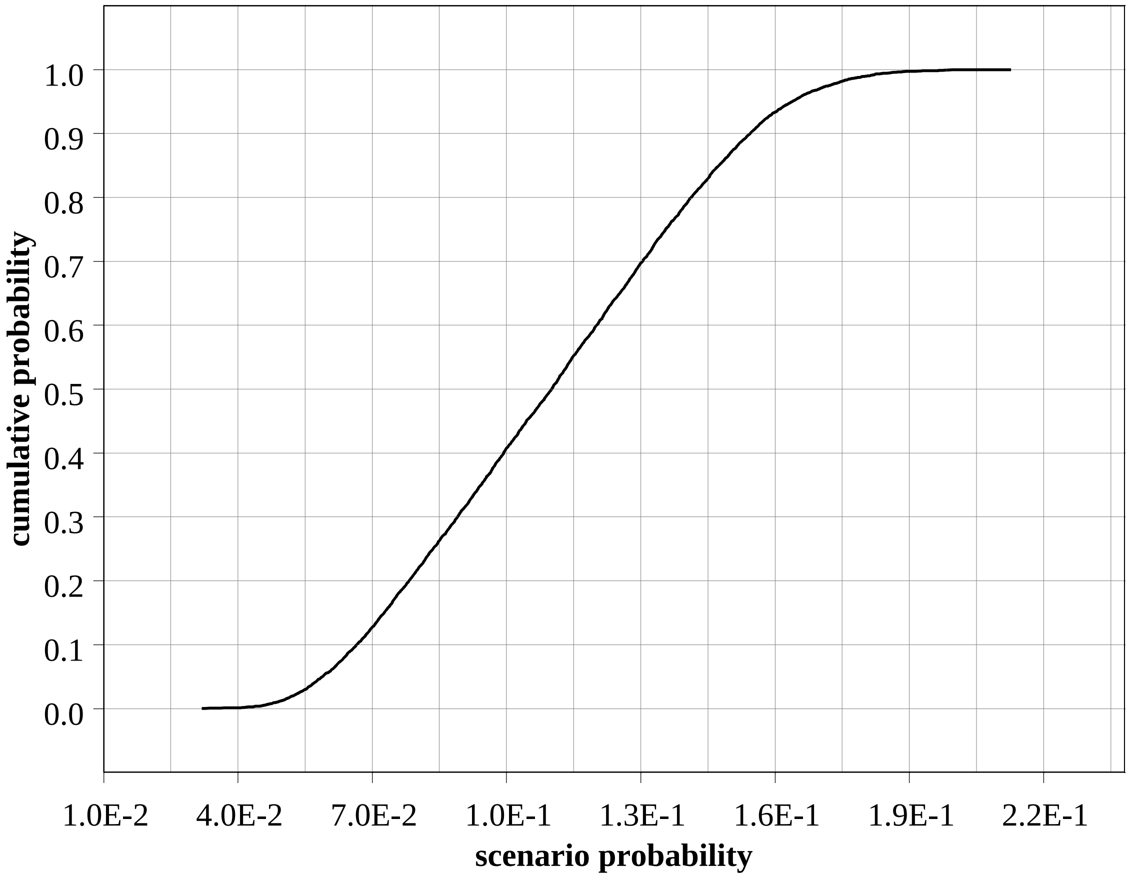


Figure E-30 Estimated cumulative distribution function for the overall probability of inadvertent human intrusion: Frenchman Flat

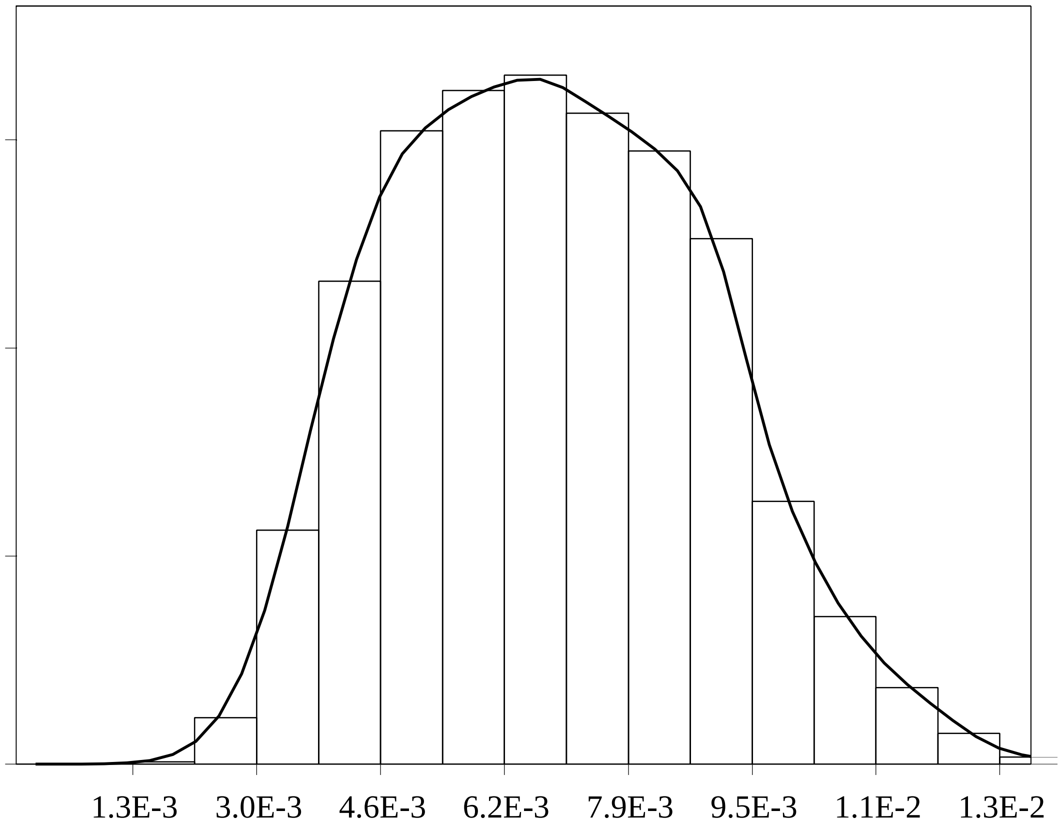


Figure E-31 Estimated distribution of the overall probability of inadvertent human intrusion overlaid on the simulated relative frequency distribution: Yucca Flat

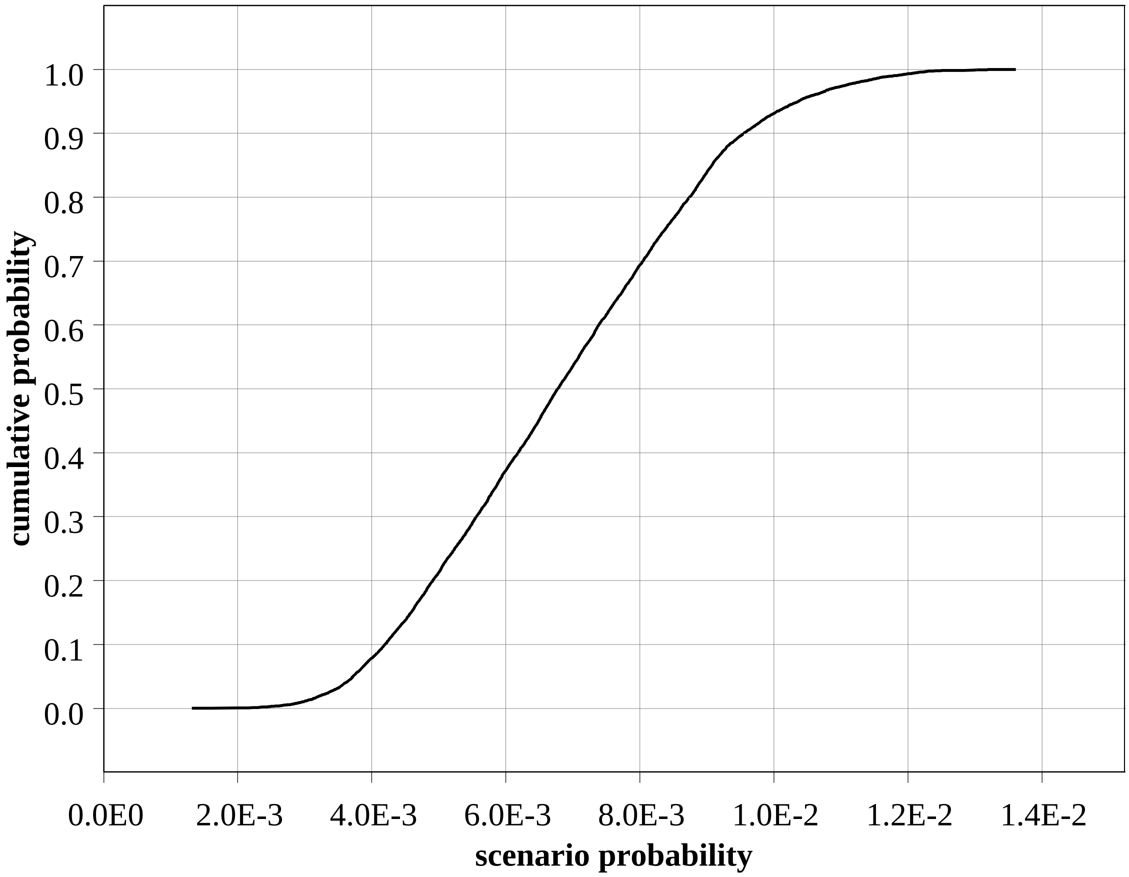


Figure E-32 Estimated cumulative distribution function for the overall probability of inadvertent human intrusion: Yucca Flat

E.5 MANAGEMENT CONTROLS MODULE

The management controls module includes the following factors:

- time frame for which institutional control might be maintained
- time frame beyond institutional control that site knowledge might be maintained
- effectiveness of surface barriers
- effectiveness of placards and markers
- effectiveness of subsurface barriers

The last three factors were measured as a probability that represented the degree of effectiveness, which corresponds to the proportion of potential well drilling events that are prevented. Efficacy of management controls is calculated as the combined effectiveness of each managerial deterrent to prevent IHI into deeply buried radioactive waste in Frenchman Flat or Yucca Flat. For example, while institutional control or site knowledge are maintained, IHI via well drilling is assumed to be not possible. Subsequent to loss of site knowledge, the more effective a surface barrier, placard or marker, or subsurface barrier, the less likely IHI is to occur. Inputs to the module indicate effectiveness, although ultimately, the ineffectiveness (the probability of failure) of management controls is used to modify scenario probabilities. Ineffectiveness was measured as the direct complement to effectiveness (e.g., the probability that a surface barrier is ineffective is one minus the probability that it is effective).

The degree of effectiveness for a single event was not considered (e.g., the potential for a surface barrier to partially deter intrusion was not considered; the surface barrier either prevents or does not prevent a particular attempt at IHI). This was measured through the elicitation process, in part, by asking SMEs questions concerning how many individuals from a large group of potential intruders, would be deterred by a given physical management control.

The evaluation period is also required for calculating the overall efficacy of management controls. Consequently, the overall efficacy is calculated based on six factors. Each of the above inputs provides a component of the probabilistic calculation. Not all of the inputs are similar in terms of the units used for their specification; however, they all relate to the probability that IHI can occur. To produce an overall probabilistic measure of efficacy, each factor must be converted into a probabilistic statement in order to perform calculations.

If any of the management controls factors are completely effective for the duration of the compliance period, then their probability of effectiveness is set to 1. For example, if institutional control lasts for 10,000 years, then the probability of IHI is zero because management controls are completely effective. Similarly, if a surface barrier is determined to be completely effective as a deterrent to drilling for 10,000 years, IHI cannot occur. To the extent that institutional control is not expected to last for 10,000 years, or that a physical barrier does not deter all drilling events, then IHI has some chance of occurring. The following sections provide a description of the calculation process for determining the efficacy of management controls.

E.5.1 Fitting the Cumulative Distribution Functions

Institutional control and site knowledge factors were fit with lognormal distributions during the elicitation. The remaining management controls factors were not subjected to curve fitting because cdfs could not be generated from the SME input. The SMEs determined that these factors were not sufficiently well defined to be able to provide distributional input, although they provided suggestions for designs for placards and markers, surface barriers, and subsurface barriers, for which they provided single-value probabilistic estimates. The following sections provide details of calculations that were performed.

E.5.1.1 Institutional Control

Institutional control measures the length of time the Radioactive Waste Management Sites (RWMSs) in Frenchman Flat and Yucca Flat will be managed by a governing institution in such a way that IHI via water-well drilling is prevented.

It should be noted that the SMEs determined that the length of time for institutional control was not a function of the type of scenario by which IHI could occur. That is, the SMEs determined that this factor did not need to be measured conditionally on any of the scenarios developed. This is consistent with the notion that the intrusion scenarios cannot be active until management controls are ineffective.

The SMEs were asked to provide input on how long institutional control could be maintained. Table E-20 provides a summary of their input.

Table E-20

SME Input for the Institutional Control Factor

Number of years of Institutional Control	Quantile
50	0.1
250	0.50
1,000	0.9

A cdf for institutional control was estimated during the elicitation session and was provided graphically to the SMEs. The SMEs were then asked to verify the reasonableness of some further quantiles based on this cdf. The SMEs concurred, and the cdf was established as representative of their expert opinion relating to this factor. In this case, the quantiles listed in Table E-17 were approximated well by a lognormal distribution with a median of 250 years, a mean of approximately 400 years, and a standard deviation of approximately 500 years. This translates to a final estimated lognormal distribution for this factor with estimated parameters *m* of approximately 5.5, and *s* of approximately 0.98. Figure E-33 provides a graphic representation of the resultant cdf for this factor. (Note that the lognormal standard deviation is calculated as the square root of the lognormal variance, which is not independent of the mean, and should not be used to directly assess interval estimates.)

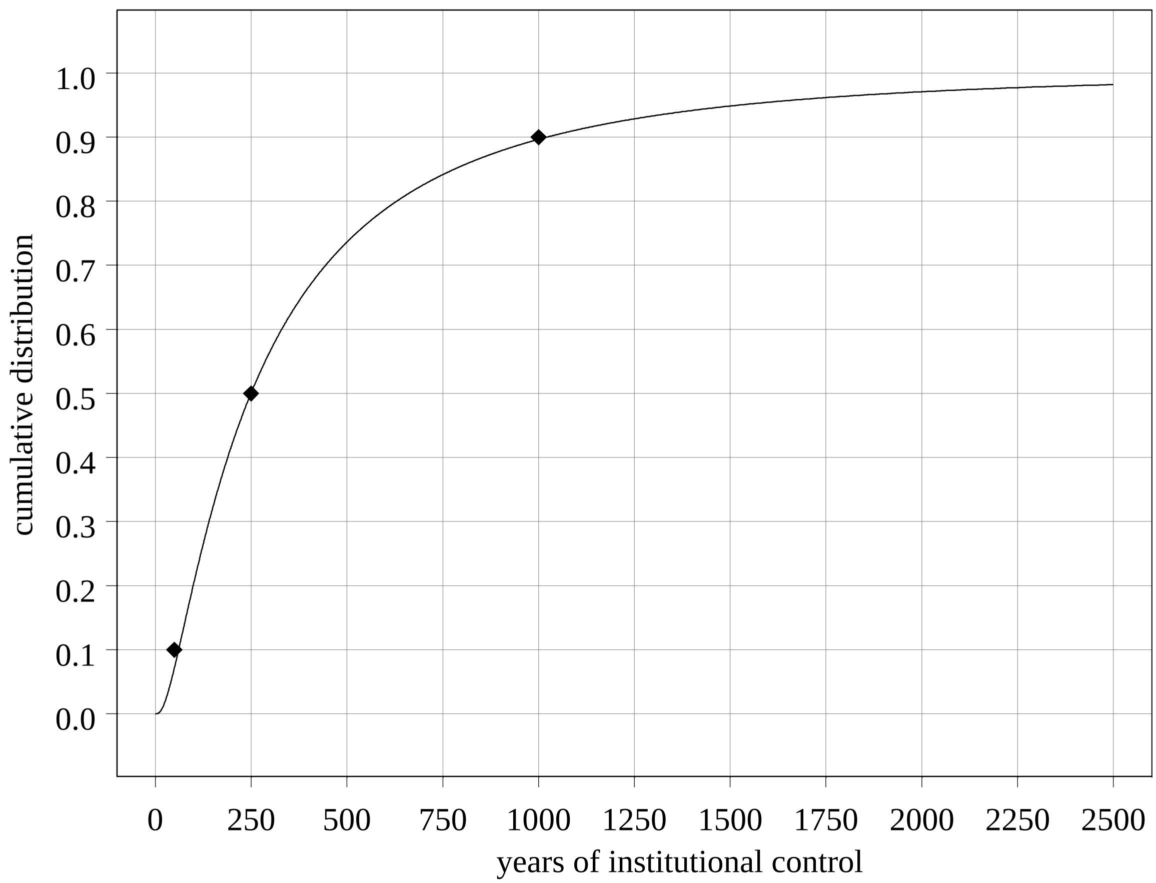


Figure E-33 Fitted cumulative distribution function for institutional control factor.

E.5.1.2 Site Knowledge

Site knowledge was evaluated in terms of the length of time beyond the period of institutional control that knowledge of the site will remain sufficient to prevent IHI at the waste sites. The elicitation followed a similar course to that for institutional control. Table E-18 provides a summary of the inputs obtained from the SMEs in terms of the quantile. Using the same methods as described above for institutional control, the distribution for site knowledge was assessed as lognormal with parameters m of 4.6, and s of 0.84. This distribution has a median of 100 years, a mean of approximately 140 years, and a standard deviation of approximately 140 years. Figure E-34 provides a graphic representation of the resultant cdf for this factor.

Table E-18

SME Input for the Site Knowledge Factor

Number of years of Site Knowledge	Quantile
50	0.25
100	0.50
140	0.75
500	0.95

E.5.1.3 Surface Barriers

The efficacy of surface barriers was measured by asking for the probability that a particular surface barrier would deter drilling. Obtaining input for this factor was complicated by incomplete designs for surface barriers. A few SME observations were pervasive, however. The SMEs indicated that surface barriers currently contemplated by DOE would not deter a drilling event. Also, the SMEs were very confident that a surface barrier could be constructed to last for 10,000 years. Consequently, the focus of the discussion and input became describing appropriate surface barriers and assessing their degree of efficacy in the sense given.

The SMEs broadly described three configurations for surface barriers for which they provided varying degrees of efficacy. The designs are listed in Table E-19, and are portrayed in Appendix D. The first row in Table E-19 corresponds to the design currently contemplated by DOE (it should be noted that the DOE design was not particularly intended to deter intrusion by well drilling but was designed for other purposes including reducing the potential for infiltration of ground water into the buried waste). The remaining rows correspond to the three designs described by the SMEs. All SME designs included the use of 10-ton boulders to limit the potential for siting a drill rig.

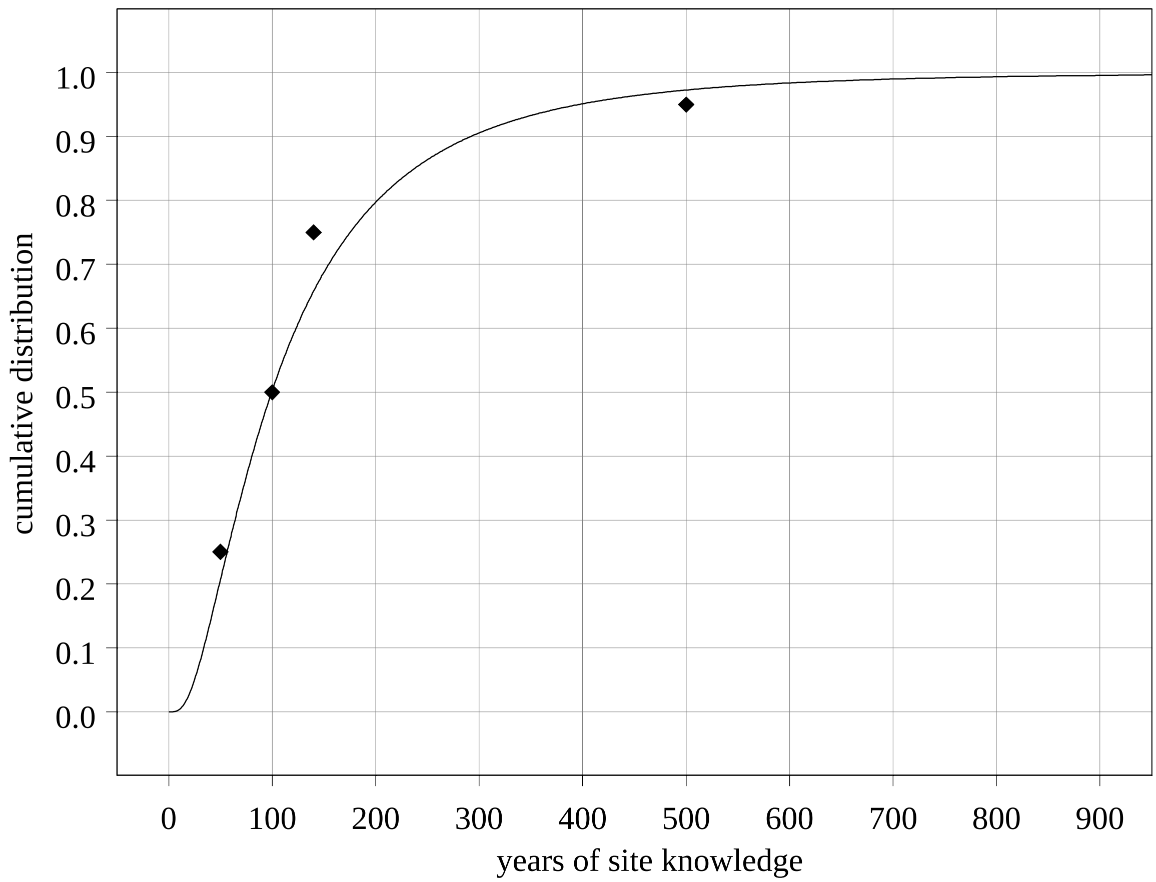


Figure E-34 Fitted cumulative distribution function for site knowledge factor.

Table E-19

SME Input for the Surface Barriers Factor

Description of barrier	Probability of Deterring Well Drilling
Currently contemplated DOE designed surface barrier (part of a more complete surface and subsurface engineered barrier).	0
Large boulders placed 10 ft apart over the entirety of the waste site.	0.1
A 10-ft-high ring of boulders with a 2:1 immediate slope.	0.5
A 35-ft rock mound with a 2:1 immediate slope (up to 10 feet in height).	0.9 – 0.95

Although four surface barrier designs were considered by the SMEs, the final results must be conditioned on a given design. Most of the focus of this appendix is to demonstrate how the SME inputs are used to generate final distributions. For this reason, later calculations may focus on specific factors, such as the design indicated in the fourth row of Table E-19, rather than all possibilities. The sensitivity analyses presented in Appendix F provide further details of the effects of different designs for surface barriers, and, more generally, of different management control factors.

The SMEs clearly specified that the surface barriers they described (rows two, three, and four of Table E-19), would endure for 10,000 years. Their concern was, therefore, focused only on the potential deterrent effect of the barriers. For example, the SMEs indicated that their most favored design would deter drilling 95% of the time. That is, if, over the course of 10,000 years, 100 drilling events were considered with the described barrier in place, only 5 would actually occur.

Only single probabilities were elicited for these different conditions, primarily because the SMEs were working with fairly crude descriptions of surface barrier designs. If these designs are to be considered for the Nevada Test Site (NTS) RWMSs, or other waste sites at any time in the future, then more thorough assessments can be made for better specified designs. The SMEs indicated a reluctance to pursue the designs indicated in Table E-19 any further without greater definition. As a consequence of this, the final results are conditioned both upon the specific surface barrier and upon its single valuation. That is, no uncertainty or variability is built into this final result based on the SME input. As shown below, the same is true for the placards and markers factor and the subsurface barriers factor.

E.5.1.4 Placards and Markers

Similar to surface barriers, the efficacies of various placards and markers were provided as fixed probabilities with no associated distribution or margin of uncertainty or variability. Again, the main reason for this was that there were not any formal designs for the placards and markers. Two placards and markers options were considered (see Appendix D). Both were assumed to be carved onto a large rock, or monolith, that would not be subject to physical deterioration, theft, or any other form of destruction. Through this design, the SMEs felt that the placard and marker would endure for 10,000 years.

The remaining question was whether the message would be effective for deterring intrusion. The SMEs indicated that, because of its complexity, the sign currently under consideration for use by DOE would have minimal impact as a deterrent to IHI. The SMEs stated their belief that a complex sign probably would not be understood by many people at the present time, and that a simple sign has by far the greatest chance of deterring well drilling or any other form of inadvertent human intrusion. Consequently, the SMEs designed a simple “life and death” symbol that they considered potentially effective. The design is depicted in Appendix D.

Two SMEs, who were considered key participants for this factor, disagreed on the potential efficacy of the SME-designed placard and marker. One indicated that this marker would be relatively effective now (around a 75% deterrent effect), but that the effectiveness is likely to be reduced over time (to approximately 10% by the end of the compliance period) because of changes in language and symbology. The other SME suggested that the probability of this sign deterring IHI would remain fairly constant over time, with a probability of approximately 20%, but perhaps as high as 50% (see Table E-23). The sensitivity analyses presented in Appendix F investigate the impacts of differing estimates of efficacy placards and markers on the overall probability of IHI. The SMEs also suggested that this issue of design and efficacy of placards and markers should be revisited when DOE has defined several options.

Table E-23

SME Input for the Placards and Markers Factors

Description of Placard and Marker	Probability of Deterring Well Drilling
Currently contemplated placard and marker	0.05 to 0.1 now reducing to 0 within 500 years
Simple caricature of person dying: Opinion 1	0.55–0.85 (median of 0.75) now reducing to 0.35– 0.4 at 1,000 years reducing to 0.07- 0.25 at 10,000 years
Simple caricature of person dying: Opinion 2	0.2 but possibly as high as 0.5

E.5.1.5 Subsurface Barriers

Subsurface barriers were also viewed as distinct types with fixed probabilities of effectiveness. Several types of subsurface barriers were contemplated. The SMEs indicated that the current DOE configuration for a combined surface and subsurface barrier would not deter water-well drilling at all. Suggestions of subsurface barriers that might prove effective to some extent were then offered as indicated in Table E-5. However, the SMEs indicated that subsurface barriers cannot readily be designed to effectively deter intrusion by water-well drilling. The issue of endurance of these subsurface barriers was not broached quantitatively; however, the SMEs doubted that any of the barriers listed in Table E-24 could endure for 10,000 years, in which case the valuations for their efficacy can be considered current.

Table E-24

SME Input for the Subsurface Barriers Factor

Description of Subsurface Barrier	Probability of Deterring Well Drilling
Currently contemplated DOE designed subsurface barrier (part of a more complete surface and subsurface engineered barrier).	0
30 ft of used automobile tires placed 20–30 ft underground.	0.05 – 0.1
30 ft of fine wire mesh fence placed 20–30 ft underground.	0.1
5 ft of concrete reinforced with 1-in. re-bar on 6-in. centers, placed 20-30 ft underground.	0.5

E.5.2 Simulations and Calculations

The objective of the calculations and simulations performed for the management controls module is to provide a modifying probability for the scenario probabilities. The modifier is generated in the form of a distribution of the probability of effectiveness, conditioned on the model and the inputs to the model. For the management controls module it should be recognized that the only sources of variability included in these calculations come from the inputs to the institutional control and site knowledge factors. All other factors have fixed values for the competing designs. Consequently, the final probability distribution reflects variability in two factors only. In effect, the final probability distribution is conditioned upon a particular set of designs for the remaining three factors, and is conditional upon their valuations. Bounds on the probability obtained are narrower than would be obtained if such conditions were not imposed. Given the lack of information about overall uncertainty or variability across all the management controls factors, the measures of central tendency, generated conditionally on each design option, are probably the only measures that should be considered meaningful.

The surface barriers factor includes four possible designs and valuations (probabilities of effectiveness of 0, 0.1, 0.5, and 0.9); three valuations were selected from the ranges provided for the placards and markers factor (probabilities of effectiveness equaled 0.05, 0.2, and 0.5); and subsurface barriers includes four, two of which have the same valuation (distinct probabilities of effectiveness equaled 0, 0.1, and 0.5). Consequently, there are 36 distinct management controls combinations considered for exploratory purposes. Simulated probability distributions have been generated for these 36 options (only institutional control and site knowledge factors were simulated). Appendix F provides a sensitivity analysis that allows for other valuations of the three physical controls.

Simulation started with random draws from the distributions for institutional control and site knowledge. For each of the 10,000 simulations the length of time of institutional control and the additional length of time of site knowledge were summed. Each summed value was interpreted as the total number of years of the compliance period during which institutional control and site knowledge combined would effectively deter a well driller. Conversion of the summed values into a probability was performed by first realizing that IHI cannot occur while institutional control or site knowledge are maintained. The number of years of institutional control and site knowledge, therefore, act as discounting factors. That is, the compliance period of 10,000 years is discounted by the number of years of institutional control and site knowledge. Consequently, dividing the summed values by 10,000 (years) yields a dimensionless product corresponding to the proportion of the compliance period for which these management controls might be effective. This proportion can be thought of as a direct measure of their combined probabilistic efficacy.

Having established a combined distribution for the first two management controls factors, the next step incorporated the remaining three factors. The remaining three factors can be regarded as independent of one another (conditional on loss of site knowledge), although the actual form of conditioning within the management controls model is irrelevant, given the input received. If independence is not assumed, then the independence interpretations must be changed, but the calculations are not affected if the SME input is used. It should also be noted that the SMEs indicated that they were comfortable with treating these factors as conditionally independent, mainly because they realized that these factors were poorly defined and did not warrant further refinement at this time. Also, if correlations were included, the probability of effectiveness of management controls would be reduced.

After institutional control or site knowledge is lost, only the remaining physical factors can deter intrusion. With the conditional independence assumptions used, the calculations can be performed simply by direct multiplication. The underlying model contains four elements (because institutional control and site knowledge are combined), each of which take two possible values: either they effectively deter drilling at the site, or they do not effectively deter drilling:

$A = 0$: Ineffective control/knowledge	$A = 1$: Effective control/knowledge
$B = 0$: Ineffective surface barriers	$B = 1$: Effective surface barriers
$C = 0$: Ineffective placards & markers	$C = 1$: Effective placards & markers
$D = 0$: Ineffective subsurface barriers	$D = 1$: Effective subsurface barriers

The joint probability of interest occurs only when all management controls are ineffective. That is, it only takes one of the factors to effectively deter drilling for management controls collectively to be effective. If institutional control and site knowledge are effective, then the other management control mechanisms are, by default, effective because no drillers would have the opportunity to attempt entry at the site. If institutional control and site knowledge are ineffective, then the joint probability of interest can be broken down into the probability statements (where *MC* represents overall management controls) presented in Equation E-5. These equations are based on an assumption that the efficacy of *B*, *C*, and *D* for deterring well drilling, when institutional control and site knowledge are ineffective, are independent of one another.

$$\Pr(MC = 0) = \Pr(A = 0, B = 0, C = 0, D = 0)$$

$$= \Pr(A = 0)\Pr(B = 0 | A = 0)\Pr(C = 0 | A = 0)\Pr(D = 0 | A = 0) \qquad \text{E-5}$$

The input received from the SMEs for the last three factors was in the form of the probability of their effectiveness. The only manipulation required to obtain the probabilities of their ineffectiveness was to subtract each from one. In summary, the overall calculations were performed by simulating number of effective years of institutional control and site knowledge, dividing by 10,000, subtracting from one, then multiplying this result by the probabilities of ineffectiveness for each physical factor, to then arrive at an overall probability that management controls are ineffective. These calculations were performed 10,000 times for each of the 36 combinations described earlier. A summary of the results is presented in Table E-25.

The interval bounds in Table E-25 (shaded columns) represent the 0.05 and 0.95 quantiles from the simulated distribution. As previously mentioned, the uncertainty or variability has been underestimated because the physical management controls factors are single valued. These results indicate that if DOE/NV wants to use this information as the basis for considering design options, then further effort should be undertaken.

Table E-25

Probability of Effectiveness for Various Conditions of the Management Controls Factors

Probability of Effectiveness (values based on inputs from the SMEs)			Overall Probability of Effectiveness of Management Controls		
Surface Barriers	Placards and Markers	Subsurface Barriers	0.05 quantile of results	Median Probability	0.95 quantile of results
0.00	0.05	0.00	0.061	0.088	0.209
0.10	0.05	0.00	0.155	0.179	0.288
0.50	0.05	0.00	0.530	0.544	0.605
0.90	0.05	0.00	0.906	0.909	0.921
0.00	0.20	0.00	0.209	0.232	0.334
0.10	0.20	0.00	0.288	0.309	0.401
0.50	0.20	0.00	0.605	0.616	0.667
0.90	0.20	0.00	0.921	0.923	0.933
0.00	0.50	0.00	0.506	0.520	0.584
0.10	0.50	0.00	0.555	0.568	0.625
0.50	0.50	0.00	0.753	0.760	0.792
0.90	0.50	0.00	0.951	0.952	0.958
0.00	0.05	0.10	0.155	0.179	0.288
0.10	0.05	0.10	0.239	0.261	0.360
0.50	0.05	0.10	0.577	0.590	0.644
0.90	0.05	0.10	0.915	0.918	0.929
0.00	0.20	0.10	0.288	0.309	0.401
0.10	0.20	0.10	0.359	0.378	0.461
0.50	0.20	0.10	0.644	0.654	0.700
0.90	0.20	0.10	0.929	0.931	0.940
0.00	0.50	0.10	0.555	0.568	0.625
0.10	0.50	0.10	0.600	0.611	0.663
0.50	0.50	0.10	0.778	0.784	0.813
0.90	0.50	0.10	0.956	0.957	0.963
0.00	0.05	0.50	0.530	0.544	0.605
0.10	0.05	0.50	0.577	0.590	0.644
0.50	0.05	0.50	0.765	0.772	0.802
0.90	0.05	0.50	0.953	0.954	0.960
0.00	0.20	0.50	0.605	0.616	0.667
0.10	0.20	0.50	0.644	0.654	0.700
0.50	0.20	0.50	0.802	0.808	0.834
0.90	0.20	0.50	0.960	0.962	0.967
0.00	0.50	0.50	0.753	0.760	0.792
0.10	0.50	0.50	0.778	0.784	0.813
0.50	0.50	0.50	0.876	0.880	0.896
0.90	0.50	0.50	0.975	0.976	0.979

E.6 PROBABILITY OF INADVERTENT HUMAN INTRUSION WITH MANAGEMENT CONTROLS

The previous discussions have provided two sets of results, one set for the management controls module, and one set for the scenarios. The results for the latter set are presented as simulated distributions of scenario probabilities, for which the condition of completely ineffective management controls is in effect. The purpose of this section is to show how the management controls modifying probabilities can be used to obtain simulated distributions of probabilities unconditional on management controls factors.

Equation E-5 summarized the basic arguments for combining management controls to arrive at an overall evaluation of the effectiveness of these factors. In effect, the scenario probabilities are conditional on each of the management controls being ineffective, so that when the condition is removed (by simple multiplication) the marginal result of interest is the same as the joint distribution result. This is because management controls all being ineffective is only one possibility out of many possibilities. The following equations summarize the probabilistic analysis (using the same notation as used in Equation E-5, Section E.5.2, and denoting a scenario probability with *SP*, a modified scenario probability with *MSP*, and *IHI* is used to represent IHI for a given scenario):

Equation E-6 provides a probabilistic statement for a scenario probability (*SP*):

$$SP = \Pr(IHI \mid MC = 0) = \Pr(IHI \mid A = 0, B = 0, C = 0, D = 0) \qquad \text{E-6}$$

Equation E-7 decomposes the modified scenario probability of IHI:

$$MSP = \Pr(IHI) = \Pr(IHI, MC = 0) + \Pr(IHI, MC \neq 0) = \Pr(IHI, MC = 0) \qquad \text{E-7}$$

The last step in Equation E-7 is true because IHI cannot happen if management controls are effective. Equation E-8 explains why the probability of IHI can be evaluated directly through multiplication of a scenario probability and the management controls modifying probability:

$$MSP = \Pr(IHI) = \Pr(IHI, MC = 0) = \Pr(IHI \mid MC = 0)PR(MC = 0) \qquad \text{E-8}$$

Consequently, the modified scenario probability is simply a product of the scenario probability and the management controls modifying probability. Because the management controls factors are poorly defined at this time, no more comprehensive calculations have been made. The main text provides indications of the effect of using combined management controls factors that are 93% effective. At this degree of effectiveness the scenario probabilities are simply multiplied by a management controls modifier of 0.07. Some sensitivity analyses are presented in Appendix F that show the effect of changes in management controls factors on the overall probability of IHI.

E.7 ADDITIONAL REFERENCES

Black, P.K., K.J. Black, M.M. Hooten, L.P. Mathai, T.S. Stockton, and M.D. Neptune. (2001). *Assessing the Probability of Inadvertent Human Intrusion at the Nevada Test Site Radioactive Waste Management Sites -–Volume I*, Prepared for the U.S. DOE Nevada Operations Office under Argonne National Laboratory Contract Number W-31-109-Eng-38. DOE/NV-593-Vol. I.

S-Plus 2000. (1999). Computer program, Data Analysis Products Division, MathSoft, Inc., Seattle, Washington.

E.8 ATTACHMENTS

E.1 GIS input for the areas of Frenchman Flat and Yucca Flat

E.9 RELATED ARCHIVED DOCUMENTS

- Computer code
- Simulated data sets

APPENDIX F: SENSITIVITY ANALYSES

CONTENTS

F.1 INTRODUCTION

The SME inputs obtained through the elicitation sessions were merged with the probabilistic model/influence diagram to provide a working mathematical/statistical model for the probability of inadvertent human intrusion (IHI). These inputs were propagated through the model to arrive at an assessment of the probability of IHI for each of the site-specific scenarios considered for waste disposal at NTS Areas 3 and 5, as described in the main text and in Appendix E. The purpose of this appendix is to describe some sensitivity analyses that were conducted to determine the impact of various factors, included in the influence diagram model, on outcome probabilities for the intrusion scenarios.

Three factors were evaluated for their direct effect on the probabilistic outcomes. These were the management controls factors that were subject to SME interpretation (i.e., efficacy of surface barriers, placards and markers, and subsurface barriers), the number of wells that might be drilled during the compliance period, and the relative size of the waste footprint compared with its encompassing area (Frenchman Flat or Yucca Flat). The number of wells that might be drilled during the compliance period is also dependent upon several uncertain factors. To assess the influence of these factors on the probability of IHI a more in-depth sensitivity analysis was under taken for the Frenchman Flat and Yucca Flat Jackass Flats Scenario. This scenario was chosen for further analysis because it is the dominant scenario as evidenced by comparison of the Frenchman Flat Jackass Flats Scenario probability with the sum of the scenario probabilities.

F.2 NUMBER OF HOMESTEADS AND COMMUNITIES

All of the scenario probabilities depend on the number of homesteads and communities settled in a particular area, which in turn drives the number of primary wells expected to be drilled during the compliance period. The final probabilities largely reflect this number, although, as the number of replacement wells increase, the spatial allocation of wells becomes more important. The purpose of this section is to indicate how the probability of IHI for each scenario might be affected by changes in the number of homesteads or communities. This analysis provides some indication of the sensitivity of the answers to this input factor.

The sensitivity analyses presented in this section are based on the results from the scenario simulations and thus are representative of the SME input. Each figure in this section represents a smooth of the simulated data such that the plotted line essentially represents the median sensitivity. The only factors that remain constant in these calculations are the size of the waste footprint, the areas of interest (Frenchman Flat and the cratered and non-cratered portions of Yucca Flat), and the base community area.

F.2.1 Homesteader Scenario

The first set of analyses were performed for the Homesteader scenario. The number of homesteads vary between 10 and 53, representing the range the SMEs expected to be settled in the compliance period for this scenario. Figure F- provides a summary plot in which the plotted line is a smoothed estimate of the simulated scenario probability and the associated simulated number of homesteads. Under this scenario few replacement wells are simulated, hence the scenario probability is well approximated by a binomial distribution calculation. At small probabilities the binomial expansion is essentially linear in sample size, especially over small ranges of values of the sample size[1]. The approximate linearity is evidenced in Figure F-1. This provides a convenient method for assessing the impact of changes in the number of homesteads for this scenario.

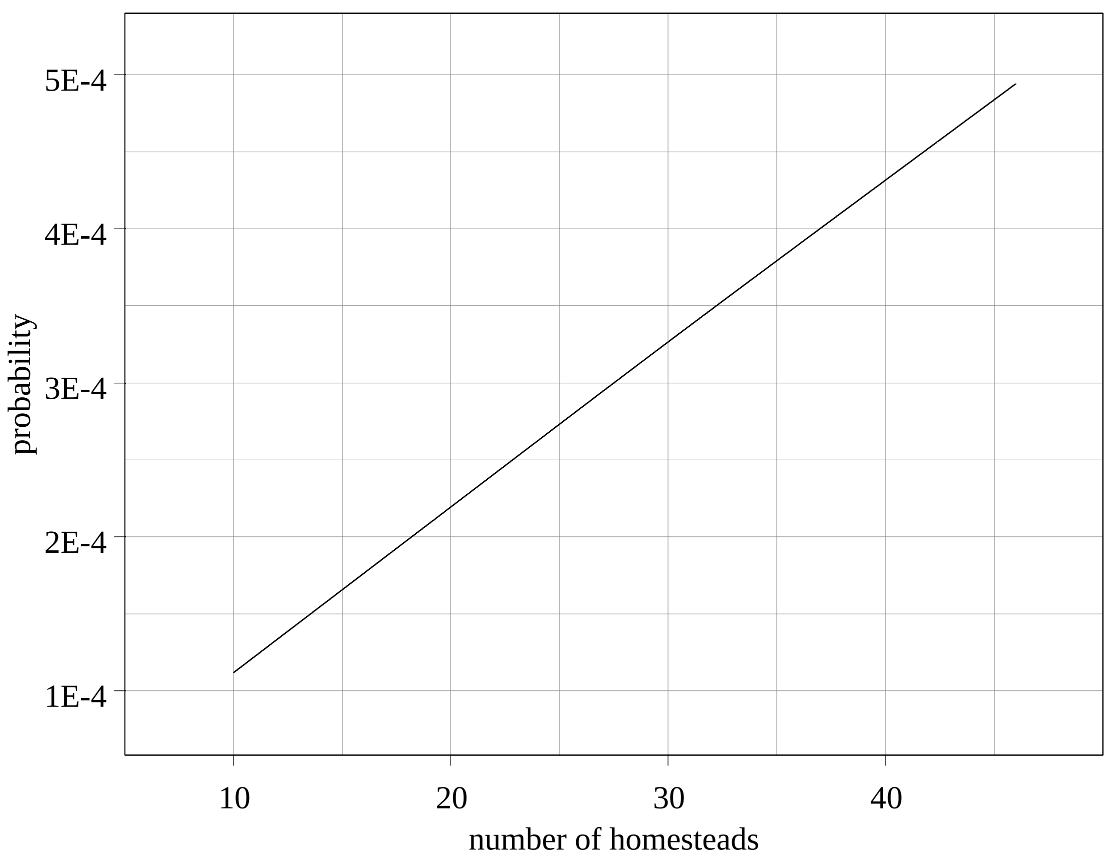


Figure F-1 Sensitivity of Homesteader scenario results: probability of IHI vs. number of homesteads on Frenchman Flat and Yucca Flat combined.

[1] The binomial calculation of interest is $1 - (1-p)^n$, where p is the proportion of the total area that is occupied by the waste footprint, and n is the number of wells expected to be drilled. This term can be easily expanded: $np + n(n - 1)p^2/2 + n(n - 1)(n - 2)p^3/3! + ...$When p is sufficiently small, then this expansion is essentially linear (= np), unless n is sufficiently large to overcome the effect.

If the number of homesteads remains in the given range, the probability of IHI does not change very much. It is always of the order E-4, a very small probability.

F.2.2 Jackass Flats Scenario

Figures F-2 and F-3 provide similar analyses for the Jackass Flats scenario, however under this scenario the number of homesteads ranges from approximately 1,500 to 8,500 for Frenchman Flat, and from approximately 800 to 4,400 for Yucca Flat. The binomial approximation does not adequately characterize the Jackass Flats Frenchman Flat scenario because of the significance of replacement wells. The changes in the scenario probability of IHI are pronounced than for this scenario, because of the large range of possible numbers of homesteads, and hence primary and replacement wells. The change, however, still appears to be approximately linear. Given the SME inputs, Figure F-2 indicates that the center of the distribution for the scenario probability of IHI is likely to be approximately 11% based on about 4,600 homesteads (the simulated average for the number of homesteads).

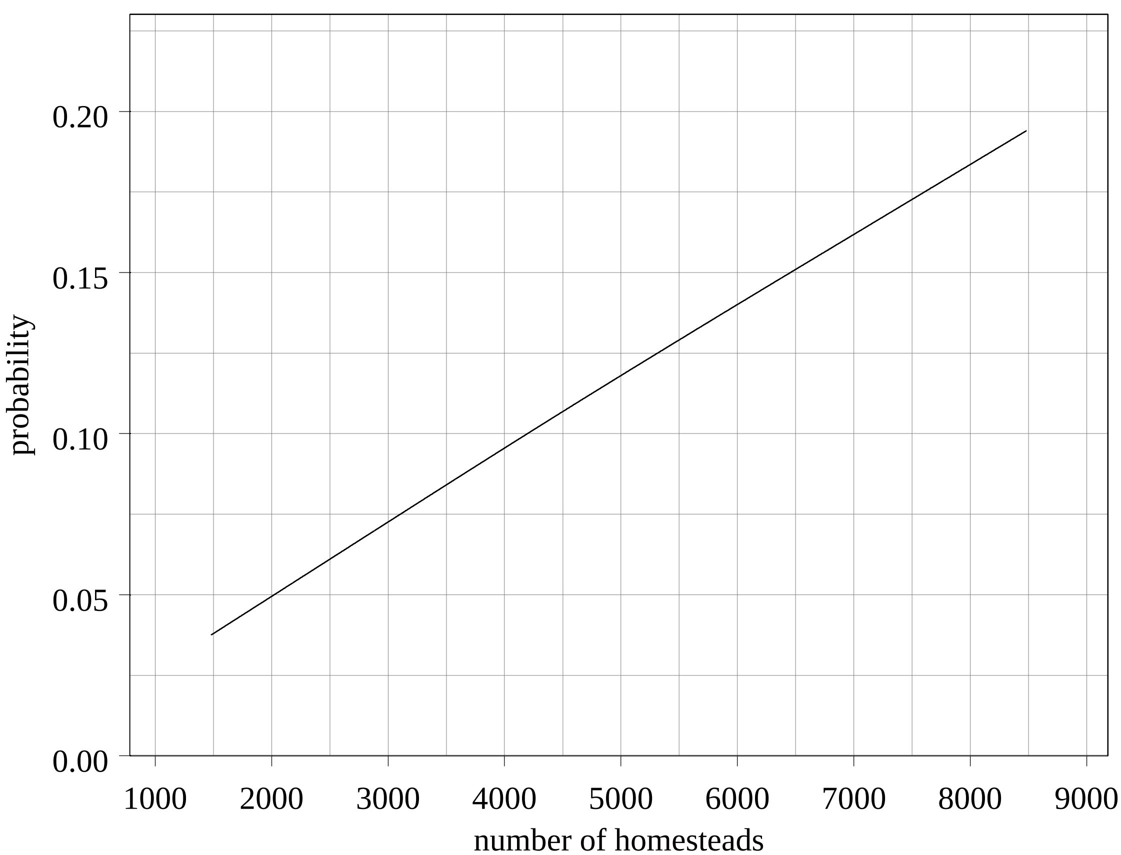


Figure F-2 Sensitivity of Jackass Flats Scenario results: probability vs. number of homesteads on Frenchman Flat.

Figure F-3 demonstrates the same effect for Yucca Flat. In this case, the probability of interest is reduced because of the reduction in the relative areas of the waste footprint to the size of the cratered area of Yucca Flat and due to the SMEs input regarding the likelihood of commuter homesteading in the cratered area. The linear effect indicates that the scenario probability is not likely to exceed 1% given the range of the number of commuter homesteads considered The average probability of IHI for this scenario (approximately 0.006), can be read of this graph by substitution of the average number of homesteads expected to be settled in Yucca Flat for this scenario (approximately 2,250).

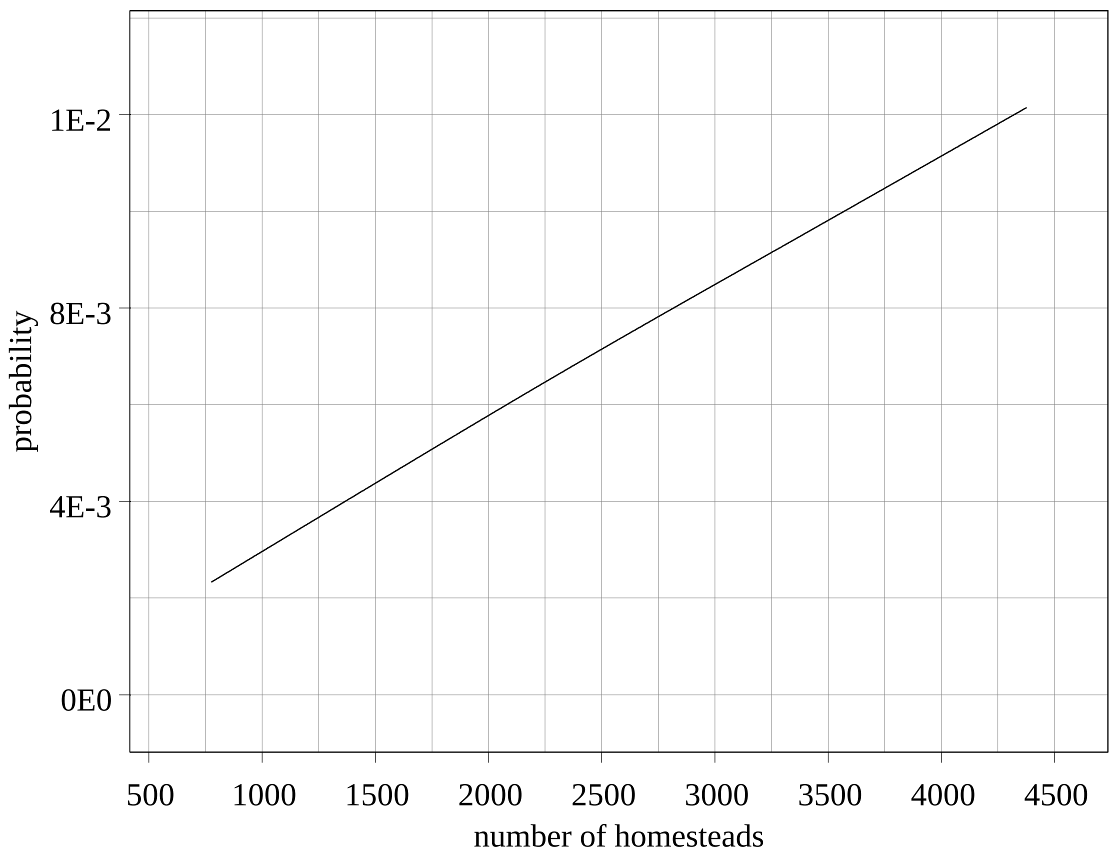


Figure F-3 Sensitivity of Jackass Flats Scenario results: scenario probability vs. number of homesteads on Yucca Flat.

The probability of IHI for this scenario is much larger than for the other scenarios. The results presented in Appendix E for the overall probability of IHI demonstrate the dominance of this one scenario. The most sensitive parameters overall, therefore, come from this one scenario, consequently, the more thorough sensitivity analyses presented in Section F-3 through F-5 are focused on the Jackass Flats scenario.

F.2.3 Base Community Scenario

Figure F-4 Figure F-shows the effect of changing the number of communities on the results for Frenchman Flat for the Base Community Scenario. Figure F-5 provides similar results for Yucca Flat. In this case the factor of interest is the number of base communities that might be settled in Frenchman Flat or Yucca Flat in the 10,000-year time frame of interest. The Base Community scenario distributions are bi-modal due to the fact that generally only one or two communities are simulated but each simulated community has four initial, or primary, wells (see Appendix E). If one community is simulated than four primary wells are simulated, however if two communities are simulated than eight primary wells are simulated. The variability around the number of wells comes from replacement wells. Despite this bi-modality in the probability of IHI for this scenario, the relationship between number of communities and probability of IHI still appears linear over the range of interest (one – six base communities). This is probably because of the comparatively small number of communities, and hence wells, used in this scenario.

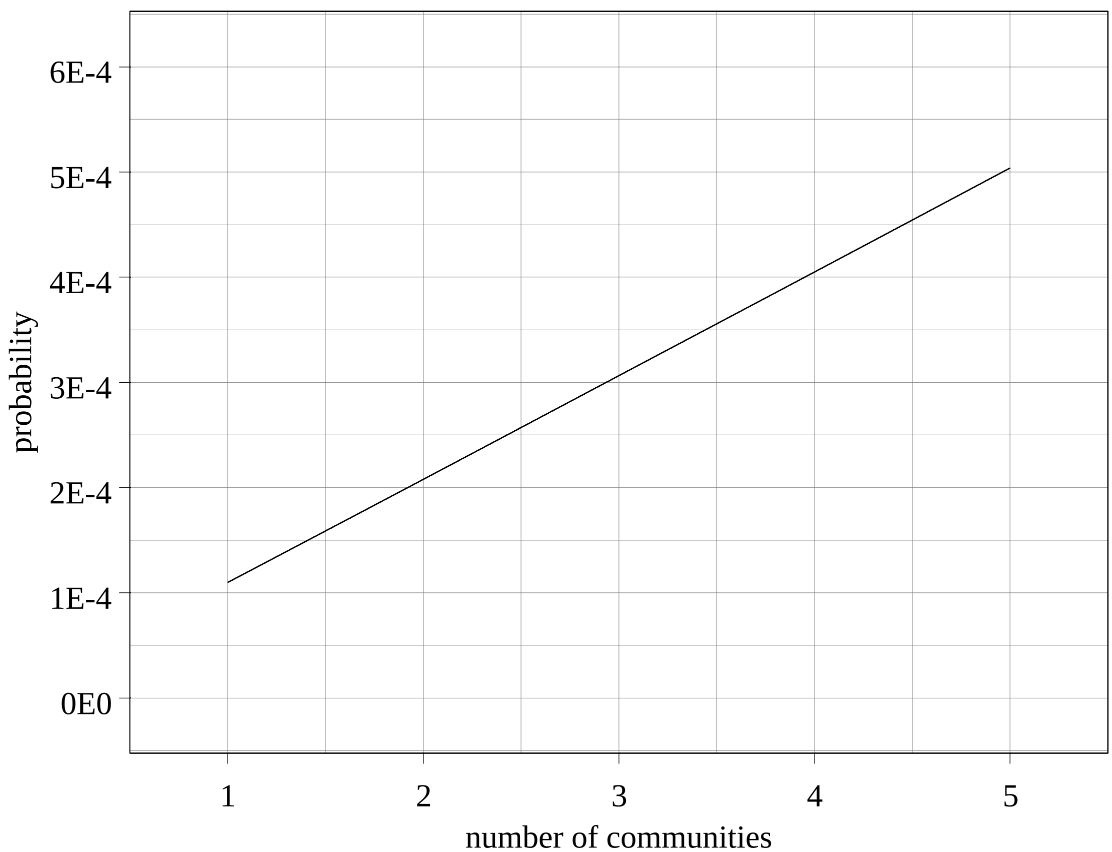


Figure F-4 Sensitivity of Base Community scenario results: scenario probability vs. number of communities on Frenchman Flat.

The probability is controlled to a large extent by the relative size of the community well field (four wells, ½ mile apart in a square) to the size of Frenchman Flat or the cratered area of Yucca Flat. The most likely number of communities is one, resulting in four primary wells (based on the assumption of four wells per community) with eight replacement wells. The average scenario probability is approximately 0.00017.

The same process was applied to Yucca Flat as presented in Figure F-5. The number of primary wells that corresponds to the scenario probability presented in the main text is often four, because only one community is usually simulated. The only difference in the final probability calculation for Yucca Flat versus Frenchman Flat is inclusion of the SMEs' input regarding the likelihood of homesteading in the cratered area. Although the number of wells placed in Yucca Flat is consistent with the number in Frenchman Flat, including the likelihood of settling the cratered area significantly reduces the scenario probability. Because of the cratered-area adjustment, the impact of changing the number of community wells is minimal for this scenario, and the scenario probabilities are very small.

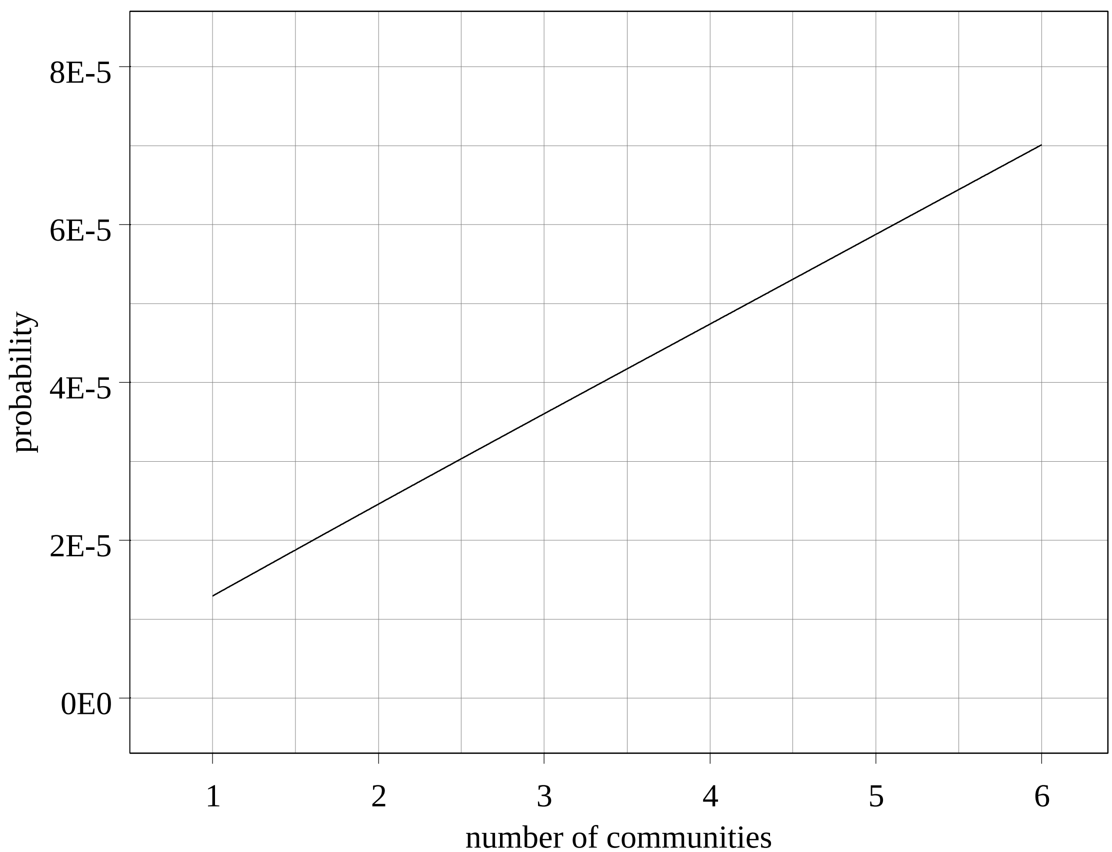


Figure F-5 Sensitivity of Base Community scenario results: scenario probability vs. number of communities on Yucca Flat.

F.2.4 Las Vegas Community Scenario

Figures F-6 and F-7 presents the Las Vegas Community Scenario results for Frenchman Flat and Yucca Flat, respectively. For Frenchman Flat the simulated number of homesteads ranges from 0 and 90, while for Yucca Flat the range is 0 to 7. The large difference in range is a result of the effect of the cratered area of Yucca Flat.

As for the Jackass Flat scenarios, the binomial approximation does not adequately approximate the scenario probability due to the significance of replacement wells. However, the relationships presented in Figures F-6 and F-7 appear linear, probably because of the very small probabilities indicated for the final results.

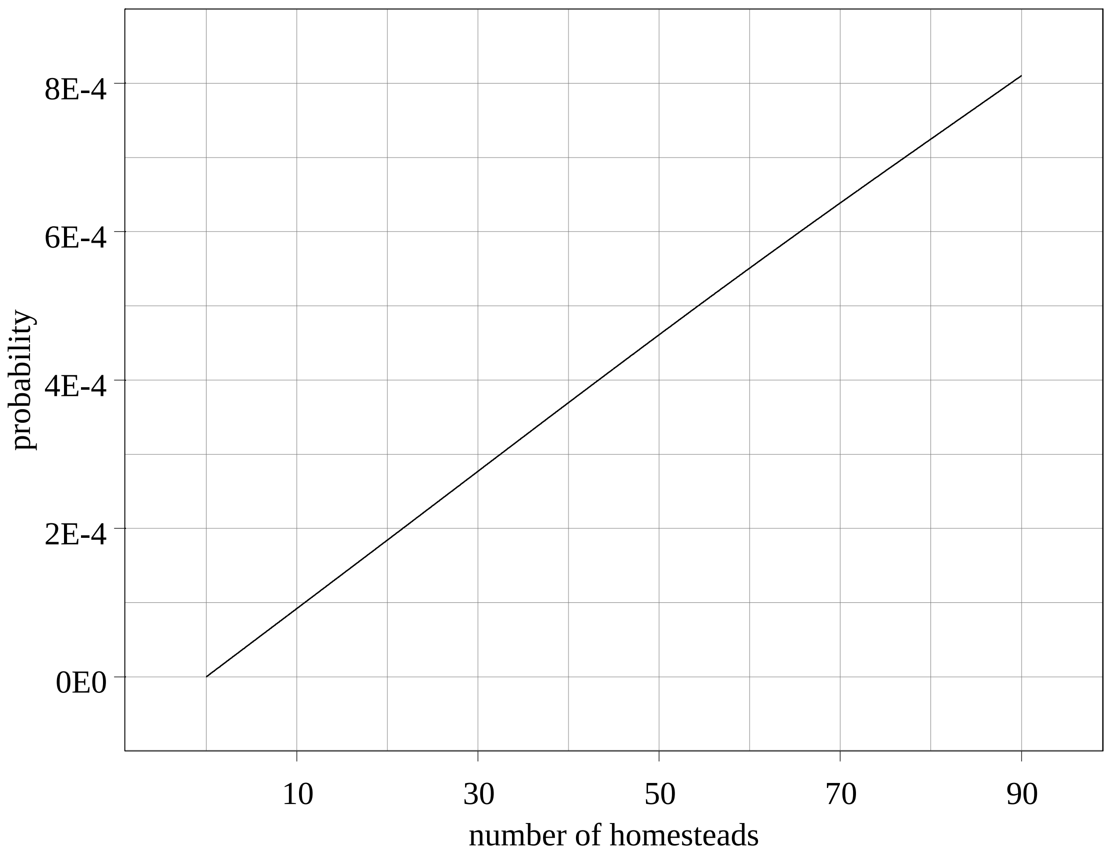


Figure F-1 Sensitivity of Las Vegas Community scenario results: scenario probability vs. number of homesteads on Frenchman Flat.

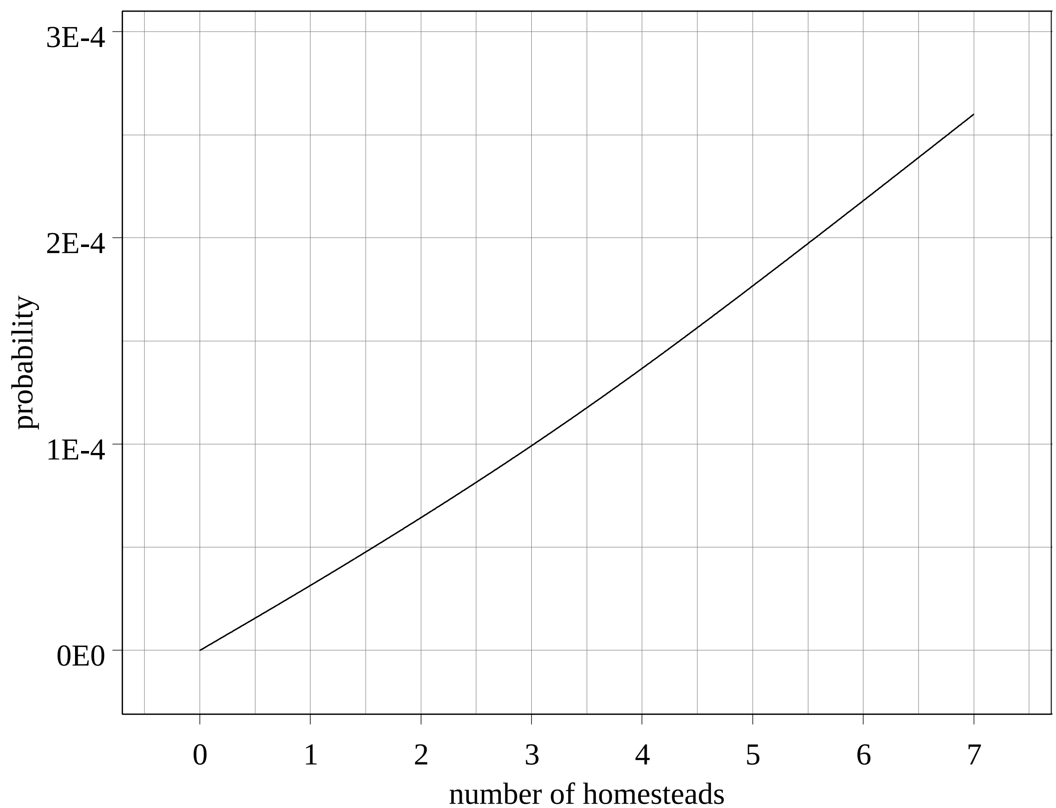


Figure F-2 Sensitivity of Las Vegas Community scenario results: scenario probability vs. number of homesteads on Yucca Flat.

F.3 WASTE FOOTPRINT AREA

The scenario probabilities will be affected by changes in the relative size of the waste footprint to Frenchman Flat and the cratered area of Yucca Flat. For the following analyses, the Jackass Flats scenario simulations were run for waste footprint areas ranging from 0.5 to 20 acres. Figure F-8 and Figure F-9 provide results for Frenchman Flat and Yucca Flat. Clearly, Figure F-8 does not reasonably approximate a straight line for the Frenchman Flat analysis. This outcome apparently occurs due to the interaction between the relatively large number of primary and replacement wells and an increasing relative size of the waste footprint to Frenchman Flat. As shown, at a waste footprint size of two acres, the scenario probability for Frenchman Flat is approximately 0.11, consistent with the results in the main text. Of importance for this scenario is that any increase in waste footprint size has a fairly pronounced effect on the scenario probability. For example, at a waste footprint size of 20 acres, the scenario probability for Frenchman Flat is approximately 0.72 and for Yucca Flat the scenario probability is still only about 0.05. If waste footprints of this size are contemplated, then clearly the implications for IHI must be carefully considered.

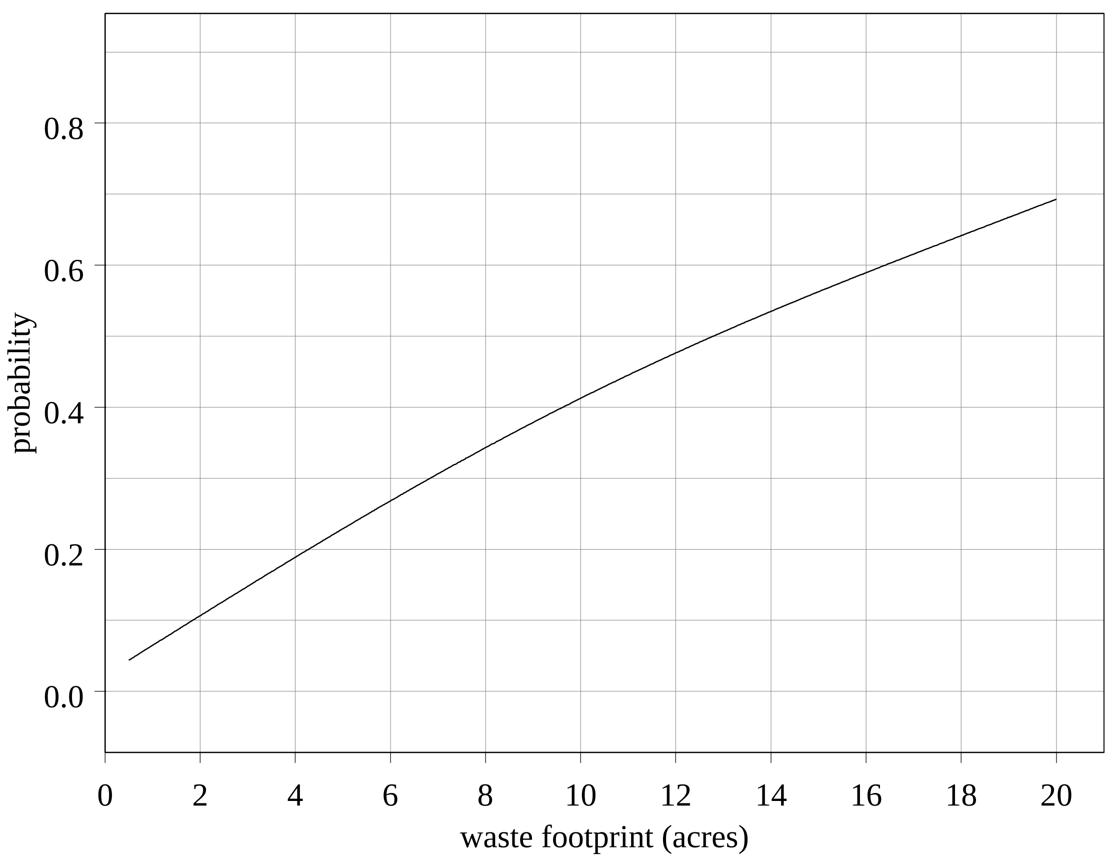


Figure F-8 Sensitivity of Jackass Flats Scenario results: scenario probability vs. waste footprint size (acres) Frenchman Flat.

For Yucca Flat, the plot indicates a straight line, again because the probability is extremely small and the number of homesteads found in the cratered area is insufficient to compensate. If the waste footprint size is increased to 20 acres, then the scenario probability is increased to approximately 0.05. This emphasizes the distinction between results for Frenchman Flat and Yucca Flat. The probability of IHI at Yucca Flat is always considerably lower than the corresponding probability for Frenchman Flat. This is because of the impact of the cratered area on the probability calculations, and also because of the smaller number of homesteads expected in Yucca Flat for the Jackass Flats scenario, based on input from the SMEs.

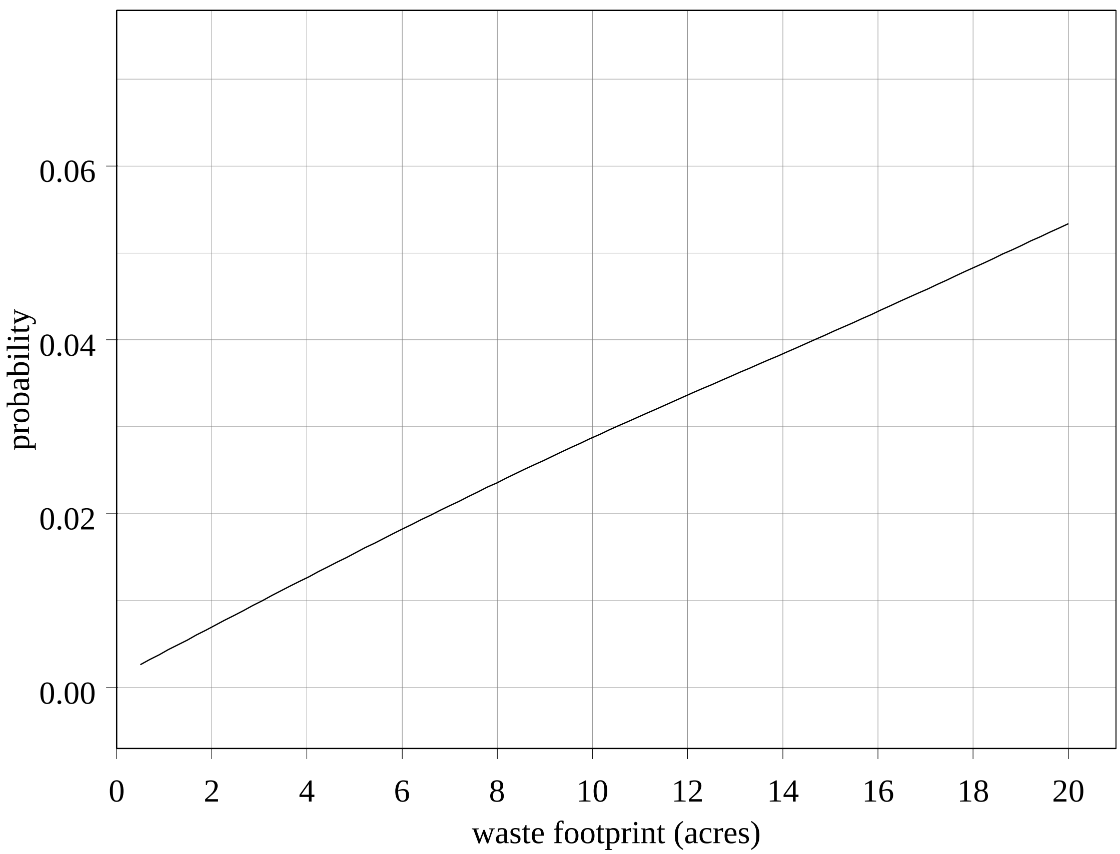


Figure F-9 Sensitivity of Jackass Flats scenario results: scenario probability vs. waste footprint size (acres) Yucca Flat.

F.4 RELATIVE INFLUENCE OF INPUT PARAMETERS

The number of wells that might be drilled during the compliance period under the Jackass Flats Scenario is dependent upon several factors including: 1) the proportion of the 10,000 year compliance period for which this commuter homesteading would be present in Frenchman Flat; 2) the lifetime of a community; 3) the number of homesteads per community; 4) the well lifetime; and, 5) the distance the replacement well is drilled from the primary well. A sensitivity analysis was undertaken to assess the relative influence of each of these factors on the scenario probability as measured by the unit change in the scenario probability from a unit change in each standardized factor.

Relative influences of each factor can be estimated by linear regression of the simulated scenario probability on the simulated factors. The structure of the Jackass Flats scenario influence diagram requires that for each simulated probability multiple community lifetimes, numbers of homesteads per community, well lifetimes, and replacement well distances are simulated. For these factors the average of the repetitions for each simulation was used in the relative influence estimation, so that only 10,000 simulated realizations are used in this sensitivity analysis for each input parameter.

To allow the estimated regression coefficients to be interpreted as relative influences, each factor and the scenario probability was first scaled by its mean and variance. This scaling places the regression coefficients on the same scale with a maximum value of one and a minimum value of negative one. The results of this relative influence estimation are presented in Figure F-10.

As expected, the period a community will be in existence in Jackass Flat is the most influential factor on the scenario probability with a relative influence (0.90) close to the maximum possible relative influence of one. Community existence is the only factor in the scenario influence diagram that is drawn once for each simulation and clearly dominates the scenario probability. The influence of this variable is realized through its relationship to the number of primary wells drilled. The longer the community existence period, the more communities and homesteads are possible, and the larger the number of wells drilled. This is the single most influential factor in the results, suggesting that refinement of this factor could lead to a better understanding of the most important factor in the model.

Community lifetime has the next largest relative influence (-0.21). The relative influence is negative because the longer the community lifetime the lower the number of communities (and subsequently the lower the number of wells drilled) simulated in a given community existence period. This factor could have potentially provided a positive influence because each homestead is assigned its community lifetime which determines, in conjunction with the well lifetime, the number of replacement wells drilled. Because of the observed negative influence, it is clear that community lifetime is exerting its influence through the number of communities simulated rather than the number of replacement wells drilled.

The average number of homesteads per community has the third largest relative influence (0.18). This influence is due to the fact that the more homesteads that are settled the more wells will be drilled. The number of homesteads and community lifetime have similar, though inverse, relative influences.

Well lifetime and replacement well distance have small (and insignificant based on regression inferences) relative influences indicating that, in general, replacement wells have a relatively small influence on the scenario probability. This conclusion is further supported by the negative relative influence of community lifetime.

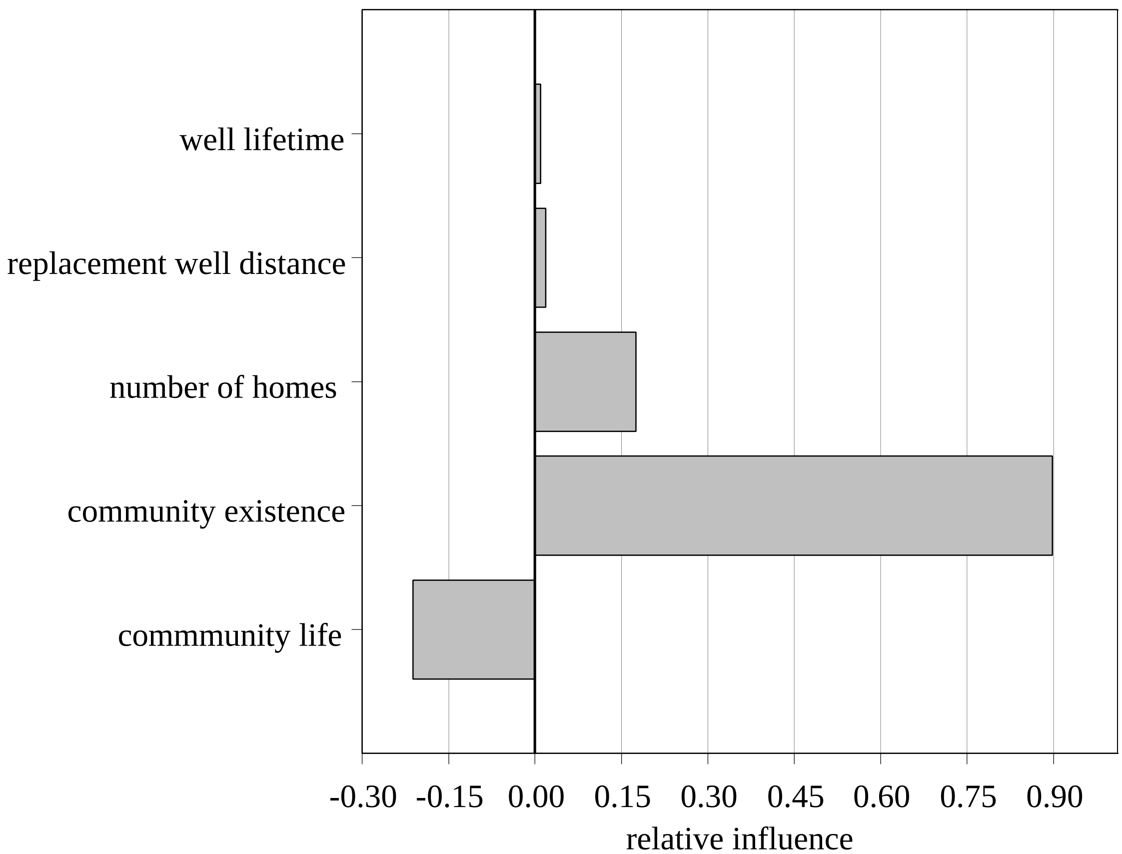


Figure F-10 Sensitivity of Jackass Flats scenario results: relative influence of input factors on the Frenchman Flat scenario probability.

F.5 DISTRIBUTIONAL SHIFTS IN INPUT PARAMETERS

Also of interest is the impact of uncertainty in the input factor distributions on the distribution of the total number of homesteads. Three input factors impact the total number of homesteads: 1) the proportion of the 10,000 year compliance period for which commuter homesteading would be present in Frenchman Flat, 2) the lifetime of a community, 3) the number of homesteads per community. To assess when a statistically meaningful change in the total number of homesteads distribution would occur based on changes in the input factor distributions a range of percent changes was applied to each input factor. The Kolmogorov-Smirnov goodness-of-fit test was then used to test the relationship between the original simulated distribution of the number of homesteads and the simulated distribution based on a percent change in an input factor. The Kolmogorov-Smirnov test is based on the magnitude of the largest difference between the two distributions. Of concern in using the Kolmogorov-Smirnov test in making inferences regarding simulated data are the impact of extreme values and an arbitrarily large sample size (in this case n = 10,000). To mitigate the effect of extreme values and the large sample size on the test results only the 0.1, 0.2, …., 0.99 percentiles (i.e., 99 data points) for each simulated dataset was used to calculate the test statistic.

In summary, 1) percent changes ranging from 0.05% to 25% were applied independently to each input factor distribution while sampling from the original distributions for the other input factors, 2) the 0.1, 0.2, …., 0.99 percentiles were calculated from the simulated distribution of the number of homesteads, and 3) the Kolmogorov-Smirnov test statistic was calculated using the percentiles of the original and test simulated distributions. The range of percent changes that are meaningful are bounded by *p*-values between 0 and 1. A *p*-value of 1 indicates that the change had essentially no impact on the number of homesteads, while a *p*-value close to 0 indicates an impact that can not be attributed to chance alone.

Figure F-11 provides results of percent changes in the input factor distributions ranging from 0.05% to 25%. A reference line at a significance level of 0.05 is provided as an indication of the percent change that may be considered statistically significant. Two features of this figure are of particular interest: 1) the influences of each of the input factors are similar and 2) a significant change (based on a *p*-value of 0.05) occurs for each factor at around a 15% to 17% change in an input variable. Community lifetime appears to have a somewhat lower impact on the number of wells distribution, which is probably reflective of its negative relative influence. The similarity in the influences of the input factor distributions can probably be attributed to the dependence structure the scenario influence diagram imposes on these factors.

If linearity can be assumed for the input factors that have positive influence, then a 15% positive change in the input distributions results in an average number of homesteads of approximately 5,200 homesteads for the Jackass Flats scenario for Frenchman Flat. This suggest that a significant change through this method results in a change in probability of IHI from 11% to approximately 12% (see Figure F-2).

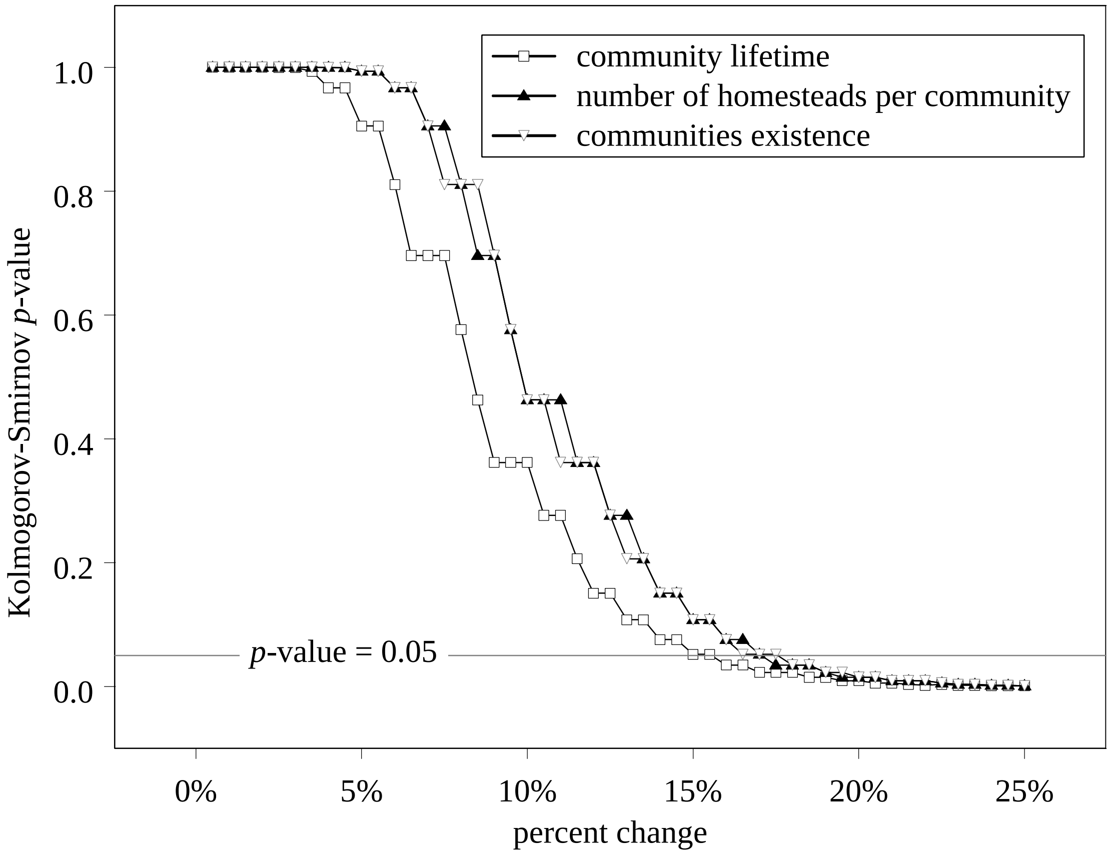


Figure F-11 Sensitivity of Jackass Flats scenario results: impact of percent changes in the distribution of input factors on the distribution of the number of homesteads in Frenchman Flat.

F.6 MANAGEMENT CONTROL FACTORS

The management controls factors included in this sensitivity analysis are labeled for convenience as presented in Appendix E:

A = 0: Ineffective control/knowledge.	*A* = 1: Effective control/knowledge.
B = 0: Ineffective surface barriers.	*B* = 1: Effective surface barriers.
C = 0: Ineffective placards & markers.	*C* = 1: Effective placards & markers.
D = 0: Ineffective subsurface barriers.	*D* = 1: Effective subsurface barriers.

The distributions for the number of years that institutional control and site knowledge will be maintained are presented in Appendix E. The mean total length of time that these two factors are expected to be effective was calculated, from the SME inputs and modeling process, to be approximately 594 years. Consequently the value used to represent Pr(*A*=0) is 0.9406 (institutional control and site knowledge are both included in the definition of variable *A*, see Appendix E). A sensitivity analysis has been performed in which three of the factors are fixed and the fourth is allowed to vary.

Variable *A* is fixed because it has little impact on the probabilistic results given the compliance period of 10,000 years. The SMEs clearly indicated that institutional control and site knowledge would not last very long, hence, are not effective long-term management controls. Only the management control factors that are effective have significant impact on their combined effectiveness, in which case it seems reasonable to fix variable *A* at its overall mean value.

Variables *B*, *C*, and *D* are interchangeable from the point of view of the probability calculations. Recall from Appendix E that underlying independence assumptions for these three factors are of little utility in this analysis. Consequently, reference to the actual factors can be avoided and two factors can be fixed while the remaining factor is allowed to vary. This technique measures the influence on the overall effectiveness of management controls. Without loss of generality, then, factors *B* and *C* were fixed, while factor *D* was allowed to vary. This process is repeated for various pairs of values for factors *B* and *C* (Figure F-32).

The vertical axis scale of Figure F-32 represents the probability of overall management controls *ineffectiveness*. Clearly, the greater the input values, the greater the overall management controls effectiveness. However, the impact of a high value is clearly seen, for example, by comparison of the top and bottom lines. The top (most sloped) line corresponds to valuations for variables *B* and *C* equal to 0.1. If variable *D* also takes a low value, then the overall management controls effectiveness is also very small (the probability that management controls are *ineffective* starts at around 0.8 for these values).

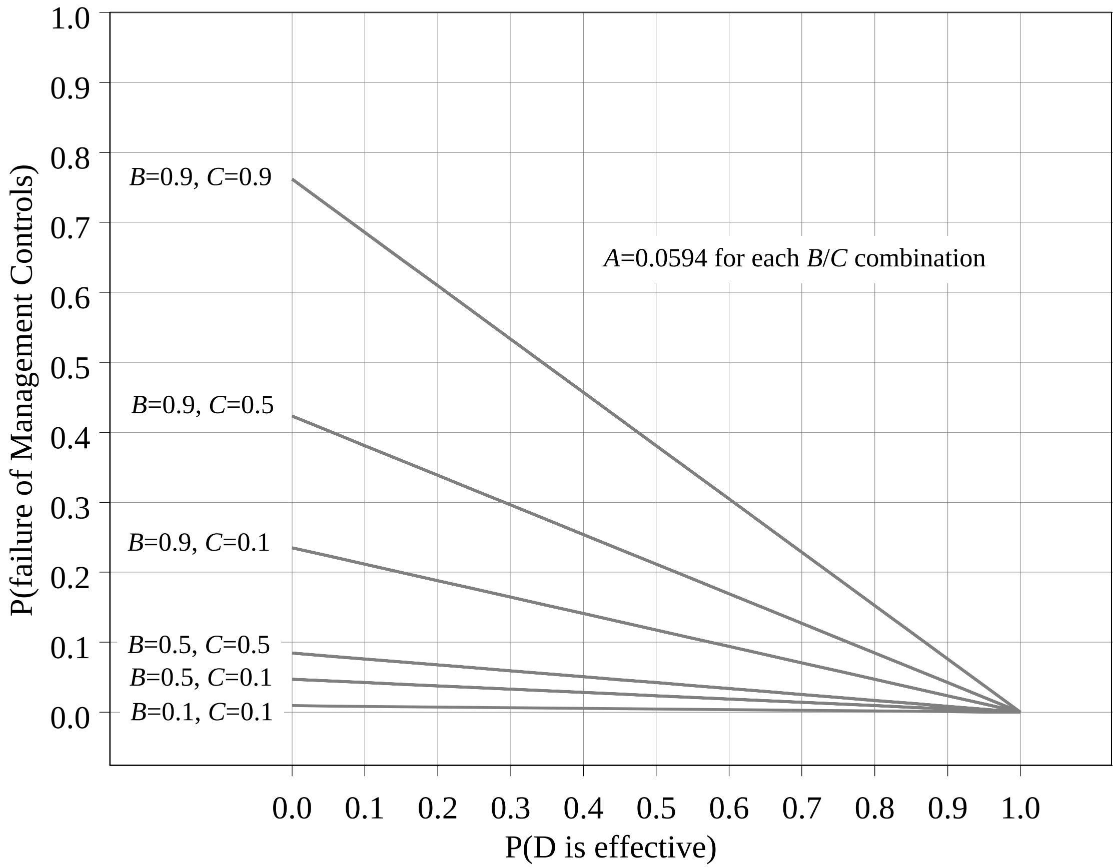


Figure F-3 Sensitivity of Management Controls effectiveness.

If, on the other hand, any one of the management controls factors is highly effective (see the bottom three lines), then the overall effectiveness is also very high (the probability that management controls are *ineffective* starts at around 0.1 for these values). It can be seen, then, that if one factor is very effective, another effective factor does not change the overall effectiveness by very much. The effect of combining two or more somewhat effective management controls is that their conjunction provides greater effectiveness, but that effectiveness still does not, in general, reach the effectiveness level of having one very effective management controls factor.

These results indicate the value of implementing one management controls factor as well as possible. Otherwise, many less effective management controls would have to be used together in order to obtain the same degree of overall effectiveness. Ultimately a decision analysis should be performed to determine the benefits of applying a single very effective solution versus several less effective solutions. Cost factors should enter the equation, and the need for effective management controls should be evaluated. At this site, the probability of IHI is already quite small, thus the actual level of management controls needed, although partially driven by regulations, should also be determined through a decision analysis.

F.7 SUMMARY

Overall, the sensitivity analyses have indicated some conditions under which the probability of IHI changes according to changes in input parameter values. Because the scenario probabilities are so small for many of the scenarios, the effect of reasonable changes in number of wells or waste footprint size, does not significantly impact the overall conclusions of the project. However, for the Jackass Flats Scenario, changes in the waste footprint size can have potentially serious effects on the probability of inadvertent human intrusion. Also for the Frenchman Flat Jackass Flats Scenario a 15% change in an SME elicited input factor distributions results in a significant change in the distribution for the total number of homesteads. Since the number of homesteads dominates the scenario probability this provides an indication of the overall impact of changes in input distributions for this scenario. A 15% increase in the median number of homesteads (4,600) simulated under the Frenchman Flat Jackass Flats scenario is approximately 5,300 homesteads. Figure F-3 indicates that moving from 4,600 to 5,300 homesteads increases the scenario probability from approximately 11% to 12.5%. Clearly it would take a more pronounced increase in the number of homesteads to realize a large change in the probability of IHI.

The sensitivity analyses for management controls indicates that just one effective management control could dominate the overall effectiveness of preventing IHI. Based on this analysis, this might be an appropriate approach for DOE/NV to consider, although a thorough decision analysis should be performed to evaluate the different options.

F.8 RELATED ARCHIVED DOCUMENTS

- Computer code
- Simulated data sets

APPENDIX G: ARCHIVED DOCUMENTS

CONTENTS

G.1 INTRODUCTION

The report has been organized into two volumes: main text and appendices. The appendices reference archived documents and attachments to the appendices, which provide the back up material associated with this project. This description of archived documents serves to provide evidence of the activities and products developed and utilized during the course of this probabilistic assessment. The archived documents are available through the DOE/NV project manager for Performance Assessments (Beth Moore), or through the Neptune and Company, Inc. project manager for this study (Paul Black). Addresses are provided in Appendix A.

G.2 APPENDIX A: QUALITY ASSURANCE

- Work plan - This document provides the planning concepts for this project. The discussion of the approach to the problem includes the value of influence diagrams, the need for a stakeholder workshop, a QA program, approach to elicitation, and a list of activities to be performed. This is a referenceable document (Black et al. 1996).

- Presentation to the peer review group between SME elicitation sessions - This presentation reflects inputs received from the first SME elicitation session and illustrates how they were applied in the influence diagrams. This is important for understanding the variable relationships for determining the probability of IHI.

- Review comments and responses - These documents include reviews and responses throughout the duration of the project from the following reviewers: Bruce Crowe, Charles Davis, Doug Duncan, and Bill Roberds, of the Peer Review Group, and comments received on various drafts of the document from Ron Whitfield of Argonne National Laboratory, Brett Mattingly and Anthony Hechanova of the Nevada Risk Assessment/Management Program, and Lawrence Barker and Stuart Rawlinson of Bechtel Nevada. Comments from representatives of the Yucca Mountain Project are also included in this section.

G.3 APPENDIX B: STAKEHOLDER WORKSHOP

- List of invitees - This list includes all of the people to whom an invitation to the stakeholder workshop was sent.

- Sign-in sheet - This is a record of all the workshop attendees and their respective affiliations.

- Flip chart notes - These notes are the result of the group discussion following the presentations. Notes were taken by the facilitators on flip charts so that the entire audience had continuous access to the salient points.

- Response to evaluation questionnaires - All of the stakeholder workshop participants were requested to provide feedback on the purpose and performance of the workshop and on the facilitation team in the form of an evaluation questionnaire. This archive consists of the three responses that were received by DOE/NV following the workshop.

- Summary report - The workshop participants were sent a summary report for their review and concurrence. The report was completed by the project team facilitators. The purpose was to make sure that the facilitators had properly captured the intent of the participants' input.

- General comments passed to the Office of Public Affairs and Information at DOE/NV - The workshop participants made several general comments that were outside the scope of this project. This archive provides a written summary of the issues raised.

G.4 APPENDIX C: SELECTION OF SUBJECT MATTER EXPERTS

- List of potential SME candidates - This list includes all the potential first round candidates in order of disciplines. The candidates on this list reflect those professionals who had verbally indicated their interest in participation in the expert elicitation sessions.

- RFP responses - This archive contains a complete set of responses to the RFP that was sent to the potential SME candidates.

- SME contracts - The final contracts for all selected SMEs are included in this archival document.

- Completed SME evaluation forms - All of the candidates were scored according to evaluation criteria that were established prior to sending out the RFPs. This archive shows how each of the candidates was scored using these evaluation sheets and, hence, how the final group of SMEs was selected.

G.5 APPENDIX D: ELICITATION PROCESS AND SESSIONS

- Background information documents - Contains all the documents sent to the SME elicitation panel to acquaint them with the NTS, radioactive waste management at the NTS, Performance Assessments, and the disposal areas.

- SME responses to session 1 elicitation questions - This archive contains written SME responses to the questions posed by the facilitators during session 1, regarding scenarios, the management controls factors, and periodic evaluation of IHI.

- Flip chart notes (session 1 and session 2) - These notes were taken during both elicitation sessions as a group record of discussion.

- Written notes (session 1 and session 2) - These notes were taken by members of the project team during the elicitation sessions. They were used during the analysis process for clarification and verification of different values used in the probabilistic determinations.

- Audio tapes - Both elicitation sessions were recorded for future reference and for clarification and verification as needed in the course of completing the probabilistic assessment.

- “Data call” items - These are the reference documents and other materials requested by the SMEs at the end of the first elicitation session.

G.6 APPENDIX E: ALGORITHMS AND CALCULATIONS

- Computer code - The computer code used to propagate the SME input through the influence diagram models, and hence, to generate the final probabilities of interest, is archived both in hard copy form and as part of a set of electronic files. The computer code was written in S-Plus 2000 Release No. 1.

- Simulated data - The computer code was based on a Monte Carlo simulation routine that generated simulated data sets that were saved for several intermediate variables as well as for the final probabilities of interest. The plots of scenario probabilities presented in the main text and in Appendix E are based on these simulated data. The simulated data sets have been archived as part of several electronic files.

G.7 APPENDIX F: SENSITIVITY ANALYSIS

- Computer code - The computer code used to perform sensitivity analyses on some of the important variables is archived both in hard copy form and as part of an electronic file. The computer code was written in S-Plus 200 release No. 1.

- Simulated data sets - The simulated data corresponding to the sensitivity analyses are archived as part of several electronic files.