APPENDIX B

INFLUENCE DIAGRAMS, PERFORMANCE MEASURES, AND SCORES

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APPENDIX B

INFLUENCE DIAGRAMS, PERFORMANCE MEASURES, AND SCORES

B.1 Performance Measures and Probability Judgments

Performance measures were defined to quantify the degree to which an ESF-repository option achieved each of the fundamental objectives identified in the Exploratory Studies Facility Alternatives Study (ESF-AS) Report Volume 2 Objectives Hierarchy for Adverse Consequences (Section 2, Figure 2-4). According to the multiattribute utility theory, performance measures can be either direct or indirect (surrogate) measures of the objectives.

Objectives are broad general goals, such as minimizing adverse impacts on health and safety of the public after closure of the repository. Other specific objectives, such as minimizing the number of health effects attributable to radionuclide releases from a repository must be achieved in order to achieve the broader objectives. The application of the analysis method required both specific and relatively detailed objectives.

To aid in the development of performance measures, detailed influence diagrams were constructed. The diagrams were used as general guidelines to assist the ESF-AS expert panelists in estimating probabilities and consequences. An influence diagram is a graphic representation of the most significant influences on a factor that has been identified as an important one for measuring performance against an objective. Each of the factors is represented by bubbles in the diagram and an arrow from one factor to another indicates a judgment that the factor at the arrow point is influenced by the factor at the arrow tail. The factors further down in the diagram are more and more detailed factors that are considered to influence the higher level factors.

An influence diagram serves two main purposes. First, the diagram assists the participants in the decision-making process. The influence diagram serves as a road map that identifies the various factors that must be taken into account in reaching a decision about the ESF-repository designs. The diagrams are used to develop a performance scale for the purpose of assigning quantitative values (scores) to each performance measure. The influence diagrams are used to identify the lowest level factors that are most easily related to ESF-repository design characteristics that differ from option to option. Certain factors are most likely to be influenced by the characteristics of the design options. The scorers will direct their attention to those factors in particular. Second, the influence diagram communicates to people not involved in the decision-making process the factors that were considered in making a decision (Merkhofer, 1990).

One influence diagram was developed for each major judgmental parameter supplied by the expert panels. There were two classes of judgmental parameters considered in the methodology. One class of judgmental parameters was probabilistic estimates of the likelihood that key uncertain events might impact the choice of an ESF-repository option. These probabilities included likelihood of approval and likelihood that testing will produce information that is interpreted as supporting a decision to go to the next step. The second major class of judgmental parameters was consequence measures that impact the desirability of the various decision paths. Two examples of consequence measures are preclosure health impacts associated with an ESF-repository option and the environmental impacts associated with an ESF-repository option.

The influencing factors on each diagram have been numbered and the numbers are included parenthetically in the text where the factors are referenced. Each influence diagram shows the influencing factors enclosed in ellipses. The ellipses are connected by arrows to indicate the direction of influence. Double ellipses specify factors whose variation is most significant in determining the factor at the highest level on the diagram.

Probabilistic judgments include both unconditional probabilities and conditional probabilities. The unconditional probability that Event A will occur is denoted by P_A or P(A). The conditional probability that Event A will occur, given that Event B has occurred, is denoted by $P(A \mid B)$.

The next 15 sections describe the influence diagrams, performance measures, and performance scales for each of the means objectives (ESF-AS Report, Volume 2, Section 2, Figure 2-4) and value objectives in the ESF-AS Objectives Hierarchy for adverse consequences. Section B.2 describes the scoring for each of the performance measures and uncertainty judgments in the ESF-AS.

B.1.1 Probability of Programmatic Viability, P_{VIAB}

The locations of summary notes and transcripts documenting the development of the influence diagram for the likelihood of near-term success in maintaining viable ESF-repository activities for the Yucca Mountain site are indicated by references in Appendix D.15.

B.1.1.1 Relationship to the ESF-AS Decision Tree

The ESF-AS Decision Tree (ESF-AS Report, Volume 2, Section 2, Figure 2-1) includes a branch that addresses the likelihood of near-term success in maintaining viable ESF-repository program activities for the Yucca Mountain Site. Decisions related to the branch are reached early in the development of the ESF-repository. The branch is labeled "Programmatic Viability." The DOE will have a viable program if the program shows tangible signs of progress and if the process of developing ESF tests to address public and regulatory concerns does not degrade the technical viability of other programs by allocating all resources to the ESF-repository program.

B.1.1.2 Factors Influencing the Probability

The near-term success in maintaining programmatic viability (Figure B-1, 1) is largely determined by the *overall program credibility* (3) in the views of several constituents. Those constituents are

- *Regulators* (for example, NRC) (39)
- *Public* (for example, State of Nevada) (40)
- *Utilities and rate payers* (41)
- *The United States Congress* (42)
- *State and local governments* (43)

State and local governments (43) were separated as a constituency distinct from *public* (40). The general public in the vicinity or region of a potential waste site is a definite constituency and these people vote for representatives in both the United States Congress and state and local legislatures. Nevertheless, the position taken by state and local governments is often different than the positions stated in polls of local residents.

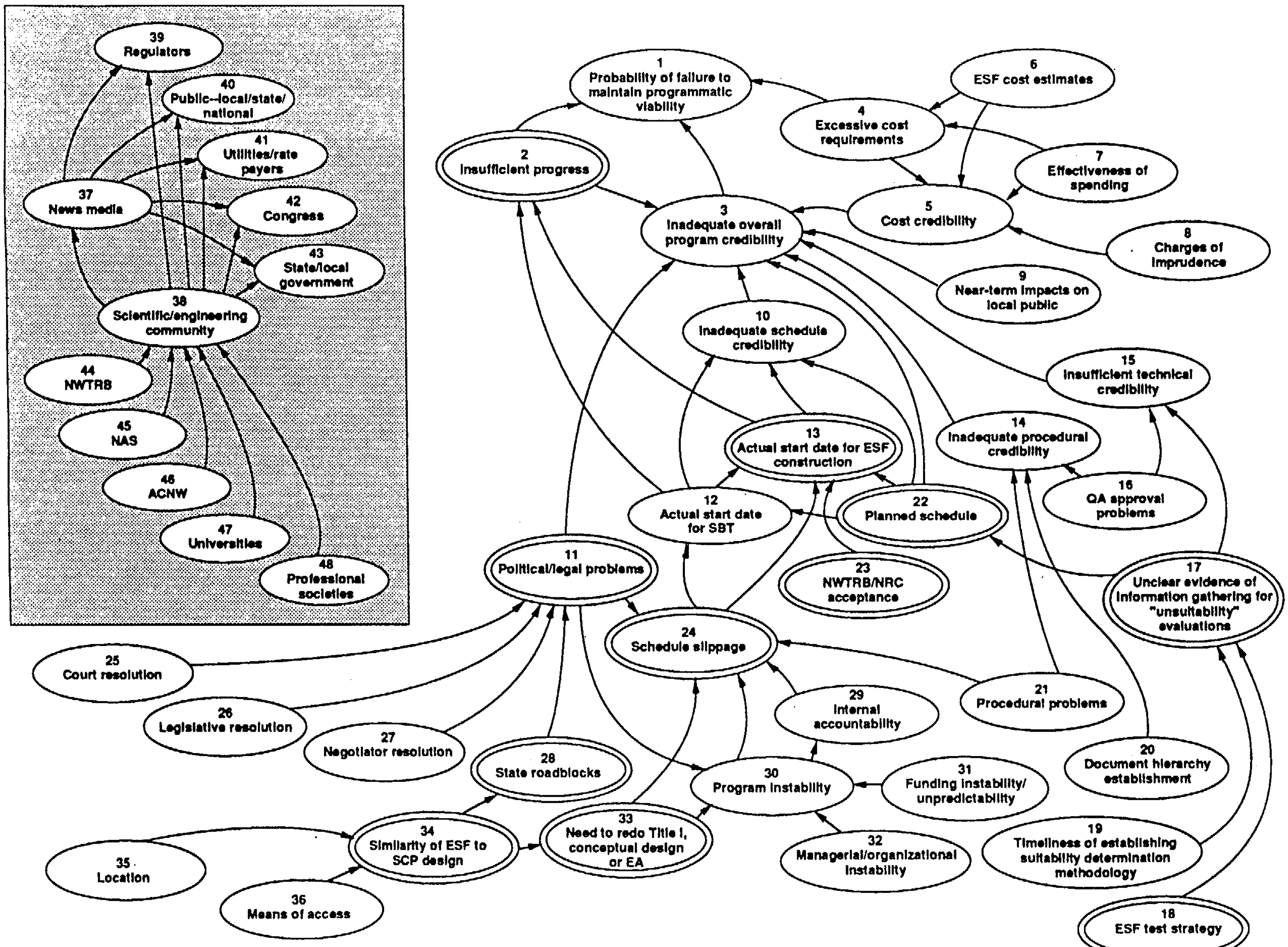

Figure B-1. Factors That Influence the Probability of Programmatic Viability.

The constituents of the program are influenced by the *news media* (37) and the *scientific and engineering community* (38). The *scientific and engineering community* (38) comprises

- *Nuclear Waste Technology Review Board* (NWTRB) (44)
- *National Academy of Science* (NAS) (45)
- *Advisory Committee on Nuclear Waste* (ACNW) (46)
- *Universities* (47)
- *Professional Societies* (e.g., American Nuclear Society, ANS, American Society of Mechanical Engineers, ASME, American Society of Civil Engineers, ASCE) (48)

The professional societies represent a forum for the interaction of ideas. The endorsements and written opinions of these groups determine in large part the credibility of the technical program for the geologic repository program.

Seven factors contribute to the *overall program credibility* (3):

- *Cost credibility* (5)
- *Schedule credibility* (10)
- *Procedural credibility* (14)
- *Technical credibility* (15)
- *Political and legal problems* (11)
- *Planned schedule* (22)
- *Near-term impacts on local public* (9)

Technical credibility (15) is based on two factors. The program must show *clear evidence that information is being gathered that can be used to determine the "unsuitability" of the site* (17). Two factors define whether the evidence is clear. The *ESF test strategy* (18) must demonstrate evidence of information gathering and the program must establish *a methodology* (19) for determining the suitability of the site. In addition, all technical activities must be conducted under rigid *quality assurance (QA) standards and procedures* (16).

Procedural credibility (14) is derived from adequate resolution of *procedural problems* (21), the establishment of the *hierarchy of documents* (20), and the *resolution of QA* *approval problems* (16) required to complete a project the size and complexity of the potential nuclear waste repository.

Schedule credibility (10) will be achieved if the ESF access is started on time (*actual start date for ESF construction* (13)), the surface based testing (SBT) is started on time (*actual start date for SBT* (12)) and if the *planned schedule* (22) for the ESF construction (shafts and ramps) is realistic. The *planned schedule* (22) along with any *schedule slippages* (24) and NWTRB and NRC *acceptance* (23) of the ESF-repository option strongly influence the *actual start date* for the *ESF construction* (13). The *Surface Based Testing (SBT) start date* (12) is important to the schedule but will not discriminate among options.

Schedule slippages (24) depend on *internal accountability* (29) resulting from a stable program (*program stability* (30)) that is able to define clear goals and near-term and long-term objectives. Program stability was defined as a program administration and management structure that remains in place. Changes in program and personnel (*managerial/organizational instability* (32)) and *funding instability and unpredictability* (31) are both programmatic factors that affect schedule. For example, QA procedures are reviewed after every program and personnel reorganization. However, for the purposes of discriminating among ESF-repository options, the major influence on *schedule slippage* (24) is whether the option will cause *a need to redo the Title I Conceptual Design or the Environmental Assessment* (33). *Program instability* (30) can lead to *schedule slippages* (24), as can *procedural problems* (21).

The other major contributors to *schedule slippages* (24) are *political and legal problems* (11) related to permitting issues and other *state roadblocks* (28). Three factors influencing *political/legal problems* (11) express the feeling that schedule slippages and program credibility are influenced by the resolutions to political/legal issues that are reached through *court resolution* (25), *legislative resolution* (26), and *negotiator resolution* (27). The major *political or legal problems* (11) are those resulting from *state roadblocks* (28). The most significant feature of the ESF-repository options that might lead to state roadblocks is the *similarity of the ESF-repository option to the SCP design* (34). The State of Nevada is more likely to delay the schedule by requesting reviews or revisions if the selected ESF-repository design differs significantly from the SCP design. The State of Nevada will want assurances that acceptable features in the SCP design have not been altered. The two principal features that the State of Nevada will examine are the *location* (35) of the ESF-repository and the *means of access* (36).

Sufficient progress (2), defined as tangible evidence of starting *SBT* (12) and *ESF construction* (13), directly influences the *probability of programmatic viability* (1). Progress in these areas will enable the DOE to break many log jams caused by *political/legal problems* (11) and *procedural credibility* (14). Not only is the start of these activities important, but the duration is important. An option that allows start of ESF testing in a relatively short time, for example, 6 years, will probably be preferred over an option that defers ESF testing for 12 years. On the other hand, the differences in these durations may not be significant in the opinion of some experts because performance confirmation will be a long duration activity relative to the duration of ESF testing. An important factor is that the cost of failure to start and complete SBT and ESF testing is high.

Cost considerations are less important in maintaining a viable program than demonstrating *sufficient progress* (2). *Excessive cost requirements* (4) influence both the *program viability* (1) and the *cost credibility* (5). Contributing factors are *ESF cost estimates* (6), *effectiveness of spending* (7), and *charges of imprudence* (8).

B.1.2 Probability of Early False Negative, P_{EFN}

The location of summary notes and transcripts documenting the development of the influence diagram for the P_{EFN} test results are indicated by references in Appendix D.13.

The probability of an early false negative is the probability that early testing will indicate that the site is "NOT OK" even though the site is OK.

B.1.2.1 Relationship to the ESF-AS Nature's Tree

The ESF-AS Nature's Tree (ESF-AS Report, Volume 2, Section 2, Figure 2-2) includes two main branches emanating from a point of uncertainty for each option related to whether the site is OK or $\overline{\text{OK}}$. (See Section 2.3 for the definition of OK used in the ESF-AS.) A site that is $\overline{\text{OK}}$ is one that is not suitable for the development of a geologic repository. Each of these branches leads to a point of uncertainty. The test outcomes may show that the parameters for conceptual models of the site are either "OK" or

"$\overline{\text{OK}}$". Conceptual models of the site are representations of the characteristics and conditions of the site, including processes that are ongoing. The probability of an Early False Negative is the conditional probability, P("$\overline{\text{OK-ET}}$" | OK), that early testing indicates the site is "NOT OK" even though the site is OK.

B.1.2.2 Factors Influencing the Probability

The factors influencing P_{EFN} (Figure B-2), as determined by the Expert Panel on Characterization Testing, include the factors that not only affect P_{EFN} but also can discriminate between and among options. Some factors were included on the influence diagram for completeness if it was not certain that the factor could discriminate between and among options. The more important factors are enclosed within two ellipses.

Four factors affect P_{EFN} (Figure B-2): *inaccurate data* (3) but more importantly, the *inability to obtain data to refute erroneous observations and interpretations* (6), *inaccurate models/analysis* (2), and *insufficient data* (4).

The *inability to obtain data to refute erroneous observations and interpretations* (6) is affected by the *inability to design or conduct engineered barrier system tests* (18) and whether the *option requires changing test configurations* (27), but more importantly by *test interference* (12) and the *inability to design or conduct natural barrier tests* (19). These factors show that it is important to be able to conduct well-designed tests, including those of the engineered barriers, in case it is necessary to refute erroneous observations that would cause a site to be incorrectly abandoned.

Test interferences (12) may be caused by *test to test interference* (13), *unexpected geologic feature influences a test* (15), and by *poor timing of tests* (25), which is affected by whether the *option requires changing test configurations* (27). *Test interference* (12) is most affected by an *adverse influence of construction on tests* (14), which is importantly affected by *adverse construction sequencing* (16) and the *construction method* (17), which also *affects adverse construction sequencing.* These factors show that it is important to conduct tests at the proper place and time so that the construction activities and the tests themselves do not adversely affect the data being collected in the tests.

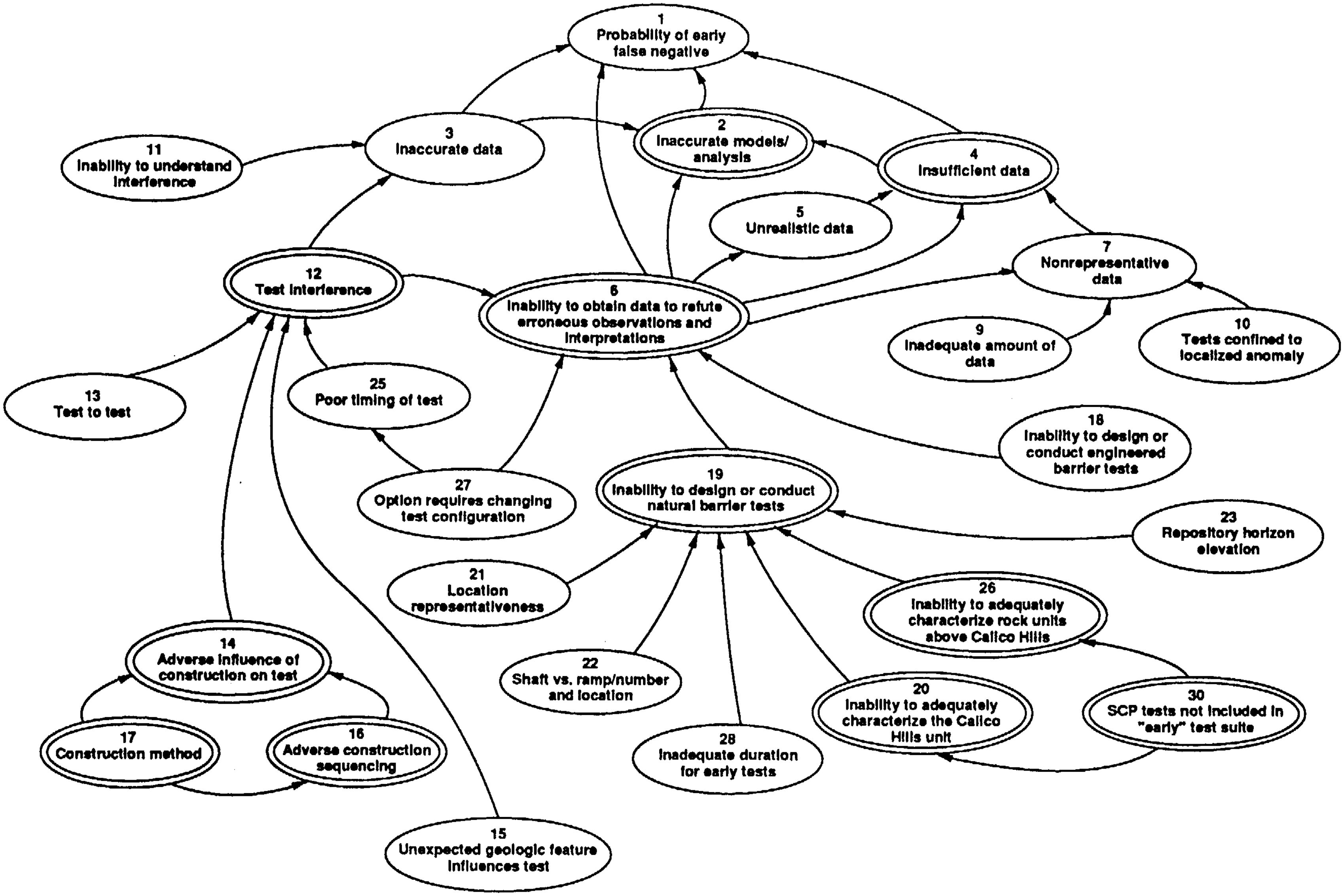

Figure B-2. Factors That Influence the Probability of Early False Negative.

The *inability to design or conduct natural barrier tests* (19) is affected by six factors, four of which are less important than the other two. The less important factors are: *location representativeness* (21) of the ESF, *shaft versus ramp/number and location* (22), *inadequate duration for early tests* (28), and the *repository horizon elevation* (23). The two more important factors are the *inability to adequately characterize the Calico Hills unit* (20) and the *inability to adequately characterize the rock units above the Calico Hills unit* (26), both of which are affected by the SCP *tests not included in the "early" test suite* (30). All these factors show that in order to correctly conduct and interpret the natural barrier tests, the tests should be conducted in representative rocks that have not been adversely affected by construction features and methods. The surrounding rocks must also be well characterized, particularly by earlier tests of adequate duration that were performed well. The number and locations of the ramps and shafts were particularly important to the panel members because of the differences in the data that will be collected.

Insufficient data (4) may be collected because of *non-representative data* (7) and *unrealistic data* (5), which is affected by the ability to refute erroneous observations and interpretations, which is described above. A more important factor affecting the sufficiency of data is the *inability to obtain data to refute erroneous observations and interpretations* (6). *Non-representative data* (7) may result from an *inadequate amount of data* (9) and *tests confined to a localized anomaly* (10). The sufficiency of the data is with respect to good data. The factors show that it is important to gather sufficient data that are also representative of the conditions of interest.

Inaccurate data (3) are affected by the *inability to understand the interference* (11), but more importantly by the *test interference* (12). These factors show that to obtain accurate data, the tests should be conducted at the proper time and place so that the construction activities and the tests themselves do not interfere with the tests.

Inaccurate models and/or analyses may result from *inaccurate data* (3), but the more important factors are the *inability to obtain data to refute erroneous observations and interpretations* (6) and *insufficient data* (4). These factors show that models and/or analyses rely on the sufficient and accurate data. Therefore, it is important to obtain sufficient and accurate data.

It is conceivable that collecting more data could actually increase the probability of false negative results, leading to the conclusion that collecting more data is detrimental to the program. Some panel members believed that collecting more data always reduced the likelihood of rejecting a site that was OK. Other panel members believed that in some circumstances, collecting more data could increase P_{EFN}.

On the one hand, an early test program with a limited scope and duration might lead to a low P_{EFN} because the early testing program is too limited to incorrectly identify a fatal flaw in the site. On the other hand, the limited early test program may produce false negatives because the data are too limited in amount to refute incorrect conclusions. The methodology lead group confirmed that in other studies, circumstances were such that collection of more data led to larger probabilities of false negatives. The panel members discussed the possibility that gathering no data would result in no false-negative results. However, if the cause of false-negative results were some global characteristic and inappropriate models, then gathering more data would reduce the probability of a false negative. Another possibility is that the probability of a false negative may vary with the amount of data available. The probability of a false negative might increase to a maximum in the early stages of data collection. As data are gathered, and the phenomena were understood better, the probability of false negative results would decrease. The panel members agreed with this possibility, but disagreed about the shape of such a probability curve with respect to the characterization test program.

B.1.3 Probability of Late False Negative, P_{LFN}

The location of summary notes and transcripts documenting the development of the influence diagram for the probability of P_{LFN} test results are indicated by references in Appendix D.13.

The probability of a late false negative is the probability that late testing will indicate that the site is "NOT OK" even though the site is "OK" and early testing indicates the site is "OK."

B.1.3.1 Relationship to the ESF-AS Nature's Tree

Nature's Tree (ESF-AS Report, Volume 2, Section 2, Figure 2-2) includes two main branches emanating from a point of uncertainty for each option related to whether the site is OK or $\overline{\text{OK}}$. A site that is $\overline{\text{OK}}$ is one that is not suitable for the development of a geologic repository (see Section 2.3 for the definition of OK used in the ESF-AS). Each of these branches leads to a point of uncertainty. The test outcomes may show that the parameters for conceptual models of the site are either "OK" or "$\overline{\text{OK}}$". Conceptual models of the site are representations of the characteristics and conditions of the site, including processes that are ongoing. The probability of a P_{LFN} is the conditional probability, P("$\overline{\text{OK-LT}}$" | "OK-ET", OK), that late testing indicates the site is "NOT OK" even though the site is OK and early tests indicate that the site is "OK."

B.1.3.2 Factors Influencing the Probability

The factors influencing P_{LFN} (Figures B-3 and B-4), as determined by the Expert Panel on Characterization Testing, include factors that not only affect P_{LFN} but also can discriminate between and among options. Some factors were included on the influence diagram for completeness if it was not certain that the factor could discriminate between and among options. The more important factors are enclosed within two ellipses.

Four factors affect P_{LFN} (Figures B-3 and B-4): *inaccurate data* (3), but more importantly, the *inability to obtain data to refute erroneous observations and interpretations* (6), *inaccurate models and/or analysis* (2), and *insufficient data* (4).

The inability to obtain data to refute erroneous observations and interpretations (6) is affected by six factors: *the inability to design or conduct engineered barrier tests* (18), *inadequate resources and/or infrastructure* (24), and whether the *option requires changing test configurations* (27), but more importantly, by *test interference* (12), *insufficient ability to change and expand the testing program* (26), and the *inability to design or conduct natural barrier tests* (19). These factors show that it is important to have a well-supported, flexible test program to conduct well-designed tests, particularly those of the engineered barriers, in case it is necessary to refute erroneous observations that would cause a site to be incorrectly abandoned.

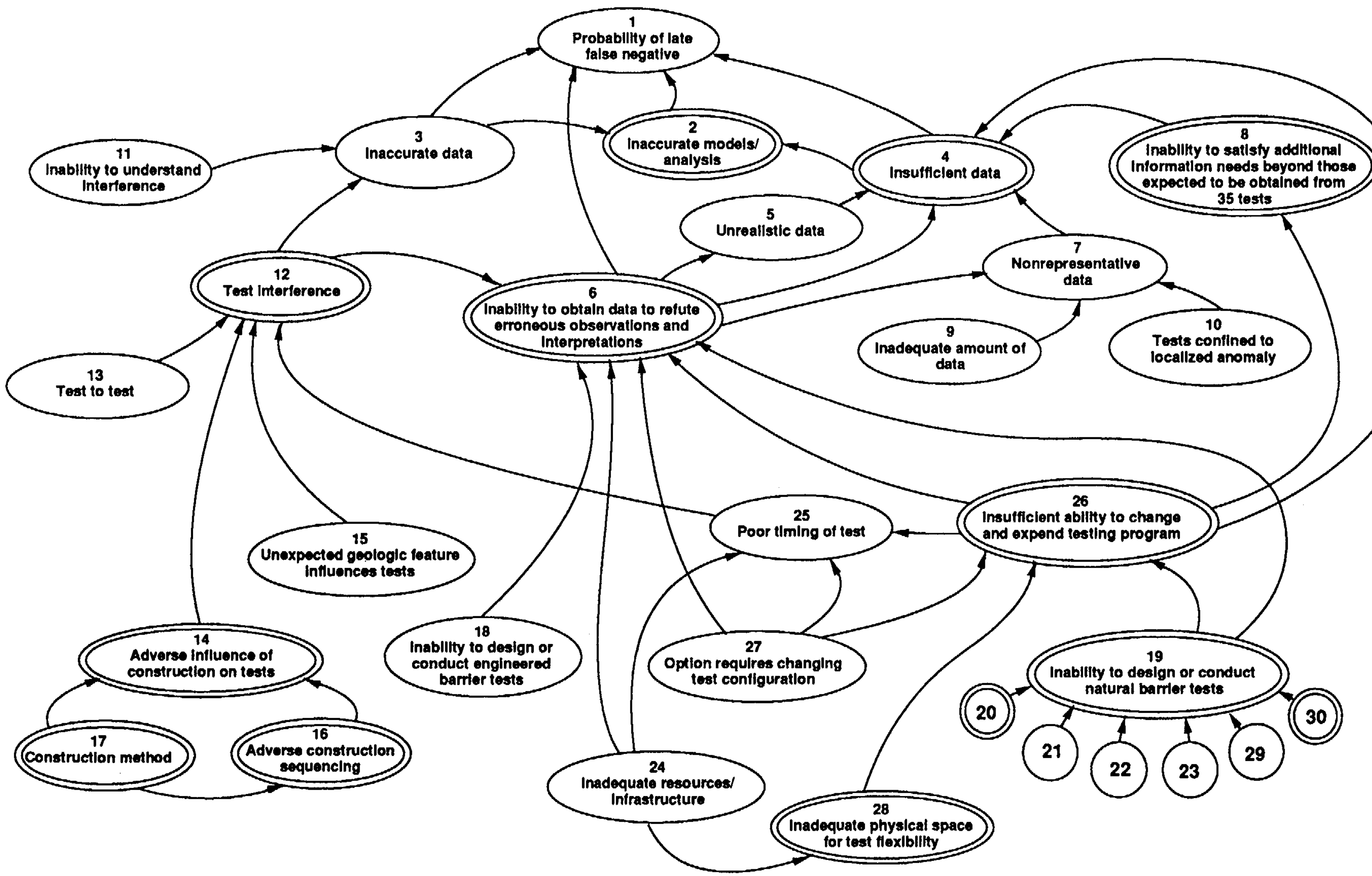

Figure B-3. Factors That Influence the Probability of Late False Negative (Page 1 of 2).

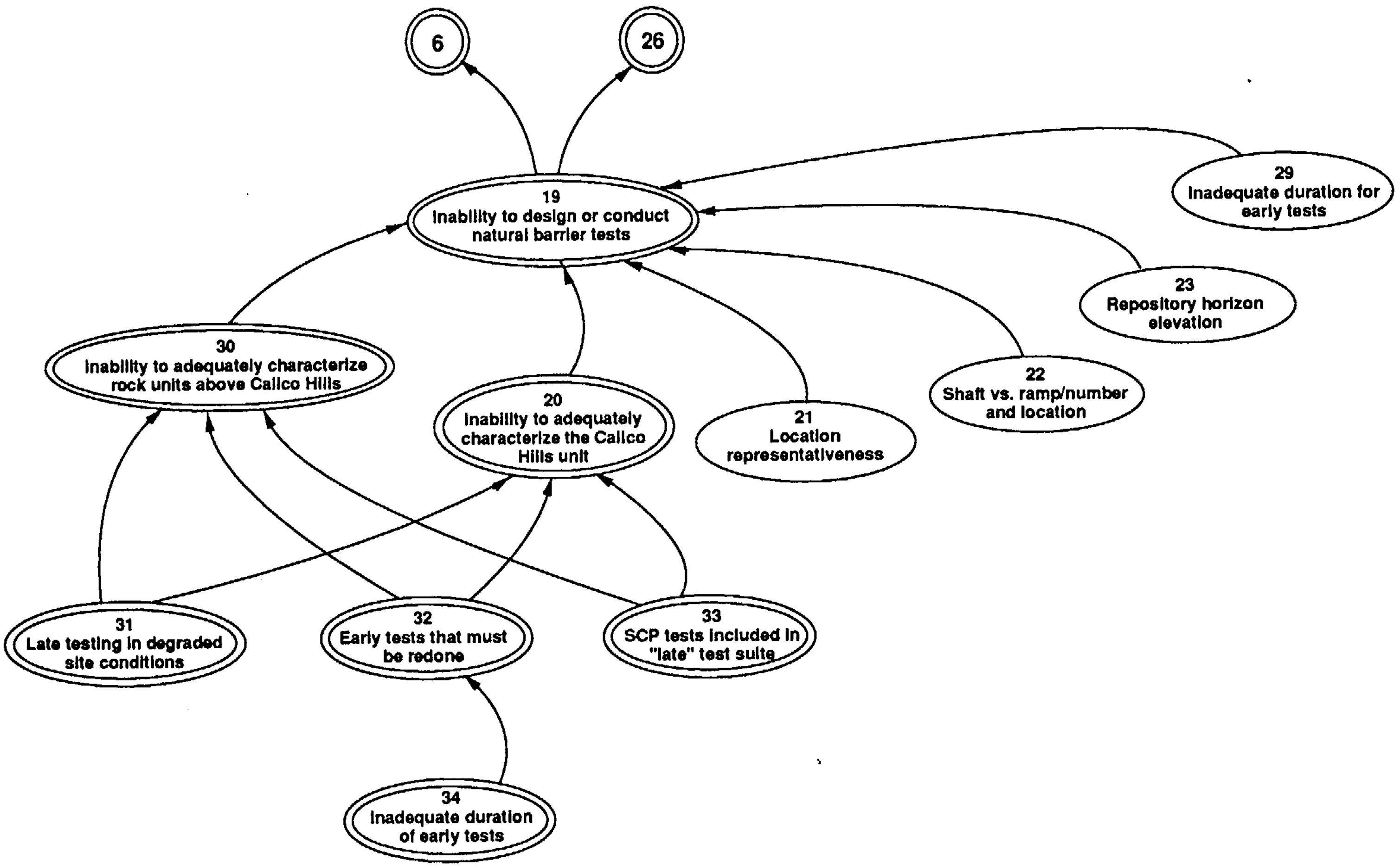

Figure B-4. Factors That Influence the Probability of Late False Negative (Page 2 of 2).

The major influence on *test interference* (12) is the *adverse influence of construction on tests* (14), which is affected by *adverse construction sequencing* (16). The *construction method* (17) affects both the *adverse construction sequencing* and the *adverse influence of construction on tests* (14). *Test interference* (12) is also affected by interference that is *test to test* (13), when an *unexpected geologic feature influences a test* (15), and by *poor timing of tests* (25). The timing of tests is most affected by an *insufficient ability to change and expand the testing program* (26). The timing of a test is less affected by *inadequate resources and/or infrastructure* (24) and whether the *option requires changing the test configuration* (27). These factors show that is is important to have a well-supported, well-timed, flexible test program to conduct well-designed tests such that the construction activities and the tests themselves do not interfere with the tests.

Insufficient ability to change and expand the testing program (26) is affected by whether the *option requires changing the test configuration* (27), but more importantly, by the *inability to design or conduct natural barrier tests* (19) and by *inadequate physical space for test flexibility* (28), which is also affected by *inadequate resources and/or infrastructure* (24). It is important to have a flexible, well-supported and well-designed test program.

Inability to design or conduct natural barrier tests (19) is affected by six factors, four of which are less important than the other two. The less important factors are: *location representativeness* (21) of the ESF, *shaft versus ramp/number and location* (22), *inadequate duration for early tests* (29), and the *repository horizon elevation* (23). The two more important factors are the *inability to adequately characterize the Calico Hills unit* (20) and the *inability to adequately characterize the rock units above the Calico Hills unit* (30). There are three important factors which affect both the ability to adequately characterize the Calico Hills unit and the ability to adequately characterize the rock units above the Calico Hills unit. These three factors are: *late testing in degraded site conditions* (31), *early tests that must be redone* (32), and the *SCP tests included in the "late" test suite* (33). Whether early tests will be redone is affected by the *inadequate duration of early tests* (34). These factors show that it is important to conduct tests in the proper places and times with a thorough understanding of the surrounding rocks, based in particular on well-conducted tests of the early test program. The location of the ESF and the accesses are less important in the late testing because the area examined in conjunction with that of the early tests will make it unlikely that an important feature is deliberately not yet examined.

Insufficient data (4) result from *non-representative data* (7), *unrealistic data* (5), and more importantly, by the following three factors: *inability to satisfy additional information needs beyond those expected to be obtained from 35 tests* (8) described in the SCP, *insufficient ability to change and expand the testing program* (26), and the *inability to obtain data to refute erroneous observations and interpretations* (6). *Unrealistic data* may be collected because of the *inability to obtain data to refute erroneous observations and interpretations* (6).

Non-representative data (7) may result from the *inability to obtain data to refute erroneous observations and interpretations.* Less important contributors to non-representative data are an *inadequate amount of data* (9) and *tests confined to a localized anomaly* (10).

The inability to satisfy additional information needs beyond those expected to be obtained from the 35 tests described in the SCP (8) is affected by an *insufficient ability to change and expand the testing program* (26).

Inaccurate data (3) are affected by the *inability to understand interference* (11), but more importantly, by the *test interference* (12) and the other factors that affect test interference.

Inaccurate models and/or analyses (2) is affected by *inaccurate data* (3), but more importantly, by *insufficient data* (4).

B.1.4 Probability of Early False Positive, P_{EFP}

The location of summary notes and transcripts documenting the development of the influence diagram for the probability of P_{EFP} test results are indicated by references in Appendix D.13.

The probability of an early false positive is the probability that early testing will indicate that the Site is "OK" even though the site is NOT OK.

B.1.4.1 Relationship to the ESF-AS Nature's Tree

Nature's Tree (ESF-AS Report, Volume 2, Section 2, Figure 2-2) includes two main branches emanating from a point of uncertainty for each option related to whether the site is OK or $\overline{OK}$. A site that is $\overline{OK}$ is one that is not suitable for the development of a geologic repository (see Section 2.3 for the definition of OK used in the ESF-AS). Each of the major branches leads to a point of uncertainty. The test outcomes may show that the parameters for conceptual models of the site are either "OK" or "$\overline{\text{OK}}$." Conceptual models of the site are representations of the characteristics and conditions of the site, including processes that are ongoing. The probability of P_{EFP} is the conditional probability, P("OK-ET" | $\overline{\text{OK}}$), that early testing will indicate that the site is "OK" even though the site is NOT OK.

B.1.4.2 Factors Influencing the Probability

The factors influencing P_{EFP}, as determined by the Expert Panel on Characterization Testing, are shown in Figure B-5. These are the factors that affect P_{EFP} as well as discriminate between and among options. If it was not certain that the factor could discriminate between and among options, those factors were included on the influence diagram for completeness. The more important factors are enclosed within two ellipses.

Three factors affect P_{EFP} (Figure B-5): *inaccurate models and/or analyses* (2), but more importantly, *misjudged global characteristic* (3) and *missed adverse feature* (4), both of which with *non-representative data* (6) also importantly affect *inaccurate models and/or analyses*. The term "global" refers to the complete volume encompassing the site. One important factor that ultimately affects *inaccurate models and/or analyses* (2), *misjudged global characteristic,* (3) and *missed adverse feature* (4), is the *inability to design or conduct natural barrier tests* (14), which is described in the following paragraph. The natural barrier tests will be conducted to determine how well the natural features of the site perform as a barrier to radionuclide migration.

Inability to Design or Conduct Natural Barrier Tests. The inability to design or conduct natural barrier tests is affected by eight factors. Three factors of lesser importance are *inadequate physical space* (13) in the ESF to conduct tests, the *repository horizon elevation* (16), and *inadequate duration for the early tests* (22). These factors suggest that to be properly interpreted, the tests should be of a sufficient size and in the appropriate location as determined partly on the results of early tests. The five more important factors are *shaft versus ramp/number and location* (15), *location representativeness* (17) of the ESF, the *inability to adequately characterize the Calico Hills unit* (18), the *inability to adequately characterize the rock units above the Calico Hills unit* (24), and the

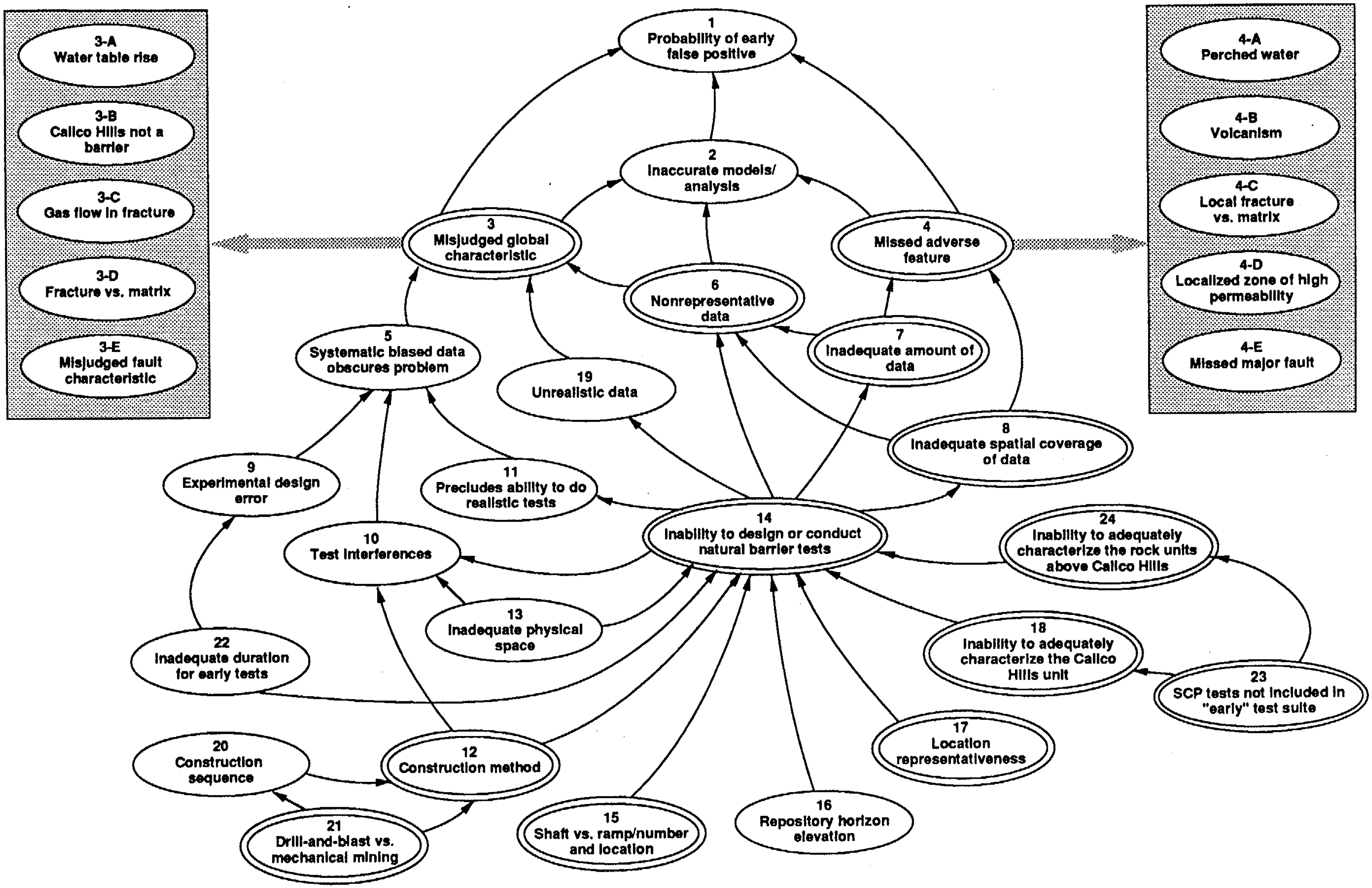

Figure B-5. Factors That Influence the Probability of Early False Positive.

construction method (12), which is affected by the *construction sequence* (20), but more importantly, by the mining methods; that is, *drill and blast versus mechanical mining* (21), which also affect the *construction sequence*. The *inability to adequately characterize the Calico Hills unit* (18) and the units above (24) are also significantly affected by whether *SCP tests are not included in the "early" test suite* (23). Again, these factors show that it is important to conduct the tests in the appropriate location, where the rocks are well understood and relatively unaffected by activities in the ramps and shafts, and by the construction method. The number of shafts and ramps are also important because of the amount, type, and locations of the data that can be gathered.

Inaccurate models and/or analyses (2) are affected by *misjudged global characteristics* (3), *missed adverse feature* (4), and *non-representative data* (6). A misjudged "global" characteristic is a widespread feature of the site that is misjudged. Five important possible misjudged global characteristics (Figure B-3) may lead to inaccurate models or analyses (2): a *water table rise* (3-A); *Calico Hills unit as a non-barrier* (3-B); *gas flow in fractures* (3-C); whether flow is *fracture versus matrix groundwater flow* (3-D); and *misjudgment of a fault characteristic* (3-E). *Misjudged global characteristics* (3) may be misjudged because of *unrealistic data* (19) and because *systematically biased data obscures the problem* (5), but the more significant cause is likely to be *non-representative data* (6). Unrealistic data are those that do not correctly describe the feature of interest. The systematically biased data, however, could be used to describe a feature if the biases were known. Non-representative data are correct but they do not adequately represent the true characteristics of concern.

Unrealistic data (19) are affected significantly by the *inability to design or conduct the natural barrier tests* (14) and the factors that affect that ability are described above. Whether *systematically biased data obscure the problem* (5) is determined by whether the option *precludes the ability to do realistic tests* (11), *test interferences* (10), and *experimental design error* (9), which is affected by an *inadequate duration for early tests* (22). *Test interferences* are affected less significantly by *inadequate physical space* (13) and more importantly, affected by the *construction method* (12). Construction method is affected by the *construction sequence* (20), but more importantly, by the issue of *drill and blast versus mechanical mining* (21), which also affects the *construction sequence* (20). Again, these factors show that it is important to conduct tests, particularly the natural barrier tests, in locations where the rocks are well characterized and relatively unaffected by construction methods or features.

The major contributors to *non-representative data* (6) are *inadequate spatial coverage of data* (8), an *inadequate amount of data* (7), and the *inability to design or conduct natural barrier tests* (14), which also affects the adequacy of the amount and coverage of data. These factors show that it is important to collect a sufficient amount of data in a sufficient number of places, particularly data from the natural barrier tests.

There are five important possible missed *adverse features* (4): *perched water* (4-A), *volcanism* (4-B), *local fracture versus matrix flow* (4-C), *localized zone of high permeability* (4-D), and *missed major fault* (4-E). Missed adverse features result principally from *inadequate spatial coverage of data* (8) and *inadequate amount of data* (7), both of which are influenced by the *inability to design or conduct natural barrier tests* (14). These factors show that it is important not to miss an adverse feature by collecting too few data in too few locations, particularly from the natural barrier tests. The amount of data that is collected is particularly important. Some panel members believed more data are helpful; some believed that in certain instances, more data could be detrimental.

B.1.5 Probability of Late False Positive, P_{LFP}

The location of summary notes and transcripts documenting the development of the influence diagram for the probability of P_{LFP} test results are indicated by references in Appendix D.13.

The probability of a P_{LFP} is the probability that late testing will indicate that the site is "OK" even though the site is NOT OK and early testing indicates that the site is "OK."

B.1.5.1 Relationship to the ESF-AS Nature's Tree

Nature's Tree (ESF-AS Report, Volume 2, Section 2, Figure 2-2) includes two main branches emanating from a point of uncertainty for each option related to whether the site is OK or $\overline{OK}$. A site that is $\overline{OK}$ is one that is not suitable for the development of a geologic repository (see Section 2.3 for the definition of OK used in the ESF-AS). Each of these branches leads to a point of uncertainty. The test outcomes may show that the parameters for conceptual models of the site are either "OK" or "$\overline{OK}$." Conceptual models of the site are representations of the characteristics and conditions of the site, including processes that are ongoing. The probability of a P_{LFP} is the conditional probability that late testing indicates the site is OK even though the site is NOT OK, and early testing indicates that the site is "OK", P ("OK-LT" | $\overline{\text{OK-ET}}$, OK).

B.1.5.2 Factors Influencing the Probability

The factors influencing the P_{LFP}, as determined by the Expert Panel on Characterization Testing (Figure B-6), include factors that not only affect P_{LFP} but also can discriminate between and among options. Some factors were included on the influence diagram for completeness if it was not certain that the factor could discriminate between and among options. The more important factors are enclosed within two ellipses.

Three important factors affect P_{LFP} (Figure B-6): *inaccurate models/analysis* (2), *misjudged global characteristic* (3) and *missed adverse feature* (4). One important factor that ultimately affects *inaccurate models/analysis* (2), *misjudged global characteristic,* (3) and *missed adverse feature* (4) is the *inability to design or conduct natural barrier tests* (14). The natural barrier tests will be conducted to determine how well the natural features of the site perform as a barrier to radionuclide migration.

The inability to design or conduct natural barrier tests (14) is affected by eight factors, three of which are not as important as the other five. The three important factors are *inadequate physical space* (13) in the ESF to conduct tests, the *repository horizon elevation* (16), and *inadequate duration for the late tests* (22). The five more important factors are: *shaft versus ramp/number and location* (15), *location representativeness* (17) of the ESF, the *inability to adequately characterize the Calico Hills unit* (18), the *inability to adequately characterize the rock units above the Calico Hills unit* (24), and the *construction method* (12), which is affected by the *construction sequence* (20), but more importantly, by the issue of *drill and blast versus mechanical mining* (21), which also affects the *construction sequence.* The ability to characterize the Calico Hills unit is affected by both *late testing in degraded site conditions* (25) and the *SCP tests not included in the "late" test suite* (23), which also affects *late testing in degraded site conditions* (25) which is affected by the *early tests that must be redone* (26). *Inadequate duration of early tests* is an important influence on the *early tests that must be redone,* which in turn affects the ability to characterize the rocks above the Calico Hills unit. All these factors show that in order to correctly conduct and interpret the natural

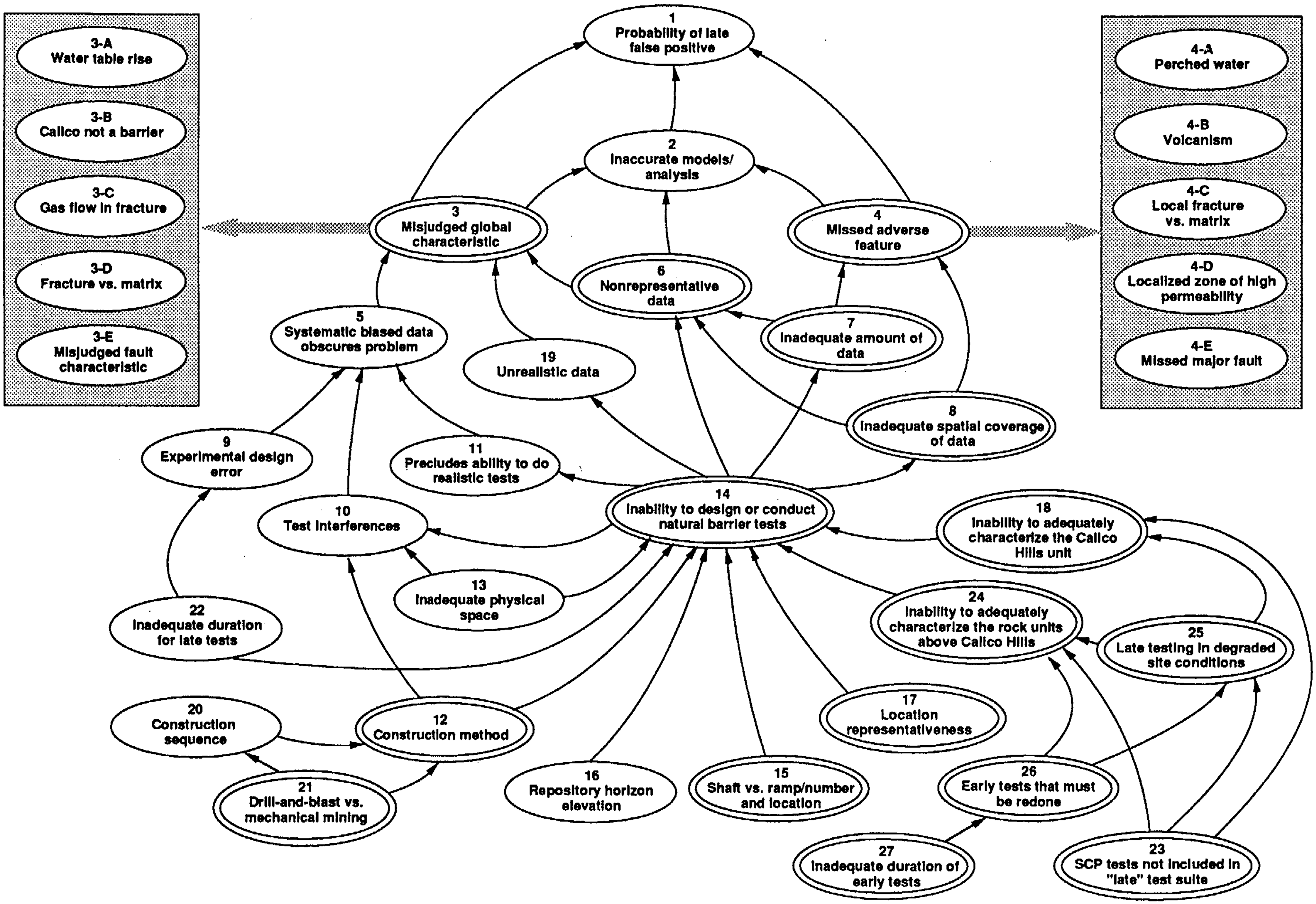

Figure B-6. Factors That Influence the Probability of Late False Positive.

barrier tests, the tests should be conducted in representative rocks that have not been adversely affected by construction features and methods. The surrounding rocks must also be well characterized, particularly by earlier tests of adequate duration that were performed well. Again, the number and locations of the ramps and shafts were particularly important to the panel members because of the differences in the data that will be collected.

Inaccurate models and/or analyses (2) are affected most by *misjudged global characteristics* (3), *missed adverse features* (4), and *non-representative data* (6). Five important possible misjudged global characteristics (Figure B-6) are: *water table rise* (3-A), *Calico Hills unit not a barrier* (3-B), *gas flow in fractures* (3-C), *fracture versus matrix flow* (3-D), and *misjudgment of a fault characteristic* (3-E). Global characteristics may be misjudged if *unrealistic data* (19) are collected or *systematically biased data obscures the problem* (5). A more important influence is *non-representative data* (6). Unrealistic data are those that do not correctly describe the feature of interest for one or more of many possible reasons. The systematically biased data, however, could be used to describe a feature if the biases were known. Non-representative data are correct but they do not adequately represent the true characteristics of concern.

The important causes of *unrealistic data* are the *inability to design or conduct the natural barrier tests* (14). Systematically biased data (5) are affected by whether the option *precludes the ability to do realistic tests* (11), *test interferences* (10), and *experimental design error* (9). An ESF-repository option that provides for *inadequate duration for early tests* (22) may lead to an *experimental design error* (9). Both the ability to do realistic tests and avoidance of test interferences are importantly affected by the *inability to design or conduct the natural barrier tests* (14). *Test interferences* (10) are affected by *inadequate physical space* (13) and more importantly by the *construction method* (12), which is affected by the *construction sequence* (20), but more importantly by the issue of *drill and blast versus mechanical mining* (21). The *construction sequence* also depends on the mining technique (21). These factors show that it is important to conduct tests, particularly the natural barrier tests, in appropriate locations where the rocks are well characterized and relatively unaffected by construction methods or features.

Non-representative data (16) are affected by three equally important factors: inadequate *spatial coverage of data* (8), an *inadequate amount of data* (7), and the *inability to design* *or conduct natural barrier test* (14), which also affects the adequacy of the amount and coverage of data. The factors that affect the *inability to design or conduct natural barrier tests* (14) are described in a section above. These factors show that it is important to collect a sufficient amount of data in a sufficient number of places, particularly data from the natural barrier tests.

There are five important possible *misjudged adverse features* (4): *perched water* (4-A), *volcanism* (4-B), *local fracture versus matrix* (4-C), *localized zone of high permeability* (4-D), and *missed major fault* (4-E). Missed adverse features result principally from *inadequate spatial coverage of data* (8) and *inadequate amount of data* (7), both of which are importantly affected by the *inability to design or conduct natural barrier test* (14). These factors show that is is important not to miss an adverse feature by collecting too few data in too few locations, particularly from the natural barrier tests. The amount of data that is collected is particularly important. Some panel members believed more data are helpful; some believed that in certain instances, more data could be detrimental.

B.1.6 Probability That the Site is OK, P_{OK}

B.1.6.1 Relationship to the ESF-AS Nature's Tree

The Expert Panel on Postclosure Health and Safety developed the influence diagram for the probability that the site is OK (P_{OK}). The first uncertainty in Nature's Tree (ESF-AS Report, Volume 2, Section 2, Figure 2-2) is concerned with the true site conditions. The definitions used in the ESF-AS Nature's Tree were developed in consultation with the members of the Expert Panels on Characterization Testing and Postclosure Health.

The results of any testing or experiment program may lead to potentially erroneous conclusions. It is possible that testing could incorrectly reject an acceptable site. The terminology used in experimental test designing refers to this result as a false negative condition, meaning the testing program falsely indicated the site was not adequate. Testing might incorrectly identify an unacceptable site as acceptable. This is referred to as a false positive condition. The ESF-AS Nature's Tree is a complete listing of all the possible testing outcomes, correct or incorrect, for both the early and the late testing programs.

Concepts such as false positive and false negative have meaning only if the probable true states of nature are clearly defined. We assume characterization testing is designed to determine the true state of nature. The ESF-AS Nature's Tree is a greatly simplified statement of the true states of nature.

The ESF-AS Nature's Tree expresses in two simple states of nature at the Yucca Mountain site. The site is either OK or it is $\overline{\text{OK}}$ (NOT OK). The ESF-AS defined OK as unambiguously as possible. The site is OK if

> *the site characteristics and conditions, including the ongoing processes are such that, if the specified ESF-repository option were constructed, operated, and closed at the site, the resulting geologic system would meet the EPA radionuclide release limits for 10,000 years after closure.*

This definition states that P_{OK} is different for each option. The panels agreed that the term "site" in the definitions for OK and $\overline{\text{OK}}$ include the Mined Geologic Disposal System (MGDS). The site includes the site characteristics as well as the degradation resulting from construction of an ESF-repository. This definition required an assessment of P_{OK} for each option. Furthermore, the definition of OK requires an assessment of the likelihood that radionuclide releases will be less than the EPA standard for 10,000 years after closure.

B.1.6.2 Factors Influencing the Probability

The influence diagrams for radionuclide releases are presented in Section B.1.9. These influence diagrams were used to assess the likelihood that releases to the accessible environment will be less than the release standards. These diagrams summarize all the factors that were taken into account regarding radionuclide releases, including groundwater transport, adverse effects to the engineered barrier system, the natural barrier system, and the waste package.

B.1.7 Likelihood of Construction/Operation Approval, P_{APP}

The location of summary notes and transcripts documenting the development of the influence diagram for the likelihood of approval are indicated by references in Appendix D.12.

B.1.7.1 Relationship to the ESF-AS Decision Tree

The Likelihood of Construction and/or Operation Approval, also called the Probability of Regulatory Approval, P_{APP}, is part of the Decision Tree (ESF-AS Report, Volume 2, Section 2, Figure 2-1). For this study, the approval concerned construction and operation of the repository after the results of both the early and late tests in the ESF show that the site is "OK." The approvals in question include, but are not restricted solely to, approvals from the DOE, the NRC, the United States Congress, and the President.

B.1.7.2 Factors Influencing the Probability

The factors influencing the P_{APP}, as determined by the Expert Panel on Regulatory Considerations, are the factors that not only affect P_{APP} but also can discriminate between and among options. Some factors were included on the influence diagram for completeness, even if it was not certain that the factor could discriminate between and among options. The more important factors were enclosed within two ellipses.

Two important factors affect P_{APP} (Figure B-7): *technical confidence* (2) and *procedural confidence* (3). In some cases, it is difficult to separate technical and procedural issues. In a general sense for this panel, the technical issues concern factors that can be calculated or measured and the procedural issues concern how well the procedural aspects, such as compliances with regulations, are handled.

Technical Confidence. *Technical confidence* is affected by two important factors, *consequence estimates* (4), and *residual uncertainty estimates* (5). The *residual uncertainty* (5) concerns the ability of the repository to be successful and is affected by the judgments which are shown as P(OK | "OK-ET," "OK-LT") (10), which is the probability that the site is NOT OK even though the results of early and late testing indicate that the site is "OK." The Expert Panel on Regulatory Considerations considered estimates of P(OK | "OK-ET," "OK-LT") that were calculated from other estimates made by the Expert Panel on Characterization Testing.

The *consequence estimates* (4) are the health, environmental, and economic cost consequences of having a repository. The consequence estimates are affected by *preclosure* (8) and *postclosure* (9) consequences. The postclosure consequences are mainly affected by *aqueous releases of radionuclides* (15) from the repository. The

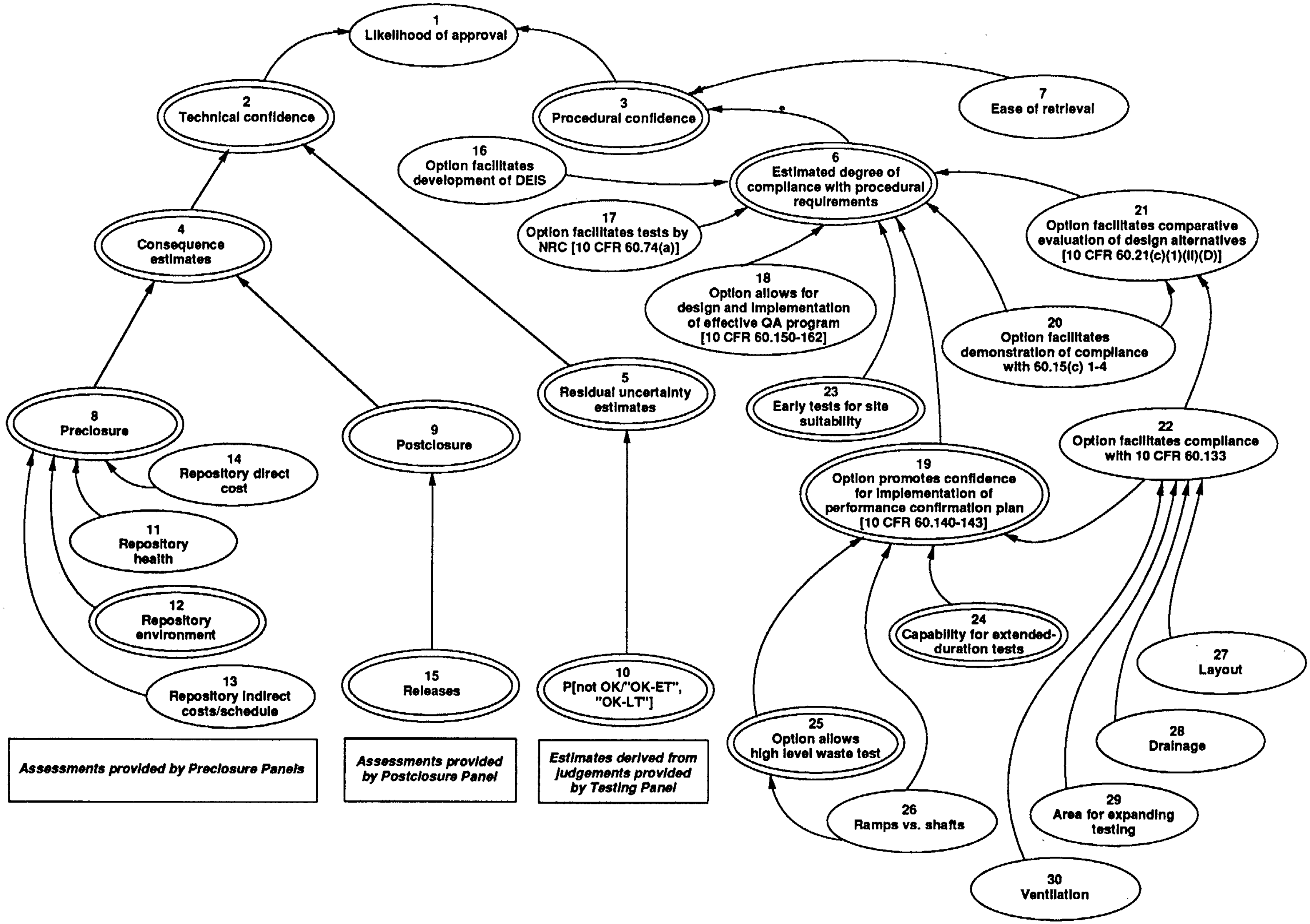

Figure B-7. Factors That Influence the Likelihood of Construction and/or Operation Approval.

Expert Panel on Regulatory Considerations considered the assessments of the releases provided by the Expert Panel on Postclosure Health. The preclosure consequences are mainly affected by the *effects of the repository on the environment* (12) and to a lesser extent by *repository health effects* (11), *repository indirect costs and schedule* (13), and *repository direct costs* (14). The Expert Panel on Regulatory Considerations considered the assessments of the preclosure effects of the repository provided by the preclosure panels. The cost and schedule and direct cost effects are measured in time and money. The health effects considered were radiological effects on the public and workers and nonradiological effects on the workers. The environmental effects considered were aesthetic and historical, including visual impacts and disturbed areas.

Procedural Confidence. The procedural confidence is affected by the *ease of retrieval* (7) of the waste packages, but is more affected by the *estimated degree of compliance with procedural requirements* (6), which itself is affected by seven factors, two of which are more important than the other five. Easier retrieval and greater compliance increase the probability of approval. Three of the less important factors that affect the procedural compliance are the ESF *option facilitates development of the Draft Environmental Impact Statement* (DEIS) (16), the capacity of the *option to facilitate tests by the NRC* (17), and the *option allows for design and implementation of an effective QA program* (18). The other two less important factors are the ESF *option facilitates demonstration of compliance with 10 CFR 60.15(c)1-4* (20) (which describes requirements of the site characterization program), which affects the estimated *degree of compliance with procedural requirements* (6) directly, and the *option facilitates comparative evaluation of design alternatives* (21), which is also affected by the compliance with 10 CFR 60.15(c)1-4. Whether the option facilitates evaluation of the design alternatives is also affected by whether the option *facilitates compliance* with *10 CFR 60.133* (22) (which concerns design criteria for the underground facility), which itself is affected by the repository *layout* (27), *drainage* (28), *area for expanding testing* (29), and *ventilation* (30). These factors are those of the design criteria that can discriminate between and among options.

The two more important factors that affect the *estimated degree of compliance with procedural requirements* (6) are how well the option allows *early tests for site suitability* (23) and how well the *option promotes confidence for implementation of the performance confirmation plan* (19). Early tests for site suitability and confidence for implementation of the performance confirmation plan will increase P_{APP}. How well the option promotes confidence for implementation of the performance confirmation plan is affected by the number of *ramps versus shafts* (26) that are needed, but is more affected by the option's *capability for extended duration tests* (24) and whether the *option allows the HLW test* (25) which is also affected by the number of *ramps versus shafts* (26) that are needed. These factors were included because interested parties have expressed an interest to the DOE concerning them.

B.1.8 Likelihood of Retrieval, P_{RET}

The location of summary notes and transcripts documenting the development of the influence diagram for the likelihood of retrieval are indicated by references in Appendix D.12.

B.1.8.1 Relationship to the ESF-AS Decision Tree

The likelihood of retrieval, also called the probability of waste retrieval, P_{RET}, is the complement of the probability of repository closure, P_{CLO}, on the Decision Tree (ESF-AS Volume 2, Section 2, Figure 2-1). The two probabilities sum to 1. This relationship implies that for this study either the repository will be closed successfully, or the waste will be retrieved and the repository will not be closed successfully. That is, for this study, the only two possible outcomes after the repository has been constructed and operated are that the waste is retrieved at some point or the repository is closed and the waste is never retrieved.

B.1.8.2 Factors Influencing the Probability

The factors influencing the P_{RET}, as determined by the Expert Panel on Regulatory Considerations (Figure B-8), are the factors that not only affect P_{RET} but also discriminate between and among options. Some factors were included on the influence diagram for completeness if it was not certain that the factor could discriminate between and among options. The more important factors were enclosed within two ellipses.

Two factors affect P_{RET}: *insufficient procedural confidence* (3); but more importantly, *insufficient technical confidence* (2) (Figure B-8). The technical and procedural issues can be difficult to separate. In a general sense, the technical issues refer more to

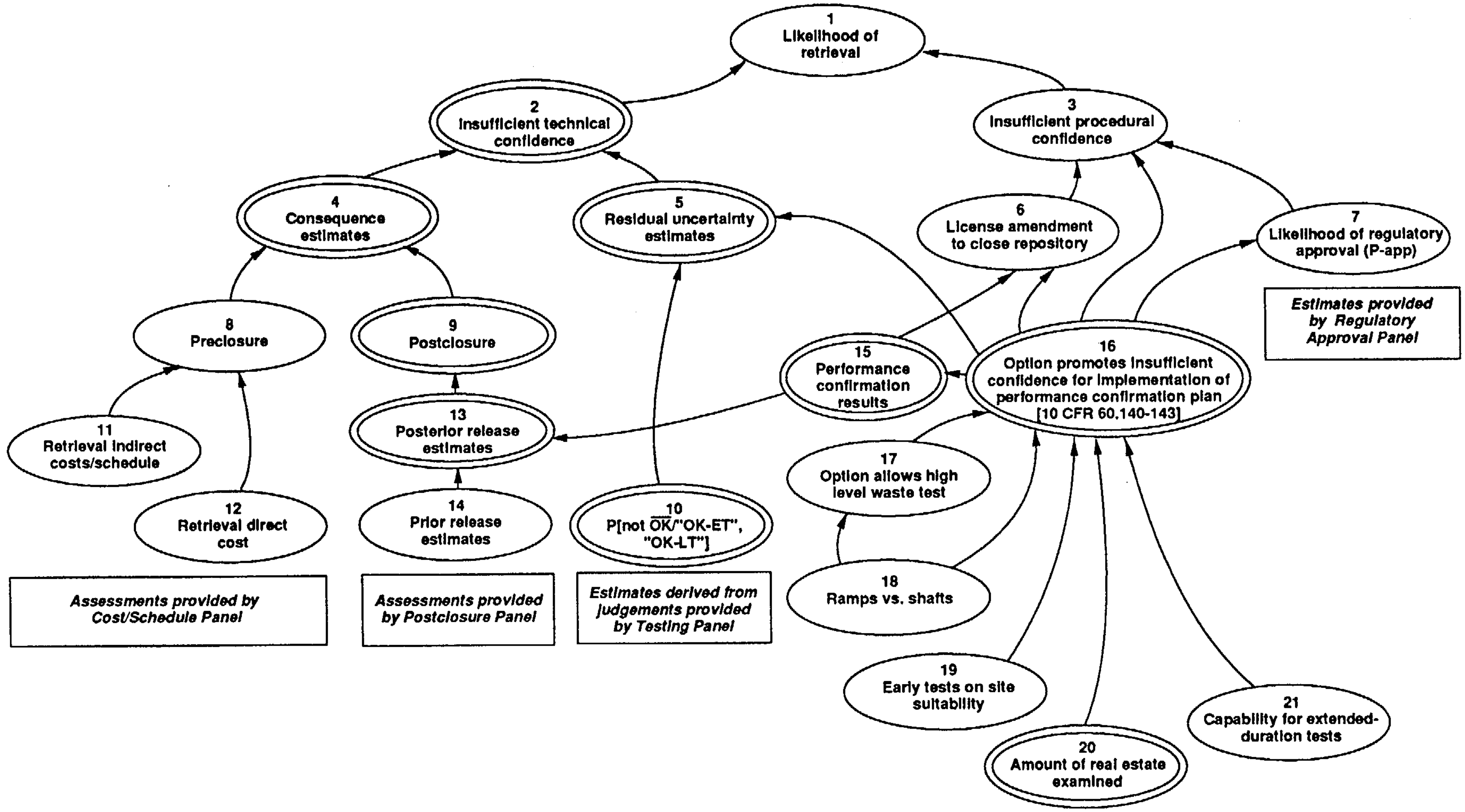

Figure B-8. Factors That Influence the Likelihood of Retrieval.

factors that can be calculated or measured and the procedural issues refer to how well those issues are handled.

Insufficient Technical Confidence. The sufficiency of technical confidence is affected by two important factors, *consequence estimates* (4) and *residual uncertainty estimates* (5). The residual uncertainty concerns the ability of the repository to be successful. This residual uncertainty P($\overline{\text{OK}}$ | "OK-ET," "OK-LT") (10) is the probability that the true site conditions are NOT OK even though the results of early and late testing indicate that the site is "OK." Whether the *option promotes insufficient confidence for implementation of the performance confirmation plan* (16) has an important effect on the *residual uncertainty estimates* (5). A well implemented performance confirmation plan would help to prevent unnecessary retrievals and aid in necessary retrieval. The *confidence for implementation of the performance confirmation plan* is affected by five factors, but most importantly by the *amount of real estate examined* (20) in the ESF. The *real estate examined* (20) refers to the rock exposed by drilling and excavation for scientific studies and site characterization. The other four factors that affect the *confidence for implementation of the performance confirmation plan* (16) are whether the *option allows for the HLW test* (17), the option permits early *tests for site suitability* (19), the *capability for extended duration tests*, and the number of *ramps versus shafts* (18) in the repository, which also affects whether there can be an HLW test. Those options that permit the appropriate tests will increase confidence for the implementation of a performance confirmation plan.

The *consequence estimates* (4) are the estimates of the important consequences that result from having a repository, including health, safety, cost, and environmental consequences. The consequence estimates are affected by *preclosure* (8) consequences, but more importantly by *postclosure* (9) consequences. The preclosure consequences are affected by the *retrieval indirect costs/schedule* (11) and *retrieval direct costs* (12), the assessments of which are provided by the Expert Panel on Cost and Schedule. The postclosure consequences are mainly affected by posterior release estimates (13) (those estimates made after closure), which are affected by the *prior release estimates* (those estimates made before closure), the assessments of which are supplied by the Expert Panel on Postclosure Health, but the *posterior release estimates* are more importantly affected by the *performance confirmation results* (15). The *performance confirmation results* are affected by whether the *option promotes insufficient confidence for implementation of the performance confirmation plan* (16), which is described in the preceding paragraph. These factors reflect that the technical confidence will be affected by how well estimates compare with prior estimates and actual measurements.

Insufficient Procedural Confidence. The sufficiency of the procedural confidence is affected by the *license amendment to close the repository* (6), the *likelihood of regulatory approval*, P_{APP} (7), the estimates of which are provided by the Expert Panel on Regulatory Considerations, and most importantly, by whether the *option promotes insufficient confidence for implementation of the performance confirmation plan* (16), which also affects the *likelihood of regulatory approval* (7) and the *license amendment to close the repository* (6), which is also importantly affected by the *performance confirmation results*, which is also affected by whether the *option promotes insufficient confidence for implementation of the performance confirmation plan* (16). The factors that affect the confidence of the performance confirmation plan are described above in the first paragraph concerning insufficient technical confidence. In summary, the ability to gain approval for prior requirements will tend to promote procedural confidence.

B.1.9 Postclosure Radiologic Health Impacts, X_1

The location of summary notes and transcripts documenting the development of the influence diagram and performance-measure scales for the postclosure health impacts are indicated by references in Appendix D.4.

B.1.9.1 Objective

The objectives for the postclosure health concerns at the ESF-repository were established by proposing alternative sets of postclosure objectives and then evaluating these alternative objectives.

One objective was identified that might be affected by the choice of the ESF configuration.

Minimize adverse impacts on public health during the postclosure period.

A surrogate for this objective was identified in order to represent more quantitatively the abstract objective of minimizing adverse impacts.

Minimize the number of health effects resulting from a particular ESF-repository design.

The Expert Panel on Postclosure Health and Safety judged that experts could estimate the increase or decrease in numbers of health effects that would result from each ESF-repository alternative. The estimates could be based on available data and calculations. The number of health effects was selected as a good indicator of the degree to which the higher level objective would be achieved. Health effects were used in the risk assessment conducted by the EPA to establish the environmental standards for geologic disposal under 40 CFR Part 191, Subpart B (EPA, 1987). The health effects of concern were the premature cancer deaths that could result from exposure to radionuclides released from the repository to the accessible environment. Genetic effects that could result from exposure to these radionuclides were also considered by the EPA but the results of detailed evaluations led to the conclusion that genetic effects are not likely to be significant in comparison with somatic effects.

B.1.9.2 <u>Factors Influencing the Performance Measure</u>

Four groups of influences were identified (Figure B-9). Each group is organized in an influence diagram: (1) health effects that may result from the releases to the accessible environment (Figure B-10), (2) radionuclide transport through natural barriers (Figure B-11), (3) transport through the engineered-barrier system (Figure B-12), and (4) changes to the waste disposal system that may influence releases from the waste package (Figure B-13).

<u>Health Effects</u>. The performance objective for postclosure health and safety was to

Minimize adverse impacts on public health during the postclosure period.

The performance measure selected to measure adverse impacts on public health during the postclosure period was

the number of health effects to the public during the postclosure period.

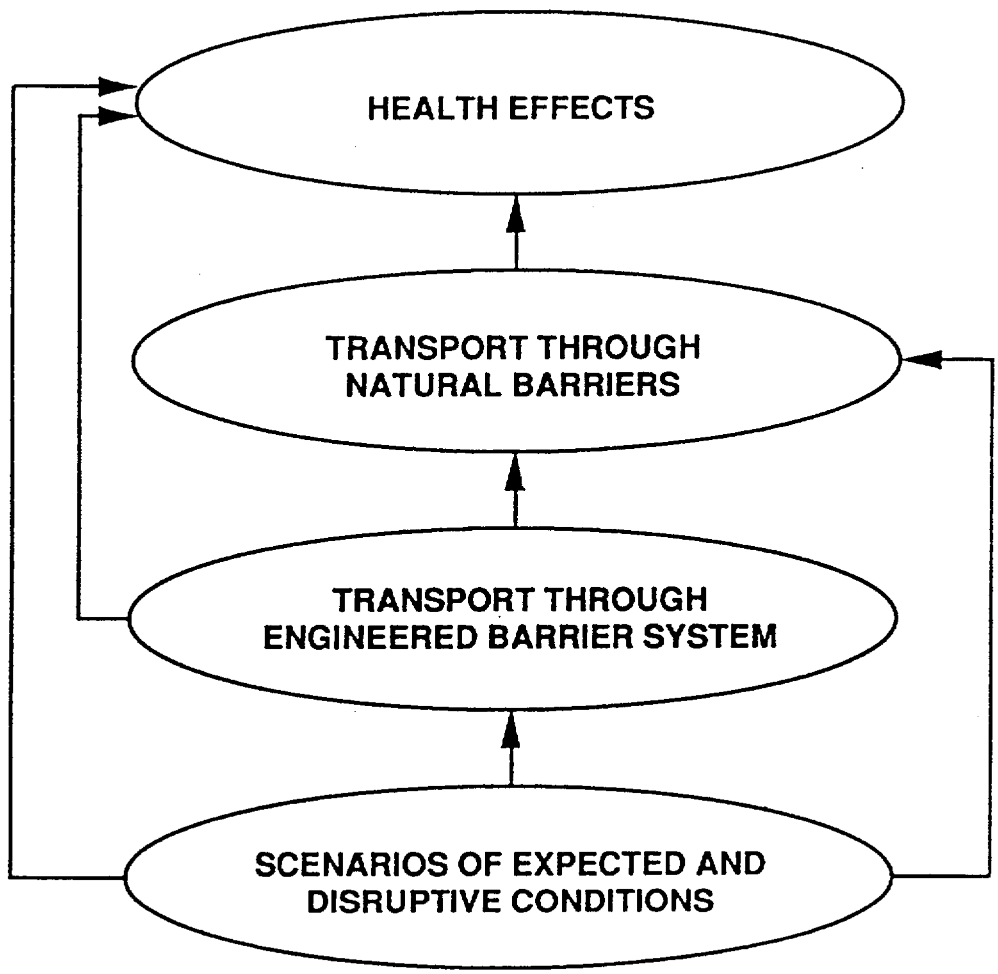

Figure B-9. Influence Diagram for Postclosure Health Effects Attributable to the Repository During the First 10,000 Years After Closure.

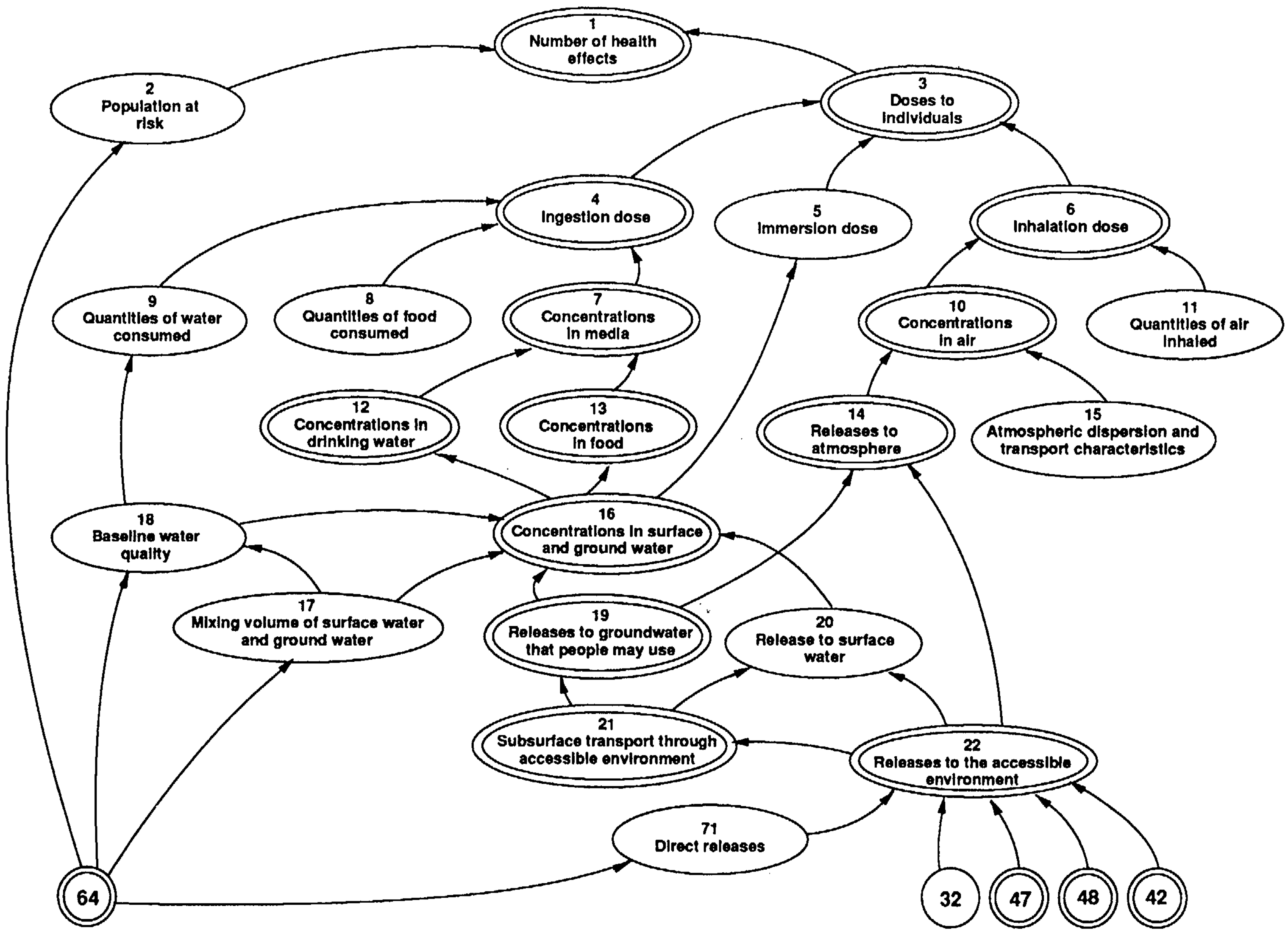

Figure B-10. Factors That Influence the Number of Postclosure Health Effects Attributable to the ESF-Repository Health Effects Portion (Page 1 of 4).

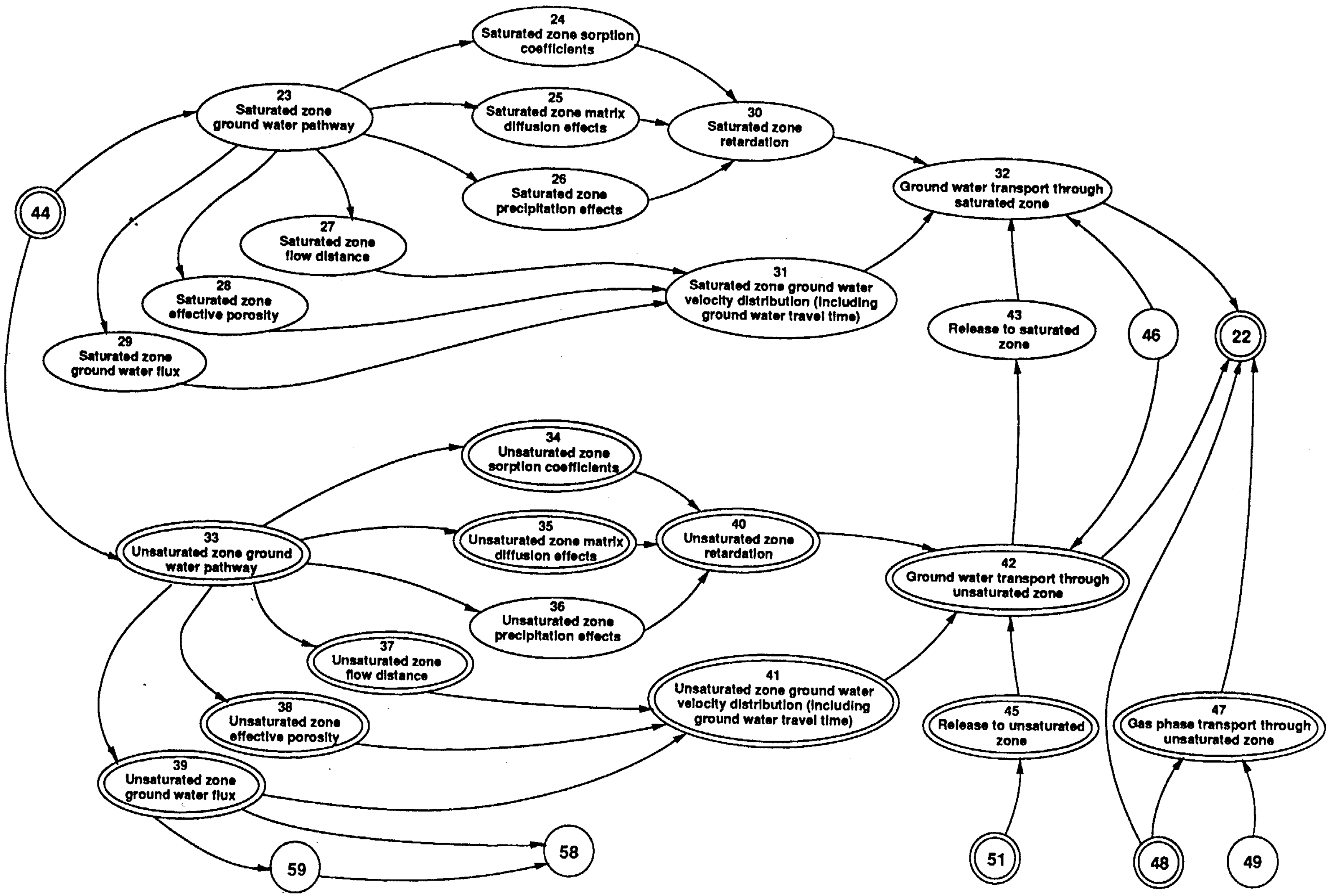

Figure B-11. Factors That Influence the Number of Postclosure Health Effects Attributable to the ESF-Repository Transport Through Natural Barriers Portion (Page 2 of 4).

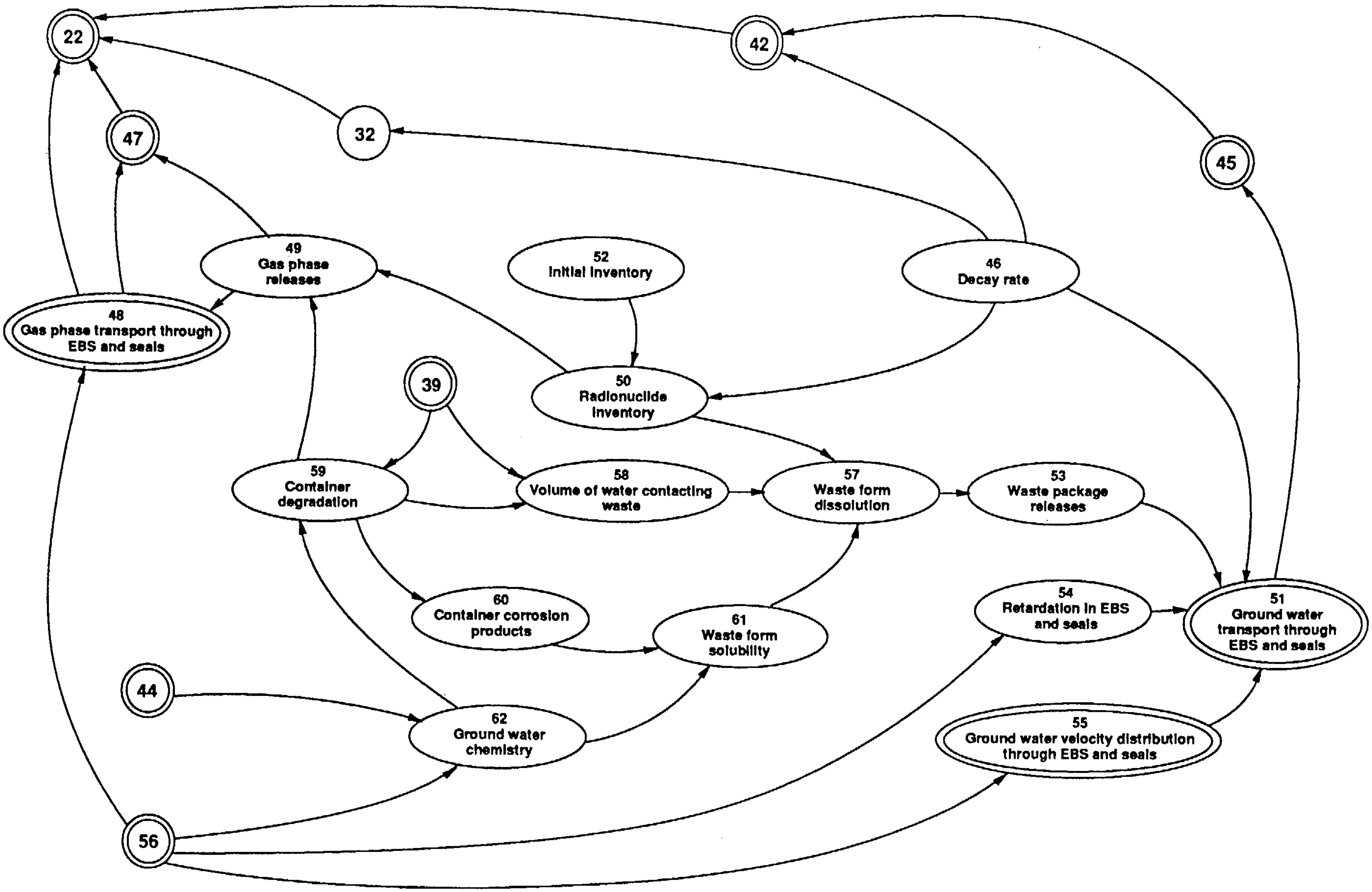

Figure B-12. Factors That Influence the Number of Postclosure Health Effects Attributable to the ESF-Repository Engineered Barrier System (ESB) Portion (Page 3 of 4).

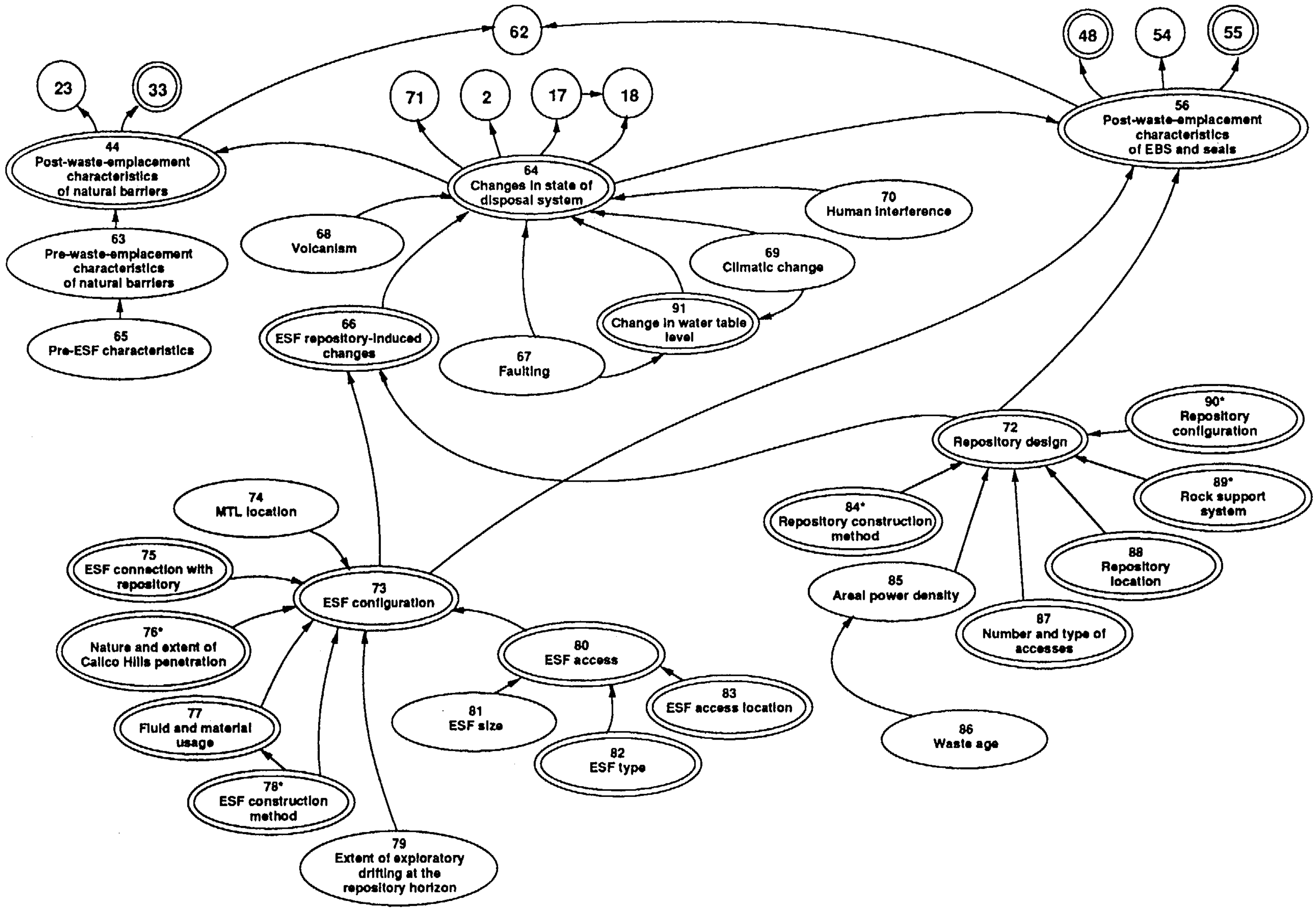

Figure B-13. Factors That Influence the Number of Postclosure Health Effects Attributable to the ESF-Repository Scenario Portion (Page 4 of 4).

This performance measure is the highest level factor in the influence diagram (Figure B-10, 1). The factors that influence the number of health effects are the *population at risk* after the repository is closed (2) and the *doses to individuals* in the population at risk (3). *The population at risk* (2) is influenced by *changes in the state of the disposal system* (Figure B-13, (64)). These changes are influenced by factors that may change the state of the repository. These factors will be discussed along with the influence diagram for scenarios. Basically, Figure B-10 summarizes the influencing factors between *releases to the accessible environment* (22) and the actual health effects that could occur.

Radiation doses (3) are grouped by three types: *ingestion, immersion,* and *inhalation* (4, 5, and 6, Figure B-10). The least likely source of dose to the population is *immersion* (5), which is determined by the *concentrations of radionuclides in surface and groundwater* (16).

Radiation doses resulting from *ingestion* (4) and *inhalation* (6) are related to several major factors that are all influenced by a common factor, *releases to the accessible environment* (22).

By definition, once radionuclides have reached the accessible environment, they are available to the *atmosphere* (14), to *surface water* (20), and for *transport through the subsurface in the accessible environment* (21). Groundwater transport in the subsurface, as it is influenced by various scenarios in the future (64, Figure B-13), may carry radionuclides to *groundwater sources that people may use* (19). Radionuclides in the *groundwater and surface water* (19 and 20) in conjunction with the *baseline water quality* (18) and any *volumetric mixing of the surface water and groundwater* (17) determine the *concentrations of radionuclides in the surface and groundwater* (16). These concentrations are directly available for doses to the population at risk by *immersion* (5) and from *drinking water* (12) and *food* (13). The doses received by the population are determined not only by the concentrations of radionuclides in food and water (7), but also by the *quantities of food and water consumed* (8 and 9). The quantity of water consumed may vary depending on the *quality* of the water prior to any contamination by radionuclides (18), which is determined by a number of scenarios that may change the accessible environment (64), as well as any *mixing of surface water and groundwater* that may occur (17).

The main pathway of radionuclide concentrations available for *inhalation doses* (6) is from the *groundwater* (19) to the *atmosphere* (14). Radionuclides are diluted, subject to the *atmospheric dispersion and transport characteristics* (15), to determine the *concentrations in air* (10). The *quantities of air inhaled* (11) and the *concentrations of radionuclides in the air* (10) determine the *inhalation doses* (6).

The panel recognized some influences that were not included in the diagram. For example, once radionuclides reach surface water (20), they will volatilize to the atmosphere. A comprehensive influence diagram would show an arrow connecting factor 20 to factor 14. However, studies suggest that the pathways for radionuclides that have more than one medium (air, water, food) are not critical pathways. The panel concluded that this influence was insignificant and unduly complicated the diagram.

The total number of factors on the diagram represent many variables that must be quantified and estimated in order to apply the decision methodology. Estimates of all the quantities would be time-consuming. Estimates of some factors would require difficult projections or calculations. For example, forecasts of the population at risk 10,000 to 100,000 years after closure of the repository require very speculative projections.

Rather than attempting to estimate all the variables represented by the influence diagram, the panel selected the *releases to the accessible environment* (22) as a surrogate performance measure for the *number of health effects* (1). The amount of radionuclides released to the accessible environment has a major influence on the higher level factors in the structure. The radionuclide releases to the accessible environment has also been the basis for regulations protecting the public health (for example, 40 CFR Part 191 (EPA, 1987)). Selection of this factor as a performance measure addresses the regulations applied to the repository as well as the issues in the decision methodology. *Direct releases* to the accessible environment (71), including drilling and a number of other changes in the state of the disposal system (64, Figure B-13), is one of five factors determining the *releases to the accessible environment* (Figure B-11, 22). The other four factors are *groundwater transport through the saturated zone* (Figure B-11, 32), *gas transport through the unsaturated zone* (Figure B-11, 47), *gas phase transport through the EBS and seals* (47), and *groundwater transport through the unsaturated zone* (Figure B-11, 42). The suite of factors related to radionuclide transport through the natural barriers at Yucca Mountain, radionuclide transport through the EBS, and the scenarios that affect the radionuclide releases to the accessible environment during the postclosure period are discussed in the following sections.

Transport Through Natural Barriers. The factors related to transport through natural barriers and affecting release of radionuclides to the accessible environment are depicted in a separate influence diagram (Figure B-11). Radionuclides may be released to the accessible environment (22) *via groundwater transport* through the natural barriers, rock, in the *unsaturated zone* (42) and the *saturated zone* (32).

Radionuclides released to the groundwater transport system in the *saturated zone* (32) must be released from the engineered barrier system to the *unsaturated zone* (45). Radionuclide transport through the *unsaturated zone* (42) is subject to influences from a number of factors related to groundwater pathways in the unsaturated zone. After the radionuclides are released to the saturated zone (43), they are transported through the saturated zone subject to the influence of several factors related to groundwater pathways in the saturated zone and released to the *accessible environment* (22).

The *rate of radionuclide decay* (Figure B-12, 46) directly influences the *transport through* both the *saturated zone and unsaturated zone* (32 and 42) because the decay reduces the concentrations of radionuclides as they are transported.

The factors influencing radionuclide transport through the *saturated zone* (32) or the *unsaturated zone* (42) are separated in the influence diagram to emphasize differences in the characteristics of the saturated and the unsaturated zones. Different groundwater pathways imply different water chemistries that, in turn, affect the sorption, precipitation, matrix diffusion, and other characteristics. For example, the groundwater chemistry of the saturated zone is different from the groundwater chemistry in the unsaturated zone, and the groundwater chemistry of both zones is different from the chemistry of the groundwater in the vicinity of the waste package. The pathways in both the unsaturated zone and the saturated zone are influenced by a host of parameters grouped together as *"post-waste-emplacement characteristics of the natural barriers"* (Figure B-13,44). However, factors such as the radionuclide retardation in the saturated zone will be different than the radionuclide retardation in the unsaturated zone.

The *post-waste-emplacement characteristics of the natural barriers* (44) emphasize the major influence of these factors for the purposes of determining performance measures for ESF-repository options. *Post-waste-emplacement characteristics of natural barriers* (44) refer to the many, many parameters that would be needed for a complete study of the effects of site characteristics on the pathway for radionuclide transport. Three key factors that are important to the ESF-AS were included in this influence diagram.

These factors are

- *sorption coefficients* (24 and 34),
- *matrix diffusion effects* (25 and 35), and
- *precipitation effects* (26 and 36).

Groundwater transport through both the the saturated zone and the unsaturated zone is directly affected by the *radionuclide retardation* (30 and 40) and the *groundwater velocity distributions* (31 and 41). The *groundwater pathways* (23 and 33) affect three factors that directly impact the distribution of *groundwater velocity*. Those three factors are *groundwater flux* (29 and 39), *effective porosity* (28 and 38), and *flow distance* (27 and 37). *The groundwater pathways* (23 and 33) influence the *retardation* indirectly by influencing three other factors: the *sorption coefficients* (24 and 34), *matrix diffusion effects* (25 and 35), and chemical *precipitation effects* (26 and 36).

Among the factors related to radionuclide transport through natural barriers, the most important are related to *groundwater transport through the unsaturated zone* (42). The important factors may be traced back to the *groundwater pathway* (33) through intermediate factors such as the *groundwater distribution in the unsaturated zone* (41) and the *distance* groundwater travels in the unsaturated zone (37). The major influences on the groundwater pathway are the *post-waste-emplacement characteristics of the natural barrier system* (Figure B-13, 44).

<u>Transport Through Engineered Barriers System</u>. A separate influence diagram (Figure B-12) was developed for the factors influencing transport through the EBS and affecting release of radionuclides to the accessible environment. Because the EBS is in the unsaturated zone, *transport through the EBS and the seals* (51) affects the radionuclide releases to the *unsaturated zone* (45). Two of the factors that influence *transport through the EBS and seals* (51) are the radionuclide *retardation in the EBS and seals* (54) and the *distribution of groundwater velocities in the EBS and seals* (55). Both these factors are influenced by the *post-waste-emplacement characteristics of the EBS and seals* (Figure B-13, 56).

Radionuclide transport through the EBS and seals (51) is further influenced by a suite of factors related to the emplaced waste. The concentrations of radionuclides *released by the waste package* (53) are determined by the *waste form dissolution* (57), which is determined by the *solubility of the waste form* (61) and the *volume of water contacting the waste* (58). Water makes the container degrade before there is any contact of the water with the waste. That is why two factors are shown influencing *volume of water contacting waste* (58). One has to do with the *container degradation* (59) and one has to do simply with the water in contact with the waste *unsaturated zone groundwater flux* (39).

Other factors related to the emplaced waste that indirectly influence the radionuclide *transport through the EBS and seals* (51) include the type and quantity (inventory) of waste that is initially stored (52) and the inventory that remains at the time the waste form dissolves (50). The container integrity (59 and 60) influences the *volume of water contacting the waste* (58) and the *solubility of the waste form* (61) in conjunction with the *groundwater flux* (39) in the unsaturated zone.

The chemistry of the groundwater (62) influences two of the factors related to the emplaced waste: the *container degradation* (59) and the *waste-form solubility* (61). The ESF-repository options may have different effects on the groundwater chemistry because the byproducts of different mining methods differ. These byproducts may have different effects on the solubility of the waste form. *Groundwater chemistry* (62) may be influenced by the location of the ESF and the mining methods, but the effect is expected to be minor. The *groundwater chemistry* (62) is determined by two factors related to the post-waste-emplacement characteristics of the barrier components of the total repository system. The two factors are determined by factors related to the events after closure of the repository. One of those factors, the *post-waste-emplacement characteristics of the EBS and the seals* (56), is a key factor among the factors related to the EBS. The characteristics of the EBS also have a major influence on such factors as the *groundwater velocity distribution through the EBS and seals* (55), the *radionuclide retardation* (54), and the *gas phase transport* (48). Many processes affect gas phase transport through the EBS in the unsaturated zone. All the processes were not included explicitly in the influence diagram because they were not considered important for evaluating or ranking different ESF alternatives. The other major influences on the groundwater chemistry are the *pre-waste-emplacement characteristics* (Figure B-13, 44).

Waste containment-time was considered for inclusion on the diagram as an influencing factor but it was not included because waste containment-time results from the volume of water contacting the waste container. The container degrades, then the dissolution of the waste form is influenced by the waste form solubility and other factors. The degradation of the container, therefore, influences waste containment-time. Factors such as the construction of the container, the container materials, and materials used during container emplacement and other factors should be examined when evaluating the effects of the container on the waste-containment time. These factors are not discussed here and are not included in the influence diagram because they were not considered important for evaluating or ranking different ESF alternatives. Degradation of the waste container includes chemical, thermal, and mechanical effects. Mechanical effects include crushing, twisting, or other deformation. Thermal effects may include thermal run-away but the major thermal effects are the effects on chemical reactions and reaction rates.

Changes to the Waste Disposal System. An influence diagram (Figure B-13) was devoted to the numerous factors that may change the *state of the disposal system* (64), the *post-waste-emplacement characteristics of the natural barriers* (44), and the *post-waste-emplacement characteristics of EBS and seals* (56).

These factors determine post-waste-emplacement characteristics that have major influences on other components of the repository system. For example, the *post-waste emplacement characteristics of the natural barriers* (44) are major influencing factors on the *groundwater pathways* in the saturated zone (Figure B-11, 23) and the unsaturated zone (Figure B-11, 33), as well as the *groundwater chemistry* (Figure B-12, 62).

The *state of the disposal system* (64) refers to all the characteristics of interest at the site, such as the rock, the waste, and the population, in the vicinity of the ESF. All sorts of events, processes, and scenarios may lead to the future state of the site. Erosion, dissolution, and tectonics, including faulting and volcanism, influence potential future states at the ESF-repository site that affect the repository.

The term scenario, which refers to a combination of events and processes that lead to a future state, was intentionally not used in the diagram. Instead, the *state of the disposal system* (64) was used. Scenarios are a convenient means of quantifying the uncertainty of potential future states. A standard method for eliciting expert judgments for release estimates is to condition the judgments on scenarios. Probable distributions of releases are obtained by eliciting several estimates of releases conditioned on other events called scenarios.

The ESF-AS elicited expert judgments by asking experts to provide estimates of releases while considering the effects of changes in the potential future state of the disposal system. The release estimates were not conditioned on scenarios, and the influence diagram does not include scenarios that are used to condition the probability of radionuclide releases. Three types of changes in the potential future state of the disposal system are expected:

- natural expected changes
- natural unexpected changes
- man-induced (ESF-repository) changes

These potential changes in the disposal system were considered in several different ways when estimating the potential for radionuclide releases for each ESF-repository option under consideration.

For example, the *ESF configuration* (73) and the *repository design* (72) could influence the effect of faulting on the post-waste emplacement characteristics (44 and 56). Knowledge of post-waste emplacement conditions is contingent upon knowledge about factors such as the likelihood and characteristics of faulting.

The connection between the *state of the disposal system* (64) and population at risk (2) is very important. It points out that some of the potential change that would produce drastic changes to the natural barriers, for example, volcanic action or major movement along a fault, could be of such magnitude as to substantially undermine the performance of the repository so as to produce either substantial deaths directly in the population or cause people to move out of the area. So the potential for exposure might be altered somewhat by the same mechanisms that damaged the performance of the repository. This connection also addresses the possibilities such as a large meteorite impact on the top of the repository. Although a large meteorite impact might lead to substantial releases, it would not necessarily result in substantial health effects *attributable to the repository*. The population at risk would no longer exist. In order to predict the population at risk or to know what the probability of any particular population size is in the future, the potential changes to the site must be defined. The future conditions at the site will be something different from the conditions today. The population at risk will depend on changes in some conditions that exist at the site. A wetter climate, for example, would probably bring more people into the vicinity. There is an influence even between changes in natural barriers and population.

The testing programs associated with each of the ESF-repository options will provide information about characteristics that affect performance. The ESF-repository option can affect the ability to obtain test information about such events as faulting, climate change, and other natural changes. Inferences based on this information, for example, inferences about future climate changes and faulting, will differ among and between ESF-repository options.

The ESF-repository option and the testing program have no influence on the probability of these natural events but testing will influence judgments of the probability of the events. These inferences, in turn, will influence the assessments of site suitability. For example, one of the concerns about volcanism, basaltic intrusion, will be addressed using information from testing conducted in the ESF. The ESF site characterization testing program will provide some information for the potential likelihood of basaltic intrusion. This likelihood will be used for performance assessments. A potential for volcanism does not necessarily mean that the whole volcanism process will be modeled. It is more likely that the impact of volcanism on things like hydrology and geology will be simulated. Then, consequences of those changes will be estimated. In summary, the information from ESF site characterization testing, which may be impacted by different options, may impact the approach to modeling other impacts. The effectiveness of the site characterization testing program associated with each ESF-repository option will, in all likelihood, impact differently the capacity to correctly predict volcanism.

The factors influencing the *changes in the state of the disposal system* (64) represent a checklist to assure that the important natural and man-induced changes are considered in the evaluation of each ESF-repository option under consideration. Factors were included only if the consequences of the changes were expected to discriminate among the ESF-repository options. Changes also were only included if the consequences would result in significant releases of radionuclides. For example, the panel considered whether the expected releases from a following volcanism would exceed 10 percent of the EPA Standard (or a factor of 10 greater or less than the base case defined by the Site Characterization Plan Conceptual Design Report (SCP-CDR) [SNL, 1987]). The meaning of significant releases could be further quantified by posing the question of whether the probability of volcanism was greater than 1 chance in 10,000 in 10,000 years.

In summary, the selected factors met the following three general screening criteria:

- Discriminate among ESF-repository options,
- Lead to significant consequences, and
- Have a significant probability of occurrence.

The six factors meeting these screening criteria were the following:

- *ESF-repository-induced changes* to the natural barrier system, EBS, and the seals (66);
- *Faulting* (67);
- *Volcanism* (68);
- *Climatic change* (69);
- *Human interference* (70); and
- *Change in water table level* (91).

Two of these factors, *changes in the state of the disposal system caused by the ESF-repository* (66) and *changes in the water table level* (91), were considered more significant than the other scenarios with respect to determining the best ESF-repository design.

Changes in water table level (91) are influenced by two other factors: *faulting* (67) and *climatic change* (69). *Faulting* (67) influences both the *changes in state of the disposal system* (64) and *change in water table level* (91) because of the possibility that the higher water table to the northwest of the mountain is held there because of the presence of a fault and relatively impermeable materials. Movements on a fault during the postclosure period might release groundwater and effectively raise the water table beneath the repository.

Volcanism (68) is not likely to be influenced by the ESF-repository design. A remote possibility is that a design could spread the waste out so as to significantly reduce the probability that the volcanic material would contact the waste.

Climate change (69) is often included as an expected change. Climate is expected to change some in 10,000 years but the disruptive or an unexpected consequence resulting from extreme changes are not known. Alterations in the rainfall amounts and patterns could cause the water table to rise or fall.

The principal concern about *human interference* (70) relates to drilling into the site and drilling into the waste. Spreading the waste over a larger area would decrease the probability of drilling into a waste package but that is about the only way the ESF-repository design could influence human interference. The various repository designs, including the base case, must accommodate 70,000 metric tons of heavy metal. The areal distribution of the waste may be slightly different within the repository block but the probabilities of intercepting a canister will probably not vary significantly between and among options, and the consequence analysis will probably not vary significantly between and among options. The options considered in the ESF-AS do not include details of the locations of waste containers. The only information available is the number of canisters, their geometric cross-section, and the area of the repository. Given this information, the probabilities of hitting one canister is likely to be the same for all the options.

ESF-repository-induced changes in the state of the disposal system (66) are related to the *design of the repository* (72) and the *ESF configuration* (73). These same factors determine the *post-waste-emplacement characteristics of the EBS and seals* (56). The designs of the ESF and repository influence the *gas transport* (48) through the engineered barrier system indirectly by influencing the *post-waste-emplacement characteristics of the EBS and seals* (56). For example, a shaft may introduce a pathway from the EBS to the *accessible environment* (22).

The major influences on the *ESF configuration* (73) are

- *ESF connection with the repository* (75). This is a major factor because an ESF that is outside and completely decoupled from the repository is a better situation than one that is within the repository. Another issue that should be considered as part of the influence of the ESF connection is whether or not the repository drifting to provide the connection of the ESF with the exploratory shaft might result in a preferential pathway for radionuclides to move to the exploratory shaft zone.

- *Nature and extent of the Calico Hills penetration* (76*[1]).

- *Fluid and material usage* (77). This factor was considered useful in discriminating among ESF-repository options. The fluids used in constructing the ESF may relate directly to the groundwater travel time, not because of the distance through the rock, but by changing the saturation. Large volumes of water may increase the saturation and thereby effectively create a saturated-zone pathway from the repository horizon to the water table. Even if the saturated pathway does not intersect the water table, there are possibilities that other fractures may create additional pathways. Calculations to determine the impact of concrete and water are not available, but options that used less offensive chemicals and lower quantities of water might be preferred.

- *ESF construction method* (78*). The NWTRB and the NRC have identified the construction method as a prominent concern. The site characterization program is designed to look at the impacts of the construction method. An option using a construction method that does not impact the site by introducing excess water or construction materials might be preferred.

- *ESF access* (80), including the *ESF type* (82) and *access location* (83).

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[1]The asterisks near factors (76), (78), (84), (89), and (90) indicate those factors that require attention in order to comply with 10 CFR 60.21 (C)(ii)(D), even though these factors were not considered discriminating among options.

Minor influences on the ESF configuration are the location of the *MTL* (74) and the *extent of exploratory drifting at the repository horizon* (79). The location of the MTL (74) was included in the diagram to recognize the possibility that the repository could be at a different depth than the ESF. The repository level is the significant factor rather than the MTL, unless there is some mechanism for getting radionuclides over into the ESF. One of the principal considerations in the options under consideration for the ESF-AS was that there was no such mechanism. The *extent of exploratory drifting at the repository horizon* (79) was considered a minor influence because the amount of exploratory drifting in the Topopah Spring unit was considered to be insignificant compared to the amount of drifting to develop the repository.

For the purposes of the ESF-AS, the repository design (72) includes the design for retrievability. Design options that ensure retrievability may affect postclosure performance. For example, retrievability may be ensured by installing steel liners on all tunnels or grouting all tunnels with concrete. Those, in turn, may influence postclosure performance. Five factors that influence the repository design (72) have equal importance for the purposes of comparing ESF-repository designs with respect to the influence on postclosure health and safety. Those five *major* factors are

- *Repository construction method* (84*);

- *Number and type of accesses to the repository* (87);

- *Repository location* (88), including the difference between locations inside the block-bounding features and locations outside the block-bounding features of the Yucca Mountain site as well as the depth of the repository;

- *Rock support system* (89*); and

- *Repository configuration* (90*) including single versus multi-level repository configurations.

Areal power density (85) varies with the *age of the waste* (86) that is stored in the repository. The areal power density influences the design, but it is a minor factor compared to the other factors, because all designs will accommodate the same amount and density of waste.

The term *pre-waste-emplacement characteristics of natural barriers* (44) refers to the characteristics of the site before it is disturbed by the construction of the repository and emplacement of waste. There will be some disturbances even before pre-waste emplacement. Those disturbances are recognized on the influence diagram as *pre-ESF disturbances* (65). The surface-based testing program is one of those activities that will contribute to the *pre-ESF disturbances* (65).

Influences, such as *groundwater flux* (29 and 39), *effective porosity* (28 and 38), *flow distance* (27 and 37), *radionuclide retardation* (30 and 40), and the *groundwater velocity distributions* (31 and 41) all vary with time. Predictions of radionuclide transport for the periods of 10,000 years to 100,000 years require estimates of these variables for the post waste-emplacement period. The estimates and inferences of these variables is represented by the influence from *pre-waste-emplacement characteristics* (63) to *post-waste-emplacement characteristics* (44). The pathway after waste emplacement will be based on inferences from measurements made before the repository is constructed and on inferences about the effects of the repository on the characteristics of the repository site. Inferences about post-waste-emplacement characteristics are unavoidable because these characteristics can never be measured.

Those *post-waste-emplacement characteristics of the EBS and seals* (56) that have major impacts on *gas transport, retardation, and groundwater velocity distributions in the EBS and seals* (Figure B-12, 48, 53, and 55) are influenced by *changes in the state of the disposal system* (64), the *ESF configuration* (73) and the *repository design* (72).

B.1.9.3 Performance Measure and Scale

A surrogate measure of adverse impacts on public health during the postclosure period was

Releases to the accessible environment (Figure B-10, 22).

The releases were expressed as a fraction of the EPA standard for releases to the accessible environment after 10,000 years (40 CFR 191). The panel examined ten factors that were considered to have a major influence on the performance measure. The maximum effects of the important factors influencing the postclosure release of radionuclides were assembled (Table B-1) for consideration by the panel in arriving at

TABLE B-1

MAXIMUM EFFECTS OF IMPORTANT FACTORS INFLUENCING POSTCLOSURE RADIONUCLIDE RELEASES

Factor	Best Case	Base Case	Worst Case
Change in Water Table Level (91)	120 m lower ⟵	⟵ base case ⟶	⟶ 120 m higher
	• Lower	No change	• Higher[a] • Higher infiltration/flux • Enhanced waste package degradation • Saturation of CH unit in NE corner
Flow Distance to Water Table (88)	**No discrimination among options**		
	50% increase ⟵	⟵ base case ⟶	⟶ 50% decrease
Transport Through EBS and Seals (56)	**No significant impact on release estimates**		
	• Effective seals ⟵		⟶ • Ineffective seals
	• Ramps better than shafts		• Shafts better than ramps
	• No influx ⟵	⟵ • 20 m^3/yr influx	⟵ • 200 m^3/yr influx
ESF Type (Ramps *vs* Shafts) (82)	**No significant impact on release estimates**		
	• High above flood plain	• Above flood plain	• Below flood plain
	• Fewer	• 4 shafts 2 ramps	• More
	• Outside block		• Inside block
	• Location above maximum flood plain level		• Location at or below maximum flood plain level
			• 200 to 2,000 m^3 influx per year per opening[b]

[a]Change in stratigraphy through which water moves.
[b]200 m^3/yr/shaft; 2,000 m^3/yr/ramp.

TABLE B-1

MAXIMUM EFFECTS OF IMPORTANT FACTORS INFLUENCING POSTCLOSURE RADIONUCLIDE RELEASES
(Concluded)

Factor	Best Case	Base Case	Worst Case
ESF Connection with Repository (75)	**No impact on radionuclide releases**		
	• Unconnected[c]		• Connected[d]
Fluid and Material Usage (77)	**No impact on radionuclide releases**		
	• Less[e]		• More
Nature and Extent of CH Penetration (76)	**No impact on radionuclide releases**		
	• No penetration[f]	• Penetration	• Penetration[g]
Construction Method of ESF-Repository (78) (84)	**No impact on radionuclide releases**		
	• Less extent of damage	• Controlled drill and blast	• Production mining drill and blast
Repository Configuration (90)	**No impact on radionuclide releases**		
	• Lower extraction ratio		• Higher extraction ratio
		• Self draining	• Low potential for self draining
	• Peferred alignment with structure		• No preferred alignment with structure
Rock Support System (89)	**No impact on radionuclide releases**		
	• Lower extraction ratio		• Higher extraction ratio
	• Circular opening	• Arched rectangular opening	• Rectangular opening

[a]Change in stratigraphy through which water moves.
[b]200 m^3/yr/shaft; 2,000 m^3/yr/ramp.
[c]Better if the connection is outside the repository emplacement area.
[d]Worse if the connection is inside repository emplacement area.
[e]No discrimination if matrix flow predominates.
[f]Minimal impact if matrix flow predominates.
[g]Worse if fracture flow predominates in combination with connection to the repository and the flow distance to the water table is small.

the performance scale. After consideration of the consequences of each factor (Table B-1), several factors were judged to have much less than one order of magnitude impact on the releases of radionuclides to the accessible environment. Some factors provided no discrimination among options. Only two factors, the *flow distance to the water table* (88) and the *change in water table level* (91) were judged to have both a significant impact on the radionuclide releases and a discriminating impact between and among options.

The performance scale for releases to the accessible environments was established by considering the releases to the accessible environment from the base case (SNL, 1987) and then considering the impact of the major influencing factors on the base case. The unit of measure for the scale is a multiple (fractional release) of the EPA standard for releases from a geologic repository after 10,000 years (40 CFR 191). The fractional releases for the base case were judged to be 10^{-7} if matrix flow was assumed and 10^{-3} if fracture flow was assumed (Table B-2). The performance scale ranges two orders of magnitude above and below the values estimated for the base case. This range resulted principally from the influence of the *change in water table level* (91). The other significant influencing factor, the *flow distance to the water table* (88), was judged to result in one order of magnitude increase or decrease if the distance to the water table differed by 50 percent among options. The minimum fractional releases estimated for each factor are shown at the left (best case) of Table B-2 and the maximum estimated fractional releases for each factor are shown in the right (worst case) column of Table B-2. Those factors that were judged either to have much less than one order of magnitude impact on the releases of radionuclides to the accessible environment or to provide no discrimination among options were assigned release estimates one order of magnitude different than the base case.

B.1.10 Preclosure Radiological Health Effects: Workers, X_2

The location of summary notes and transcripts documenting the development of the influence diagram and performance-measure scales for the preclosure radiological health effects to workers are indicated by references in Appendices D.5 and D.6.

TABLE B-2

MAXIMUM ESTIMATED RELEASES RESULTING FROM IMPORTANT FACTORS INFLUENCING POSTCLOSURE RADIONUCLIDE RELEASES (MULTIPLES OF EPA STANDARD FOR RELEASES AFTER 10,000 YEARS)

	Best Case		Base Case		Worst Case	
Factor	Matrix Flow	Fracture Flow	Matrix Flow	Fracture Flow	Matrix Flow	Fracture Flow
Change in Water Table Level (91)	10^{-9}	10^{-4}	10^{-7}	10^{-3}	10^{-5}	10^{-2}
Flow Distance to Water Table (88)	10^{-8}	10^{-4}	10^{-7}	10^{-3}	10^{-6}	10^{-2}
Transport Through EBS and Seals (56)[a]	10^{-8}	10^{-4}	10^{-7}	10^{-3}	10^{-6}	10^{-2}
ESF Type (Ramps vs Shafts) (82)[a]	10^{-8}	10^{-4}	10^{-7}	10^{-3}	10^{-6}	10^{-2}
ESF Connection with Repository (75)[a]	10^{-8}	10^{-4}	10^{-7}	10^{-3}	10^{-6}	10^{-2}
Fluid and Material Usage (77)[a]	10^{-8}	10^{-4}	10^{-7}	10^{-3}	10^{-6}	10^{-2}
Nature and Extent of CH Penetration (76)[a]	10^{-8}	10^{-4}	10^{-7}	10^{-3}	10^{-6}	10^{-2}
Construction Method of ESF (78)[a] and Repository (84)[a]	10^{-8}	10^{-4}	10^{-7}	10^{-3}	10^{-6}	10^{-2}
Repository Configuration (90)[a]	10^{-8}	10^{-4}	10^{-7}	10^{-3}	10^{-6}	10^{-2}
Rock Support System (89)[a]	10^{-8}	10^{-4}	10^{-7}	10^{-3}	10^{-6}	10^{-2}

[a]These factors were judged to have much less than one order of magnitude impact on the radionuclide releases from the repository during the postclosure period or to have no discriminating differences among options. One order of magnitude impact was assigned arbitrarily to these factors.

B.1.10.1 Objective

One preclosure performance objective (ESF-AS, Volume 2, Section 2, Figure 2-4 was related to the radiological effects on the health of workers during the preclosure period of the repository.

> *Minimize radiological health effects that are experienced by facility workers and are attributable to the ESF-repository facility.*

Preclosure health and safety impacts of the ESF-repository may be attributable to the repository itself or to waste transportation. The impacts of waste transportation were disregarded for the purposes of the ESF-AS because the volume of waste transported to the site will be the same regardless of which design is used for the ESF-repository design. The health and safety impacts that are attributable to the repository may be caused by radionuclide releases resulting from accidents or hazards. Two populations may be affected by radionuclide releases during the preclosure period, members of the public and workers at the ESF-repository. This section addresses the radiological health effects on workers.

B.1.10.2 Factors Influencing the Performance Measure

The performance measure selected to measure adverse impacts on public health during the preclosure period is

> *The number of health effects to workers during the preclosure period.*

The number of premature cancer fatalities related to radiation exposure is a surrogate measure for other health-and-safety effects. Potential illnesses and injuries were not explicitly estimated in the study because these effects are strongly correlated with fatal health effects. The implications of this assumption were examined in the sensitivity analyses. The analyses using significantly increased weights assigned to fatalities in the multiattribute utility function did not differ significantly from the results using the original weights. These results suggest that the inclusion of nonfatal health effects would not lead to any additional insights or change any implications of the analysis.

The number of *radiological health effects* that are experienced by facility workers and are attributable to the ESF-repository facility (Figure B-14, 1) result from the following three factors:

- *Exposure due to normal conditions* (2),
- *Worker-population dose from accidents* (3), and
- *Dose/response relationship* (4).

The major influencing factor among these three is the *worker-population dose from accidents* (3). Routine operations will be conducted under normal working conditions in the surface facilities and in the underground testing and storage facilities. Normal operating conditions will have comparable consequences to exposed workers at facilities constructed according to all the design alternatives. *Exposure due to normal conditions* (2) is included for completeness, but it was not considered a discriminating factor, and therefore, not a significant factor relative to *doses from accidents* (3). The *dose/response relationship* (4) was also considered nondiscriminating because the relationship will be the same for all designs.

The worker population will receive *doses from accidents* (3) of three major types: *drift collapse* (5), *underground transporter accidents* (6), and *container drop accidents* (7). Accidents at the surface do not discriminate among options because the surface facility is substantially the same for all options. Of the three types of accidents, the dose from *underground transporter accidents* (6) is the more significant factor for the purpose of the ESF-AS. The potential for doses from drift collapse increases with the frequency of *drift collapse* (8), which varies with the mining technique, *drill-and-blast or tunnel boring machine* (9). Shaft liner collapse was not included in the influence diagram because none of ESF-repository designs include a shaft for transporting waste. The only way a shaft-liner collapse might influence radiation doses would be to create a dust cloud that would clog the high-efficiency particulate air (HEPA) filters. Collapse of a shaft liner could then contribute to radiation doses if the collapse occurred in conjunction with another accident that released radiation. The potential dose to workers from *container drop accidents* (7) will be the same for all designs because vertical emplacement of the same volume of waste must be accommodated by all alternative designs. For this reason, *container drop accidents* (7) were not included as a major influencing factor. *Underground transporter accidents* (6) remained as the major influence on *worker-population dose from accidents* (3). These accidents may occur when specially designed and constructed waste transporters are carrying waste to the waste-emplacement rooms,

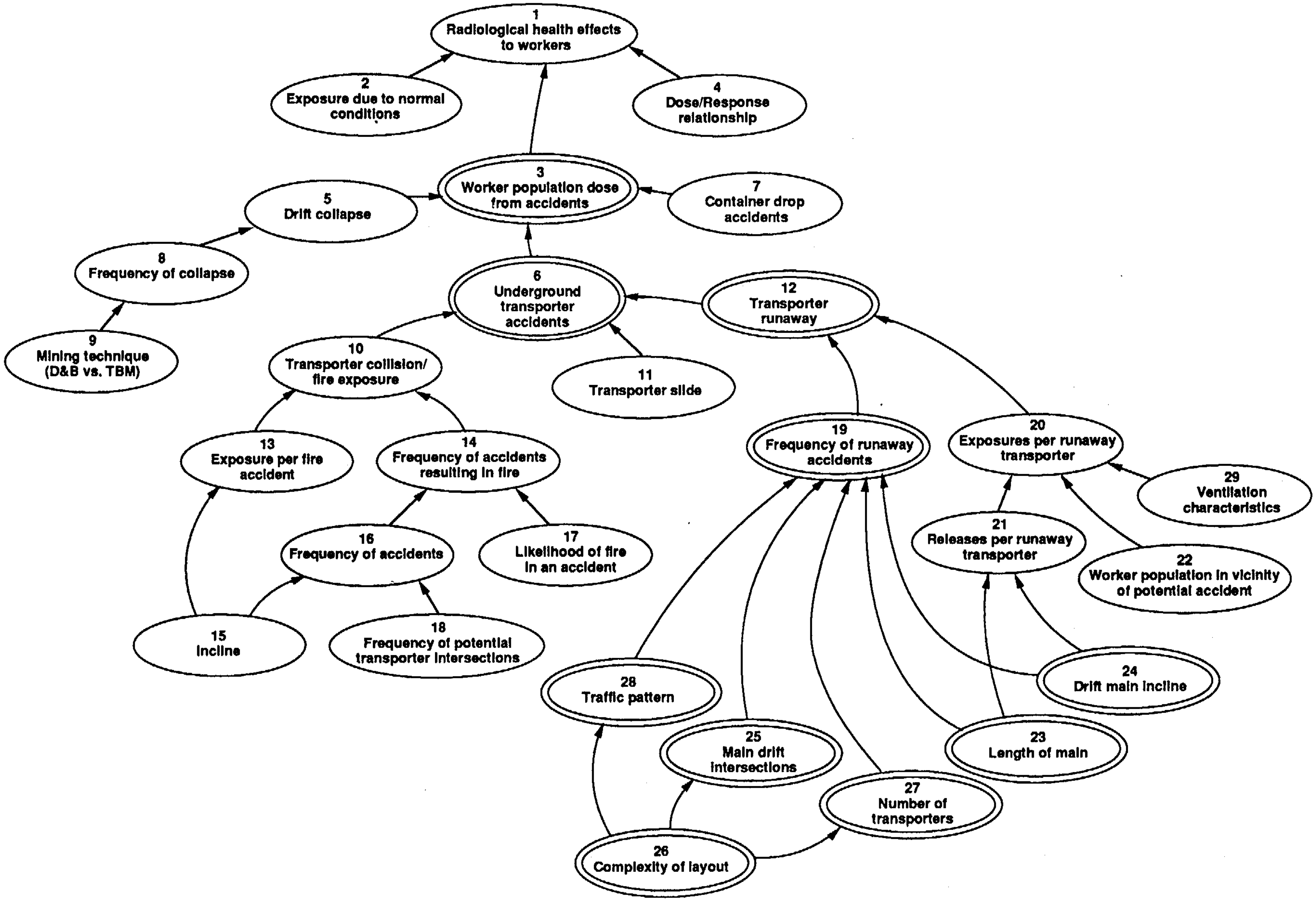

Figure B-14. Factors That Influence the Radiological Health Effects Incurred by ESF-Repository Workers.

emplacing the waste containers, or returning from the waste-emplacement rooms. The probability of a radionuclide release in the event of a transporter accident is much lower than the probability of the accident. The massive shields provide an absorber of energy that must be destroyed before radionuclides are released.

The principal concerns about *underground transport accidents* (6) relate to *transporter runaway* (12) accidents. Without a fire, a transporter accident is unlikely to lead to a radiation release. Therefore, transporter collisions were coupled with fire exposures (10). Other causes of transport accidents are *transporter collisions with fire exposure* (10) and *transporter slide* (11) accidents. Each of the designs have similar grades for emplacement rooms, so the potential for the transporter to slide while emplacing waste is the same for all designs. Factor 11 provides no discrimination among design alternatives. Two factors influence Factor 10: *exposure per fire accident* (13) and the *frequency of accidents resulting in fire* (14). Transporters will not be operating in areas where any development work is in progress. That is a basic assumption for all of the ESF-repository options. The only potential collisions, therefore, are transporter-transporter collisions. The major influencing factors on the frequency of transporter-transporter collisions are human error. If the traffic patterns resulting from the layout drift layout in an ESF-repository design are confusing and more conducive to accidents, then that could be an influencing factor. The transporters move so slowly that the number of intersections may have minimal impact on the accidents. Furthermore, the only intersections that would have any influence on potential collisions are the intersections where other transporters are also moving. An examination of the ESF-repository layouts and drift inclines provide the basis for judgments as to complexity of the cross traffic and for the possibility of transporter-transporter collisions. Logically, the frequency of accidents resulting in fire is directly related to the *likelihood of fire in an accident* (17) and the *frequency of accidents* (16). Higher main drift *inclines* (15) and the *higher frequencies of potential transporter intersections* (18) increase the potential *frequencies of accidents* (16).

Transporter collisions with fires (10) may vary with the number of entry-entry intersections; however, the transporter velocity is so slow that the impact from a collision is not sufficient to breach a waste container. An associated fire is not likely to cause a radiation leak. The only fuel available is from the transporter tires. The resulting heat is not sufficient to raise the temperature of the transporter sufficiently to breach the waste container.

The health hazards from *transporter runaway accidents* (12) increase with the *frequency of runaway accidents* (19) and the *exposures per runaway transporter* (20). The waste containers carried by the transporters do not vary significantly among the ESF-repository options, so the *frequency of runaway accidents* (19) is the more discriminating factor and is influenced equally by the following five major factors:

- *Traffic pattern* (28),
- *Main drift intersections* (25),
- *Number of transporters* (27),
- *Length of main* (23), and
- *Main drift incline* (24).

The *traffic pattern* (28), *main drift intersections* (25), and *number of transporters* (27) differ among options because of differences in the *complexity of the ESF-repository layout* (26).

A less important factor influencing the radiological health effects of a *transporter runaway* (12) is the *exposure per runaway accident* (20), which varies with the *radionuclide release per runaway transporter* (21), the number of *workers in the vicinity of the potential accident* (22), and the *ventilation* (29) system in relation to the congregations of workers for a given accident scenario. For example, if an accident releases radiation upstream from a large number of people, the radiation exposure will be greater than from accidental releases upstream from fewer people or downstream from larger numbers of people.

B.1.10.3 Performance Measure and Scale

A review of the influence diagram for preclosure radiological health effects to workers (Figure B-14) revealed five major influencing factors that should be used to develop performance measures.

- Traffic Patterns
- Number of Main/Drift Intersections
- Drift Incline
- Number of Transporters
- Length of Main

The consequences of these factors were compiled (Table B-3) for consideration in developing the performance measure and the performance scale for radiologic effects on workers.

A natural scale for measuring the performance of each option with respect to the performance measure for radiological health effects is the radiation dose (person-rems[2]) received by workers.

The dilution of concentrations to workers was based on the mine ventilation airflow rate. Ground particles were not considered when calculating cases to workers. The calculations considered two types of workers:

- Workers downstream from an accident are subject to airflow velocities of 45,000 cubic feet per minute (cfm), and

- Workers in the surface facilities and development area are subject to exhaust airflow velocities of 70,000 cfm.

The dominant impact is to workers downstream from an accident that breaches a waste container and releases particles of radionuclides to the air.

The estimated typical dose to underground workers under the assumed accident scenario was

$$Dose_{typ} = 1800 \text{ person-rems per accident.}$$

This dosage was combined with the estimated probabilities of a runaway transporter accident ($P_{RT} = 10^{-2}$ per year) and a container breach ($P_{CB} = 10^{-4}$ per accident) to obtain the annual risk to underground workers.

$$Risk_{ug} \text{ per year} = P_{RT}\, P_{CB}\, Dose_{typ} \approx 2 \times 10^{-3} \text{ person-rem/year}$$

---

[2]Person-rem is a unit of 1 rem received by one human being. Rem (roentgen equivalent man) is the dosage of an ionizing radiation that will cause the same biological effect as one roentgen of X-ray or gamma-ray dosage.)

TABLE B-3

MAXIMUM EFFECTS OF IMPORTANT FACTORS INFLUENCING PRECLOSURE RADIOLOGIC HEALTH EFFECTS ON WORKERS

Factor	Best Case (Lowest Person-Rems)	Base Case (SCP-CDR Design)	Worst Case (Highest Person-Rems)
Traffic Pattern	• Simpler		• Complex
Number of Main/Drift Intersections	• Fewer		• More
Drift Incline	• Horizontal		• Steeper
Number of Transporters	• Fewer		• More
Length of Main	• Shorter		• Longer

The panel considered other factors in the influence diagram that might cause variations from this estimate, for example, collisions. The estimate was considered to be a crude order of magnitude calculation. Perturbations such as downstream or upstream monitors were considered to cause less than one order of magnitude variation from this estimate.

Another variation among options and within the SCP-CDR base case was airflow in the ventilation system. The airflow velocities in the main drift range from 300,000 cfm to 500,000 cfm. The number of people in the vicinity of an accident may also vary. A typical number of five people in the vicinity of an accident was adopted for the purpose of the scoring exercise.

B.1.11 Preclosure Radiological Health Effects: Public, X_3

The location of summary notes and transcripts documenting the development of the influence diagram and performance-measure scales for the preclosure radiological health effects to the public are indicated by references in Appendices D.5 and D.6.

B.1.11.1 Objective

The ESF-AS Objectives Hierarchy (ESF-AS Report, Volume 2, Section 2, Figure 2-4) defined one preclosure performance objective related to radiologic health effects to the public.

> *Minimize radiological health effects that are experienced by the public and are attributable to the ESF-repository facility.*

Preclosure health and safety impacts of the ESF-repository may be attributable to the repository itself or to waste transportation. The impacts of waste transportation were disregarded for the purposes of the ESF-AS because the volume of waste transported to the site will be the same regardless of which design is used for the ESF-repository design. The health and safety impacts that are attributable to the repository may be caused by radionuclide releases resulting from accidents or hazards. Two populations may be affected by radionuclide releases during the preclosure period, members of the public and workers at the ESF-repository. This section addresses the radiological health effects on members of the public. The public population for which health effects must be considered is the population within 50 miles of the controlled area around the repository, visitors to the site, and commuters moving on and off the site to support the construction and operation of the ESF-repository.

B.1.11.2 Factors Influencing the Performance Measure

The performance measure selected to measure adverse impacts on public health during the preclosure period is

Number of health effects to the public during the preclosure period.

The number of premature cancer fatalities related to radiation exposure is a surrogate measure for other health-and-safety effects. Potential illnesses and injuries were not explicitly estimated in the study because these effects are strongly correlated with fatal health effects. The implications of this assumption were examined in the sensitivity analyses. The analyses using significantly increased weights assigned to fatalities in the multi-attribute utility function did not differ significantly from the results using the original weights. These results suggest that the inclusion of nonfatal health effects would not lead to any additional insights or change any implications of the analysis.

The factors affecting the radiological health effects to the public (Figure B-15) are nearly the same factors that influence the radiological health effects to workers. The surface facilities in all ESF-repository designs are so similar that the only discriminating factors with respect to radiological health effects are radionuclide releases from *underground accidents* (3). The major potential for exposing the public to radiation during the preclosure period comes from the potential for an *underground transporter accident* (6). Only two mitigating factors cause the doses to the public to differ from the doses to repository workers in the event of an underground accident. Radionuclide concentrations dilute when the radionuclides are transported from the underground accident up the ventilation system and through the air to the boundary of the controlled region surrounding the repository site. The dose received by the public is also affected by the fact that some of the radioactive particles may be deposited on the ground surface. The major factors influencing the potential for underground transporter accidents (Figure B-15) are the same as those included in the influence diagram for radiological health effects to workers (Figure B-14). The only factor that differs from those on the influence diagram for radiological health effects to workers is the *public population within 50 miles of the site* (22).

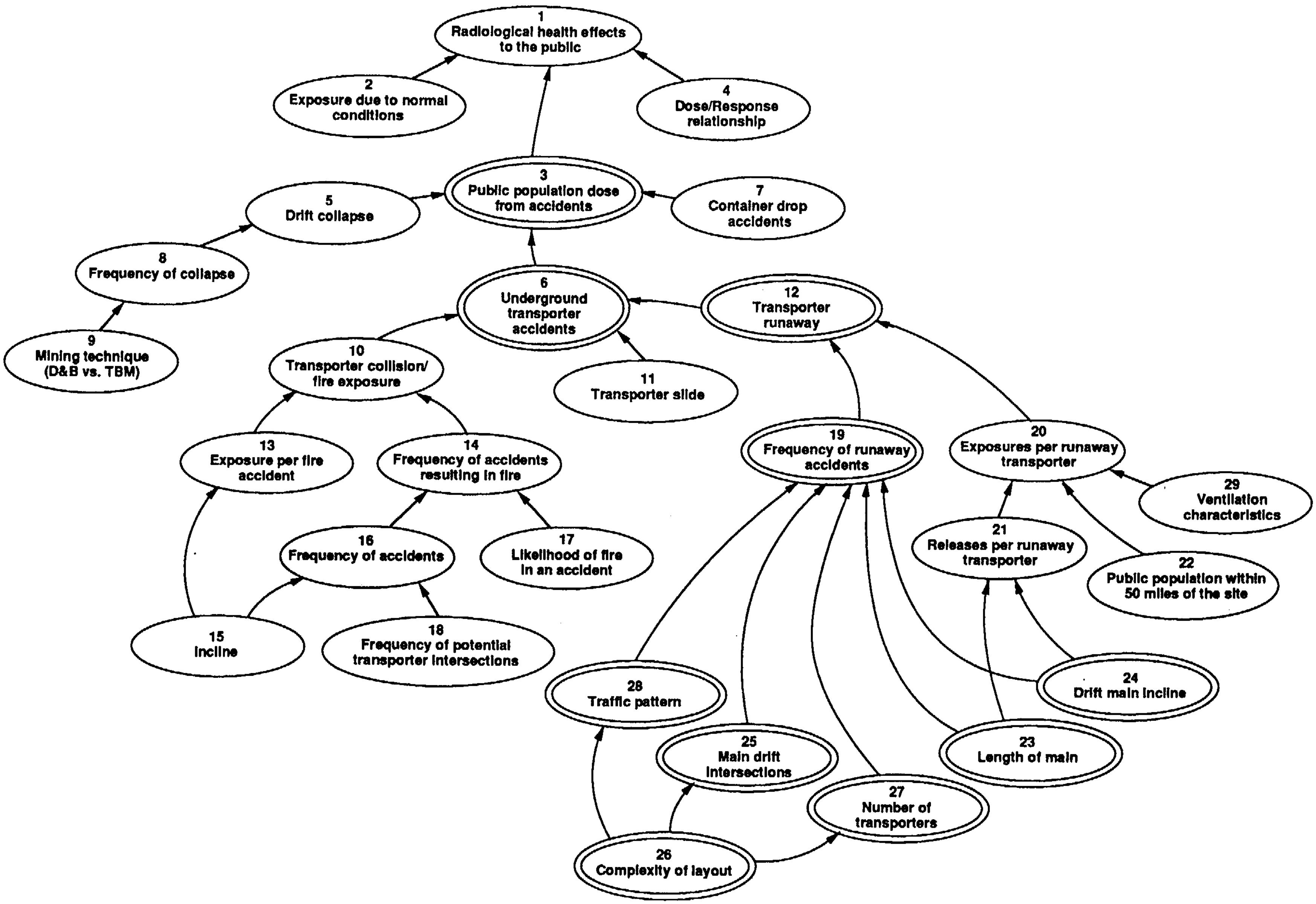

Figure B-15. Factors That Influence the Radiological Health Effects Incurred by the Public.

B.1.11.3 Performance Measure and Scale

The performance measure is the number of premature cancer fatalities to members of the public during the preclosure period attributable to radiation from radionuclides that escaped from the repository facility. The important factors influencing this performance measure are the same factors that influence the performance measure for radiologic health effects on workers (Table B-3).

B.1.12 Preclosure Nonradiological Safety Effects: Workers, X_4

The location of summary notes and transcripts documenting the development of the influence diagram and performance-measure scales for the preclosure nonradiological health effects to workers are indicated by references in Appendices D.5 and D.7.

B.1.12.1 Objective

The ESF-AS Objectives Hierarchy (ESF-AS Report, Volume 2, Section 2, Figure 2-4) identified one performance objective related to the safety of workers and not related to radiological health. The performance objective was to

Minimize nonradiological health effects that are experienced by facility workers and are attributable to the ESF-Repository facility.

Preclosure health and safety impacts of the ESF-repository may be attributable to the repository itself or to waste transportation. The impacts of waste transportation were disregarded for the purposes of the ESF-AS because the volume of waste transported to the site will be the same regardless of which design is used for the ESF-repository design. The nonradiologic safety impacts that are attributable to the repository may be caused by releases resulting from accidents or hazards. This section addresses the nonradiological safety impacts of the ESF-repository on workers.

B.1.12.2 Factors Influencing the Performance Measure

The performance measures related to nonradiological health and safety objectives are numbers of fatal accidents and air pollution. Air pollution was included mainly for completeness. It was not expected to cause fatalities. The main causes of nonradiological fatalities among both the workers and public are traffic accidents during transportation of waste.

The performance measure for nonradiological safety effects was the estimated number of fatal accidents among ESF-repository workers. The number of fatalities is the top-level factor affecting worker safety (Figure B-16, 1). The largest number of nonradiologic fatalities anticipated at the ESF-repository are *fatalities to miners* (2). All other nonradiologic fatal accidents can be grouped together (3) representing a less significant influence on the total number of fatalities. Both the *miner fatalities* (2) and *other fatalities* (3) are determined by the types of hazards that confront the miners (5) and other workers in the facility (7), as well as the number of man-hours the miners must spend in hazardous activities (4) and the number of man-hours that other workers must spend in hazardous activities (6).

The types of hazards that may cause *miner fatalities* (2) in the ESF-repository are the *materials handling system* (42), *horizontal openings* (22), the *rock support system* (41), the *ramps* (23), the *vertical shaft* (24), and the *ventilation system* (40). The relative hazard represented by both the *materials handling system* (42) and the *horizontal openings* (22) are influenced by the *average grade of the horizontal openings* (26) and this factor is influenced by the mining technique, *drill-and-blast* (31) or *mechanical mining* (32).

The *materials handling system* (42) and the *ventilation system design* (40) are minor hazards relative to the hazards represented by *horizontal openings* (22), *ramps* (23), *vertical shafts* (24), and the *rock support system* (41). The hazards in the ventilation system arise from the *numbers of ramps and/or shafts* (43) that must be excavated to implement the system. The ventilation system represents a greater or lesser hazard depending on whether the pressure system in the design is *positive or negative* (44).

The hazards represented by *horizontal openings* (22), the *rock support system* (41), and the *ramps excavated by tunnel boring machines* (23) are all influenced by the *orientation of the openings with respect to the natural rock stratigraphy and structures* (39), which is the most fundamental influence on the rock support system. Hazards related to the *horizontal openings* (22) are also influenced by the *average grade of the horizontal openings* (25) and the *mining technique* (25), *drill-and-blast mining* (29), or *mechanical mining* (30).

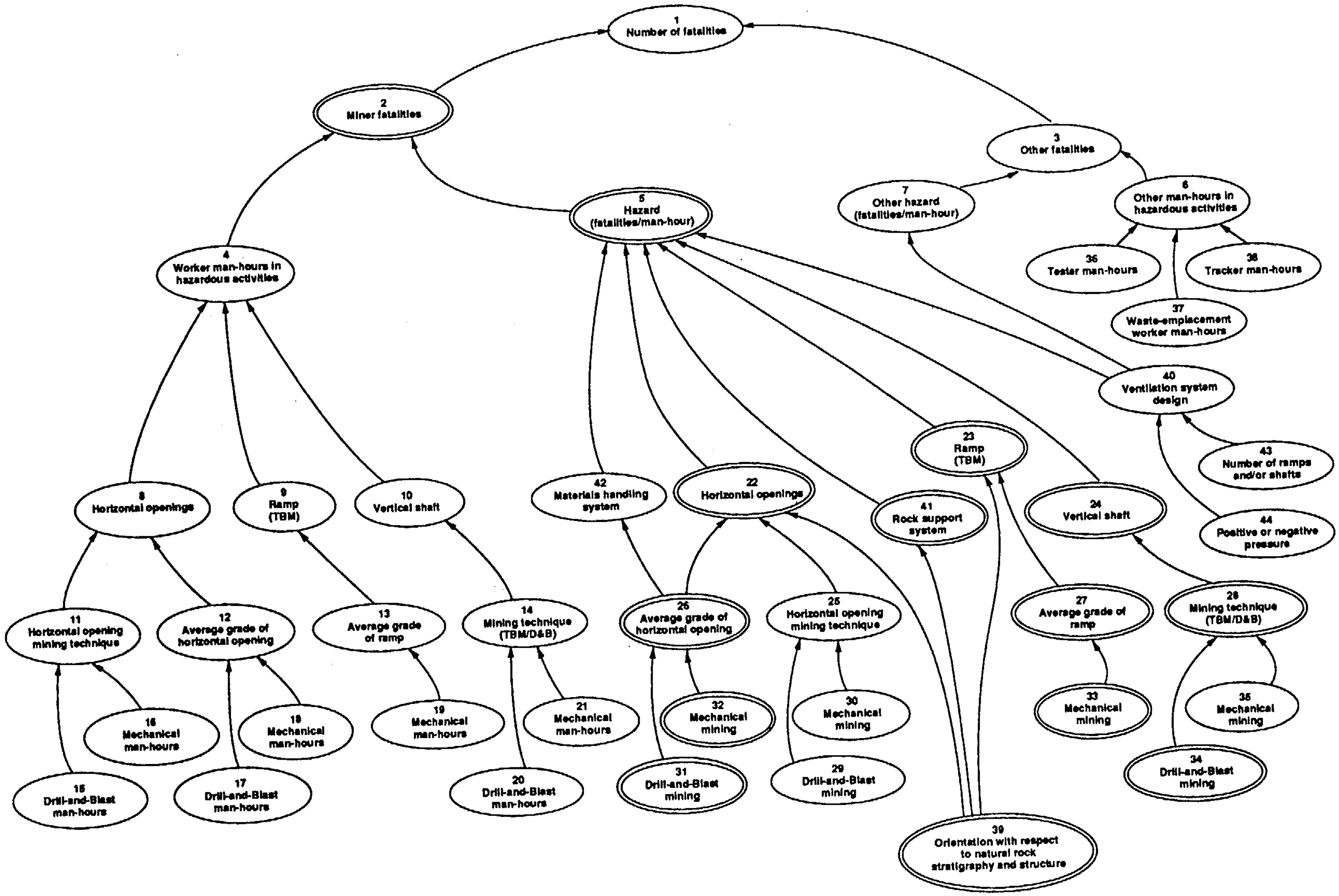

Figure B-16. Factors That Influence the Number of Nonradiological Fatalities Incurred by ESF-Repository Workers.

Hazards related to *ramps excavated by tunnel boring machines* (23) are also influenced by the *average grade of the ramp* (27) because ramps with higher inclines are more hazardous to excavate than ramps with lower inclines. Because none of the ESF-repository alternative designs call for ramps to be excavated by drill and blast mining methods, only fatalities related to *mechanical mining methods* (33) were considered in estimating the hazards related to ramps.

The relative hazards associated with excavating *vertical shafts* (24) differ depending on the *mining technique* (28). *Drill-and-blast techniques* (34) are more hazardous than *mechanical mining techniques* (35).

Hazards associated with the *ventilation system design* (40) increase in proportion to the number of *ramps and shafts required for the design* (43). Ventilation systems that have *positive pressure* (44) are more hazardous than those that have *negative pressure* systems (44). The *ventilation system design* (40) also influences hazards *other than mining hazards* (7).

Worker-hours in *hazardous activities* (4) will be conducted in three types of underground excavations: *horizontal openings* (8), *ramps* (9), and *vertical shafts* (10). The time required for hazardous activities in horizontal openings will differ depending on the *mining techniques* (11) and the *average grade* (12) of the openings. The worker-hours required for *drill-and-blast techniques* (15 and 17) and *mechanical mining methods* (16 and 18) must be considered for horizontal openings and horizontal openings with a grade.

Worker-hours in other hazardous activities (6) will be accumulated by workers other than miners who work in hazardous activities. These workers include *personnel conducting tests* (36), *waste-emplacement workers* (37) and personnel who are tracking (38) the progress of the ESF-repository operation.

The only hazard that affects workers other than miners and that might differ among alternative designs is the *ventilation system* (40), which is required by the *number of ramps and/or shafts* (43) and the *positive or negative pressure* in the mined area (44).

B.1.12.3 Performance Measure

Consideration of the influence diagram for preclosure nonradiological safety effects to workers (Figure B-16) revealed four major influencing factors that should be considered in developing performance measures and in scoring options.

- *Average grade of ramp or repository openings* (27)
- *Vertical shafts* (24)
- *Ventilation system design* (40)
- *Orientation with respect to natural rock stratigraphy and structure* (39)

The effects of these factors are summarized in Table B-4.

B.1.12.4 Performance Scale

A natural scale for measuring the performance of each option with respect to the performance measure for nonradiological safety is the number of fatal accidents among workers.

Experts in the areas of mining engineering and mining safety provided judgments of the number of worker fatalities expected as a consequence of each of the six paths through the ESF-AS Decision Tree (ESF-AS Report, Volume 2, Section 2, Figure 2-1). These estimates were made for each of the 34 options under consideration. The estimates also accounted for fatalities incurred during restoration of the site after abandonment or closure.

B.1.13 Preclosure Environmental Impacts: Aesthetics, X_5

The location of summary notes and transcripts documenting the development of the influence diagram and performance-measure scales for the preclosure environmental impacts to the aesthetic qualities are indicated by references in Appendices D.8 and D.10.

TABLE B-4

MAXIMUM EFFECTS OF IMPORTANT FACTORS INFLUENCING PRECLOSURE NONRADIOLOGIC SAFETY

Factor	Best Case (Lowest Fatalities)	Base Case (SCP-CDR Design)	Worst Case (Highest Fatalities)
Average Grade of Ramp or Repository Openings	• Lower Grade		• Higher Grade
Vertical Shafts	• Mechanical Raise Boring and Blind Boring	• Drilled Pilot Hole/V-Mole Enlargement	• Drill and Blast
Ventilation System	• Negative pressure		• Positive pressure
Orientation With Respect to Stratigraphy and Structure	• Perpendicular to Structure		• Acute Angle of Intersection

B.1.13.1 Objective

The Objectives Hierarchy for the ESF-AS (ESF-AS Report, Volume 2, Section 2, Figure 2-4) identifies three objectives related to environmental impacts attributable to the ESF-repository. One of those objectives was related to the impact of the ESF-repository on the aesthetic quality of the Yucca Mountain site.

> *Minimize the aesthetic impacts on the environment that are attributable to the ESF-repository.*

Both the effects from the repository facility itself and from waste transportation and emplacement were considered in this objective. Water usage was not expected to differ appreciably among the ESF-repository options.

B.1.13.2 Factors Influencing the Performance Measure

The performance measure was the significance of the aesthetic impact attributable to the ESF-repository. This performance measure is represented as the highest-level performance measure in the influence diagram (Figure B-17). Two factors affect the significance of the aesthetic impact with equal importance. Those factors are

- *Visibility of the aesthetic impact to populations* (2), and
- *Magnitude and locations of the aesthetic impact* (3).

Visibility To Populations. Aesthetic impacts have little significance if they are not visible to populations. One of the two factors that determine the visibility to populations is the *population experiencing potential vantage points* (4); that is, populations that may *reside* (23) at vantage points where the aesthetic impacts are visible or that may visit vantage points on a *transient* (24) basis. The more important influencing factor is the *location of the impact relative to vantage point on the ground* (5). Two locations were identified as significant vantage points, *roads and rest stops* (17), and the *Amargosa Valley community location* (18). Vantage points exist in the Amargosa Valley community (18) but the more frequented and clear vantage points are the roads and rest stops on roads in the area (17). Among the various roads that approach the Yucca Mountain site, the most likely vantage point is along *US Highway 95* (20). Other less likely vantage points are along the *Bureau of Land Management (BLM) access road* (19), *county roads* (22), and *other roads* (21).

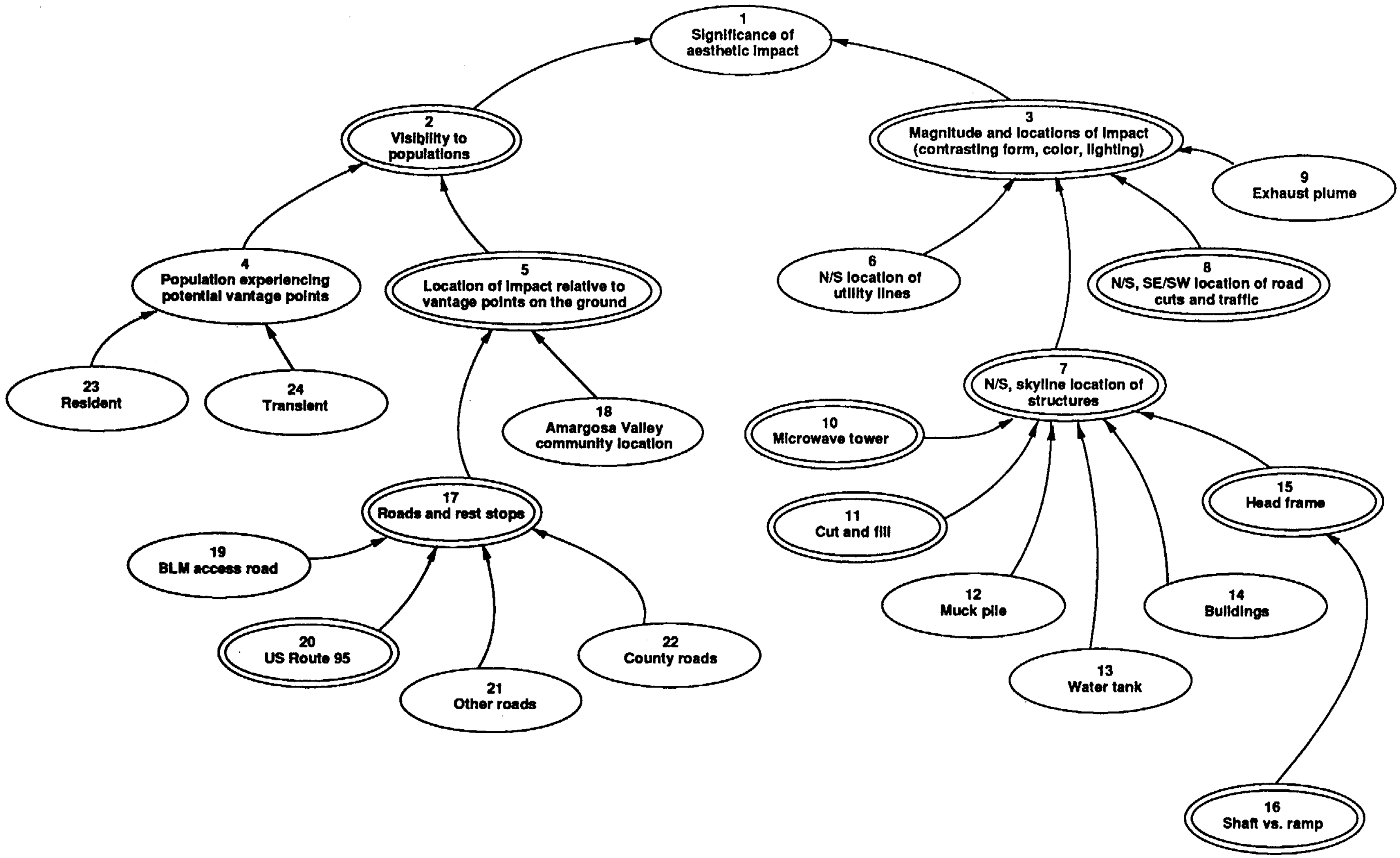

Figure B-17. Factors That Influence the Aesthetic Impact of the ESF-Repository.

Magnitude And Location Of Impacts. The magnitude and location of the aesthetic impacts include such characteristics as the content, form, color, and lighting associated with the impacts. For example, buildings or shaft headframes have less aesthetic impact if they are painted to blend with the color of the countryside. Four factors influence these characteristics. *The north-south location of utility lines* (6) will degrade the aesthetic qualities of the Yucca Mountain site. *Exhaust plumes* (9) will almost certainly be visible from several vantage points. The most important factors influencing the magnitude and location of impacts are the *north-south skyline location of structures* (7) and the *north-south and southeast-southwest location of roadcuts and traffic* (8).

The *north-south skyline location of structures* (7) are significant because several types of structures may be located on the skyline. The structures that will have the largest impacts are the *headframes* (15) which will be different for *shaft versus ramp constructions* (16) and the *microwave towers* (10), and *cut-and-fill structures* (11). The less significant structures are the *muck piles* (12), *water tanks* (13), and *buildings* (14).

B.1.13.3 Performance Measure and Scale

Visibility impact was selected as the performance measure for the aesthetic impact on the environment. Based on the factors in the influence diagram, visibility impacts can be grouped into the following three categories:

- Major impacts: skyline structures,
- Moderate impacts: structures and facilities, and
- Minor impacts: road-cuts and traffic.

The visibility impact is greater if it can be seen from more than one vantage point.

A scale was constructed to measure the significance of visibility impact. A constructed scale of values ranging from zero to 12 (Table B-5) was based on the features of the ESF-repository facility that might be visible from vantage points such as roads and hills. An option that resulted in no impacts visible from any vantage point would be assigned the highest score of "12." The worst scores would result from options that included visible skyline structures, structures and facilities, and road cuts and traffic.

TABLE B-5

PERFORMANCE SCALE FOR THE PERFORMANCE MEASURE FOR ENVIRONMENTAL IMPACTS: VISUAL IMPACTS

Score	Description
12 (Best)	No impacts visible from any vantage point
11	Minor impacts (road cuts/traffic) visible from one vantage point
10	Minor impacts (road cuts/traffic) visible from multiple vantage points
9	Moderate impacts (structures/facilities) visible from one vantage point
8	Moderate impacts (structures/facilities) visible from one vantage point **plus** Minor impacts (road cuts/traffic) visible from one vantage point
7	Moderate impacts (structures/facilities) visible from one vantage point **plus** Minor impacts (road cuts/traffic) visible from multiple vantage points
6	Moderate impacts (structures/facilities) visible from multiple vantage points
5	Moderate impacts (structures/facilities) **and** Minor impacts (road cuts/traffic) visible from multiple vantage points
4	Major impacts (skyline structures) visible from one vantage point
3	Major impacts (skyline structures) visible from one vantage point **plus** Minor impacts (road cuts/traffic) visible from multiple vantage points
2	Major impacts (skyline structures) visible from multiple vantage points **plus** Moderate impacts (structures/facilities) visible from multiple vantage points
1	Major impacts (skyline structures) visible from multiple vantage points
0 (Worst)	Major impacts (skyline structures), Moderate impacts (structures/facilities), and Minor impacts (road cuts/traffic) visible from multiple vantage points

B.1.14 Preclosure Environmental Impacts: Historical Properties, X_6

The location of summary notes and transcripts documenting the development of the influence diagram and performance-measure scales for the preclosure environmental impacts to historical properties are indicated by references in Appendices D.8 and D.9.

B.1.14.1 Objective

The Objectives Hierarchy for the ESF-AS (ESF-AS Report, Volume 2, Section 2, Figure 2-4) identifies three objectives related to environmental impacts attributable to the ESF-repository. One of these objectives was related to the historical features at the Yucca Mountain site.

Minimize degradation of historical properties that is attributable to the ESF-repository.

Both the effects from the repository facility itself and from waste transportation and emplacement are considered in this objective.

B.1.14.2 Factors Influencing the Performance Measure

The principal effect of the ESF-repository was considered to be the effect on historical properties at the Yucca Mountain site. Therefore, a performance measure was developed to measure the

"*adverse effects on historical properties.*"

The influence diagram describing the adverse effects on historical properties (Figure B-18) shows that the *adverse effects on historical properties* (1) is really equivalent to the *residual adverse effects on mitigated but unavoided historical properties* (2). All historical properties within the area of the ESF-repository will be avoided if possible. Those historical properties that cannot be avoided will be mitigated. That is, the research data from the property will be collected. The only adverse effects to historical properties will be the residual adverse effects to mitigated but unavoided historical properties.

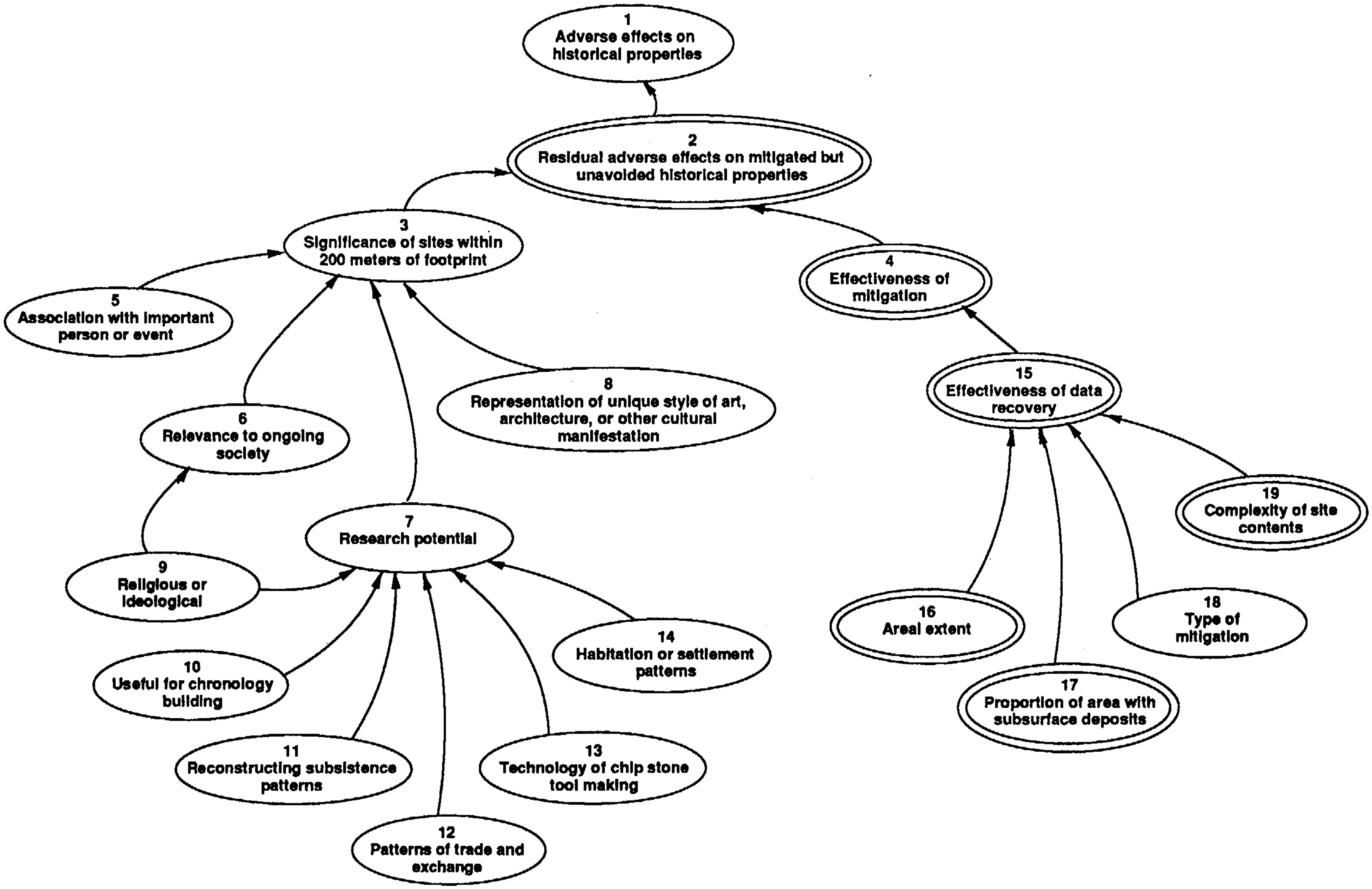

Figure B-18. Factors That Influence the Adverse Effects to Historical Properties.

The residual adverse effects will result from two factors, the *significance of the sites within 200 meters of the ESF-repository area* (3) and the *effectiveness of the mitigation* (4). The significance of the sites within 200 meters of the area is less discriminating than the effectiveness of mitigation, because within the definitions used by the DOE, no sites are more or less significant than others. All sites will be mitigated to the maximum possible extent without regard to significance.

Significance. The potential for degradation of a historical property site increases in direct proportion to the significance of the sites that will be mitigated by the ESF-repository activities. The area of concern includes a region that extends 200 meters from the boundary of the repository area. For the purposes of comparing the impact of ESF-repository options, the significance of the historical property sites is measured by the *association of the site with an important person or historical event* (5), the *relevance to an ongoing society* (6), the *research potential of the site* (7), and the *representation of a unique style of art, architecture, or other cultural manifestation* (8).

The *research potential* (7) associated with a historical property site was based on five factors. These five factors relate to information about

- *chronology building* (10),
- *reconstruction of subsistence patterns* (11),
- *religious or ideological history* (12),
- *the technology of chip-stone manufacturing* (13), and
- *habitation or settlement patterns* (14).

In addition to influencing the research potential of a site, the *religious or ideological significance of a site* (9) may affect the *relevance of a site to ongoing societies* (6).

Effectiveness of Mitigation. The *effectiveness of mitigation* (4) is a more important impact than the *significance of sites* (3) in determining the residual adverse effects on mitigated sites. The intent of mitigation is to recover the information that will be valuable to society for a variety of reasons. The DOE will attempt to recover all the data from the site. However, the mitigation techniques may not be 100 percent effective and some data will inevitably be lost. Some data may be overlooked because the importance of the data is not appreciated. The *effectiveness of data recovery* (15) is determined by the *areal extent of the mitigated site* (16), the *proportion of the site area that is below the ground surface* (17), the *type of mitigation* (18) that is used, and the *complexity of the site contents* (19). The two most important factors are the areal extent (16) and the *subsurface proportion of the site area* (17). The greater the areal extent, the less likely all data will be retrieved. The more historical properties are subsurface, the less likely the mitigation will be complete.

B.1.14.3 Performance Measure and Scale

The major factors revealed in the diagram by double ellipses led to the consensus that the performance measure for degradation of historical properties is *effectiveness of mitigation* (4). The two major factors contributing to this performance measure are areal extent of the historical property (16) and the *fraction of area with subsurface deposits* (17).

The performance measure, X_6, is the weighted areal extent (in hectares) of historical properties sites within the area of a ESF-repository site.

$$X_6 = \sum_{i=1}^{N} S_i \times F_i \qquad \text{(B-1)}$$

where

N = Total number of historical properties sites within the repository boundaries that are not common to all repository sites,

S_i = Areal extent of site i (in hectares),

$$F_i = \begin{cases} 5 \text{ if the } i^{th} \text{ site is subsurface, or} \\ 1 \text{ if the } i^{th} \text{ site is surface only.} \end{cases}$$

The areal extent of the historical properties site is more precisely defined as the areal extent of artifacts identified (area of minimum convex encompassing surface) where the definition of the historical properties site is based on judgment. The historical properties sites have been identified and were established at the time of the ESF-AS.

The performance scale is a natural scale measured in square meters. A scale ranging from 6 square meters to 70,000 square meters (0.0006 to 7.0 hectares) encompasses weighted areal extents of any historical properties site in any of the options.

B.1.15 Preclosure Direct Cost Impacts, X_7

The location of summary notes and transcripts documenting the development of the influence diagram and performance-measure scales for the preclosure direct cost impacts are indicated by references in Appendix D.11.

B.1.15.1 Objective

Costs have been regarded as a measure of one of the key objectives of the ESF-repository option choice. There is a desire to minimize costs. Lower costs are better than higher costs, all other things being equal. The Objectives Hierarchy for the ESF-AS (ESF-AS Report, Volume 2, Section 2, Figure 2-4) identifies one objective as

minimize cost impacts.

Two cost impacts were identified in the objectives hierarchy. One of those impacts was the direct costs of constructing and operating the ESF-repository. Therefore, one objective of the ESF-AS was to select an option that would

minimize the direct costs of the ESF-repository.

The highest level objective in the DOE's total system of nuclear waste management activities is the minimization of total system life cycle costs (TSLCC). The total budget for the TSLCC must include the repository life cycle costs (RLCC) for the first geologic repository as well as the second repository. Other considerations in the total TSLCC include benefits, the material retrieval system (MRS) and development and evaluation (D&E). The costs of development and evaluation represent 42 percent of the total radioactive waste management budget. The cost of developing and evaluating the ESF-repository is considered a part of the total system development and evaluation budget. Other contributors to the D&E budget are the surface-based testing, oversight personnel and inspectors, technical support, and management costs. Based on these considerations, the two high-level objectives related to the ESF-AS are

- Minimization of the first repository life-cycle cost, and
- Minimization of the cost of the ESF.

B.1.15.2 Factors Influencing the Performance Measure

Cost performance differs from other performance measures because the science, or at least the semantic methodology, of cost estimation is probably better developed than the methodology for estimating other performance measures, such as biological degradation, particularly since costs can be summed using more detailed cost factors. The methodology for estimating costs is to a great extent a matter of identifying cost elements and then summing those elements. Identification of all the cost elements is important and specialists in the cost estimation field are quite good at identifying the individual cost elements and then summing them up in an appropriate way. The estimation of costs for the ESF-AS application required something more. There are substantial uncertainties at this time regarding exactly the ultimate costs for a specific ESF-repository option and its associated repository. Typically, cost estimators devote more attention to a baseline estimate of costs than a probability distribution reflecting uncertainty in cost or the minimum or maximum costs. The ESF-AS is one of those applications where these uncertainty estimates are important. The study is concerned not only with a best professional estimate, but also the uncertainties in those cost estimates. The study should especially point out those ESF-repository options that have much more uncertainty in costs than others. The study will be particularly concerned about the possibility of a very high cost. It is important to understand the probability associated with the very high cost. Influence diagrams are a means for identifying factors that influence in a probabilistic way rather than a cause-effect way. Strictly speaking, the technical literature on influence diagrams define, in mathematic terms, what it means to have a bubble higher than another bubble. The relationship is expressed in terms of a probabilistic relationship. If all the cost elements were put into a graphic diagram, the diagram would be so huge and unwieldy that it would not be useful. The influence diagram for the ESF-AS should provide an aid to an expert panel that will help them provide professional judgment with regard to costs. The diagram should identify those factors that are uncertain.

The ESF-AS Expert Panel on Cost and Schedule developed three influence diagrams to assist in identifying the performance measures related to the objective of minimizing the costs attributable to the ESF-repository during the period before the repository is closed. For the purposes of developing a performance measure for minimizing costs, all dollar amounts will be discounted. Dollars required early in the schedule will have greater value than dollars required later in the schedule. The annual Analysis of the Total System Life Cycle Cost for the Civilian Radioactive Waste Management Program [DOE, 1989] was used as the basis for cost estimates. Costs were developed in 1989 dollars because the analysis for 1990 was not available for this study.

Separate influence diagrams were developed for each of the categories' main factors influencing ESF-repository costs (Figure B-19), and the diagrams were subdivided into component diagrams. *Discounted direct costs* (Figure B-20, 1) will be calculated using an *annualized stream of ESF-repository life cycle costs* (2) and the discount rate (3) selected for the ESF-AS. The annualized stream of ESF-repository life cycle costs will have two major components, the *first RLCC* (4) and the *ESF cost* (14).

Repository Life Cycle Cost. The influence diagram for the first Repository Life Cycle Costs (RLCC) (Figure B-21, 4) may be divided into three broad categories, the *cost of emplacement containers* (67), the *cost of surface facilities* (9), and the *cost of underground facilities* (8). The cost of *surface facilities* (9) and *emplacement containers* (67) were judged to be so similar among the 34 options under consideration that these cost provided no basis for distinguishing among the options. The *costs of surface facilities* (9) were not subdivided further for the purposes of the ESF-AS.

Four major contributors to the cost of *underground facilities* (8) were identified. A relatively minor contribution is the design cost (15) of the underground facilities. The three major cost factors related to *underground facilities* (8) are the cost of initial construction (16), the *costs of operating the underground storage facility* (17), and the costs of *closing and decommissioning* (18) the repository. All the ESF-repository options provide for an initial construction period during which main drifts and emplacement drifts are constructed. After the initial construction period, construction of the remainder of the repository will proceed at the same time as the emplacement of waste.

The cost of *initial construction* (16) isolates only those costs associated with the initial construction period. (According to the current schedule, the initial construction period is between 2004 and 2009.) The major factor influencing the cost of initial construction

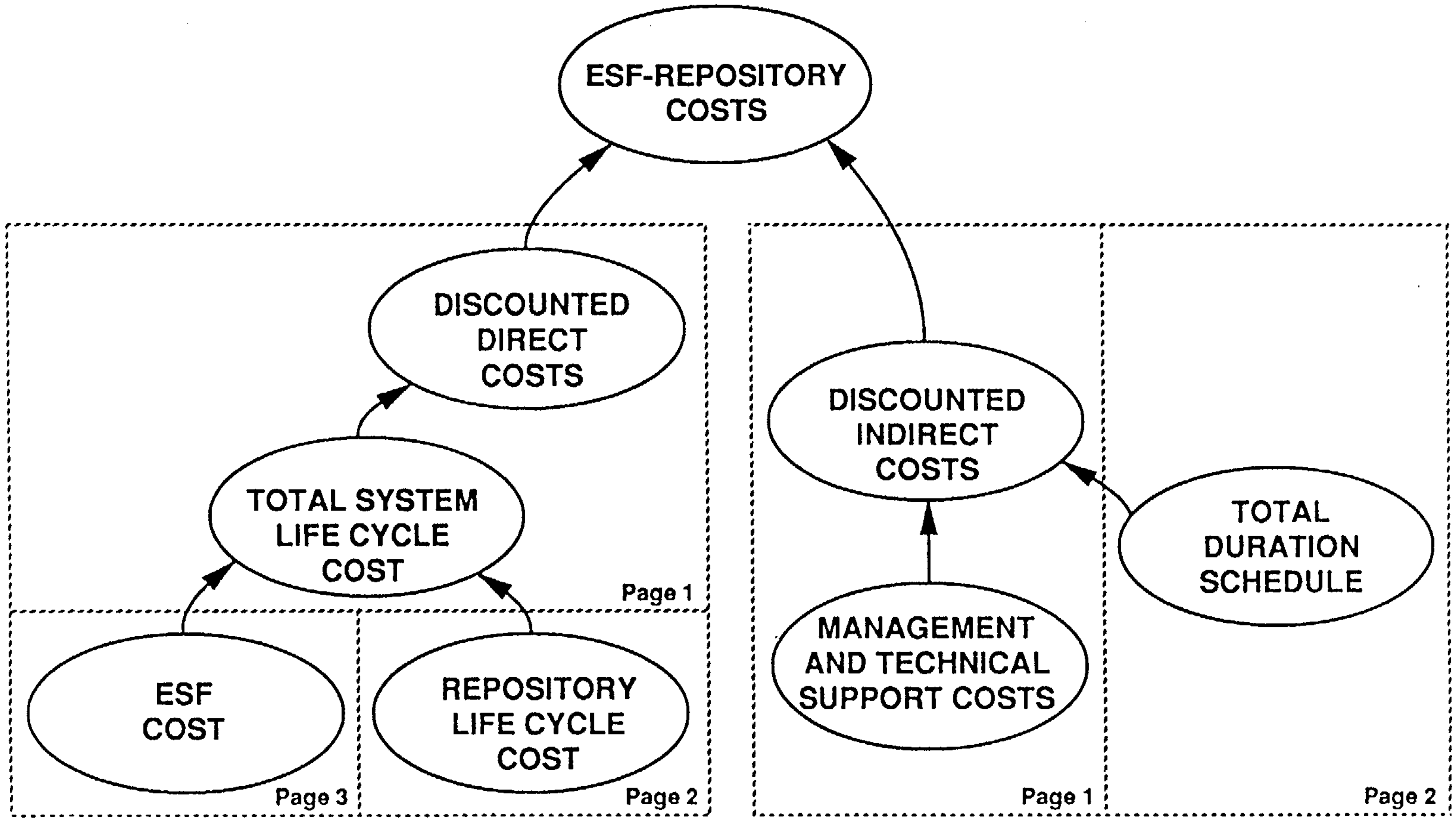

Figure B-19. Influence Diagram For Cost and Schedule Impacts of the ESF-Repository.

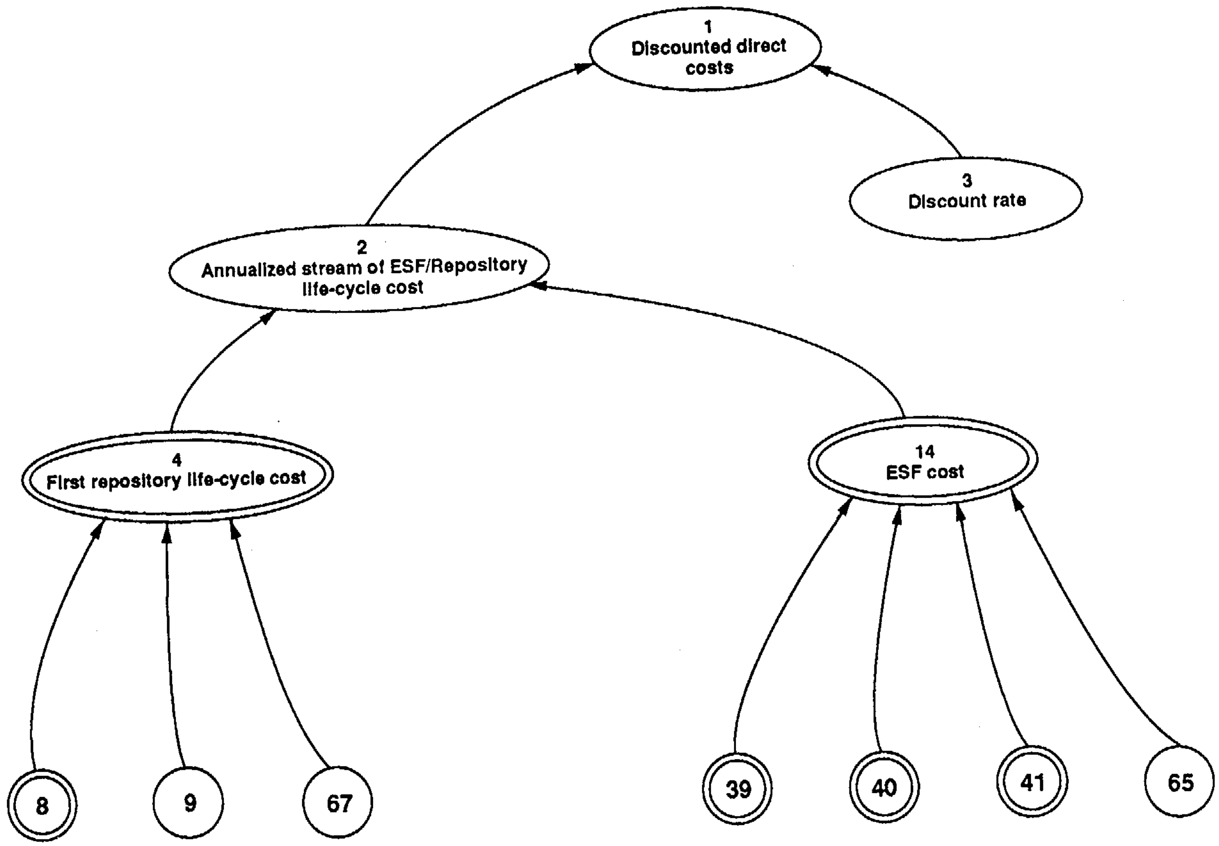

Figure B-20. Factors That Influence the Total System Life-Cycle Cost of the ESF-Repository (Page 1 of 3).

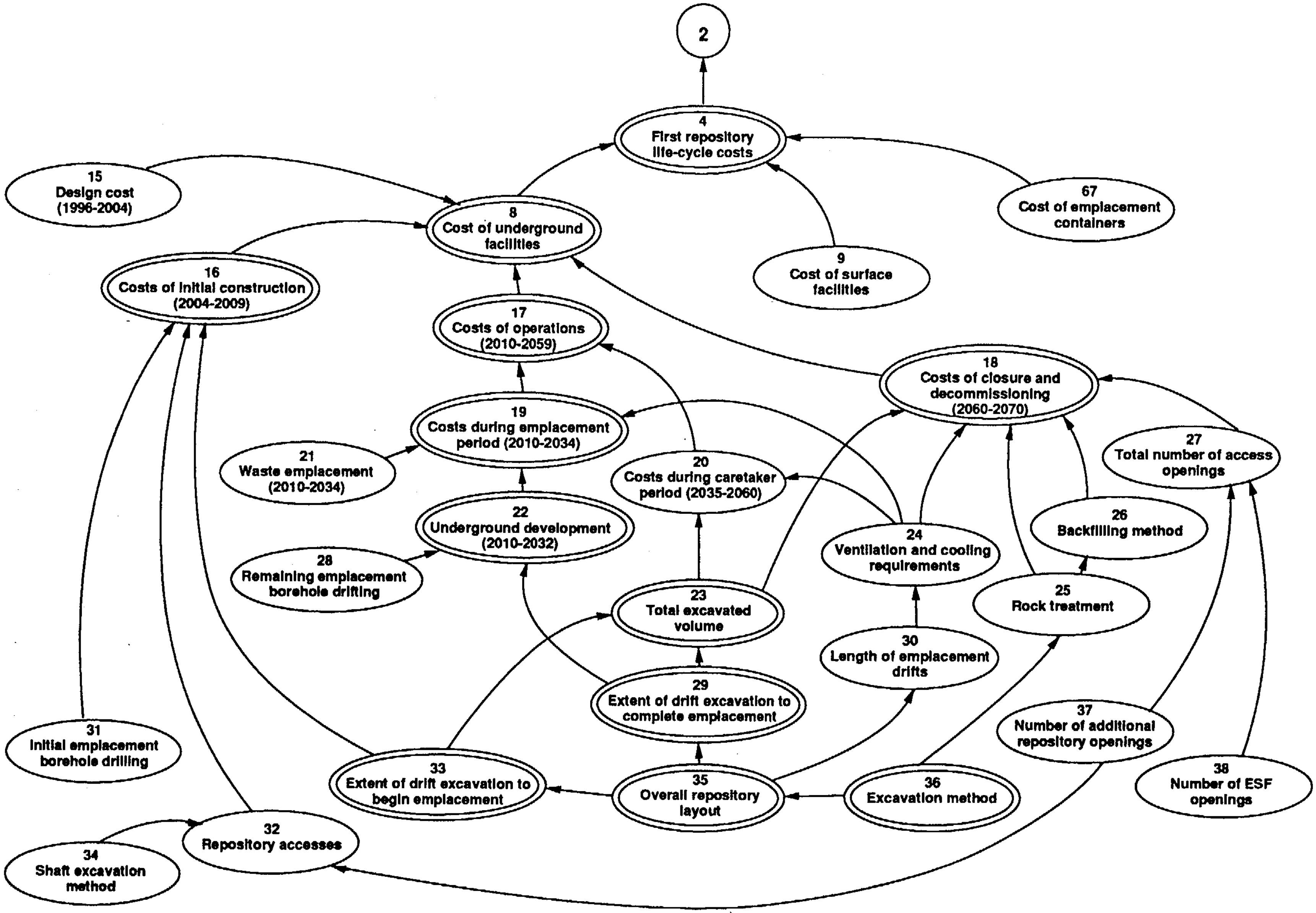

Figure B-21. Factors That Influence the Total System Life-Cycle Cost of the ESF-Repository (Page 2 of 3).

(16) was judged to be the *extent of drifts* (33) that must be excavated to begin emplacement of waste. That factor was most influenced by the *overall repository layout* (35). The overall repository layout is determined by the excavation method (36) because each of the ESF-repository options were designed based on specific assumptions about the excavation method. The methods will be drill-and-blast mining techniques, mechanical mining techniques, or specific combinations of these methods. The panel considered other contributing costs to the total cost of initial construction but considered them to be either insignificant or not different among the ESF-repository options. Some minor influences on the costs of initial construction included the costs of *initial emplacement borehole drilling* (31) and the cost of developing repository accesses (32). The cost of developing *repository accesses* is influenced principally by the *shaft excavation method* (34) and the number of repository openings in addition to the number of ESF openings that must be constructed (37). Although Factor 32 was potentially a discriminating factor among ESF-repository options, the influence was considered insignificant relative to the costs of developing drifts to begin emplacing waste (33).

The second major cost related to *underground facilities* (8) is the cost of *operating the underground facility* (17). The *costs during the emplacement period* (19) were considered more significant than the costs of maintaining the facility after the waste was emplaced (*costs during caretaker period* (20)). Of three major contributors to the *costs during the emplacement period* (19), the costs of *underground development* (22) were expected to exceed the costs of *waste emplacement* (21) or *ventilation and cooling requirements* (24).

The costs of *underground development* (22) are directly impacted by the *extent of drifts required to complete the emplacement of waste* (29) and that factor, like the *extent of drifts excavated to begin emplacement of waste* (33), is determined by the *overall repository layout* (35). A lesser influence on the underground development was the cost of *drilling the remaining emplacement boreholes* (28).

The third major factor influencing the cost of *underground facilities* (8) is the *cost of closure and decommissioning* (18), which assumes its major importance because of the *total excavated volume* (23) of rock. Costs increase in direct proportion to the *total excavated volume* (23), which is determined by two major influences, the *extent of drift excavation to begin emplacement* (33) and the *extent of drift excavation to complete emplacement* (29).

Other less significant factors contribute to the *cost of closure and decommissioning* (18). *Ventilation and cooling requirements* (24) increase the *cost of closure and decommissioning* (18) if the *overall repository layout* (35) increases the *length of emplacement drifts* (30). *Rock treatment* (25) costs during closure and decommissioning will vary with the excavation method and will impact the *backfilling method* (26). *The costs of closure and decommissioning* (18) increase with the *total number of access openings* (27), which is meant to include the *number of ESF openings* (38) and the *number of additional repository openings* (37).

ESF Cost. The ESF cost (Figure B-20, Factor 14) is the second major cost factor relevant to the ESF-AS. The influence diagram for ESF cost (Figure B-22) illustrates the opinion of the expert panel that four factors of equal importance contribute to the ESF cost. Those factors are construction of *surface facilities* (39), construction of *underground facilities* (40), *operation* of the ESF (41), and *environmental monitoring reconfiguration* (65).

The surface construction costs (39) increase principally because of the *terrain* (42) and the *water and power requirements* (43) for the construction. The latter is the most important influencing factor because it is influenced by the *number and locations of underground accesses* (44) which vary from option to option.

The underground construction costs (40) are contributed by three factors, *underground accesses* (45), *MTL configuration and extent* (46), and the *cost of exploratory drifting* (47). Of these three costs, the *underground accesses* (45) and the *exploratory drifting* (47) are of equal magnitude. The underground accesses include shafts and ramps that provide access for men and materials. The *underground accesses* (45) are determined by the *schedule* (48) and the *contingency cost of technology uncertainty* (49). The *schedule* (48) is determined by the *method of construction* (54) and the *number and duration of underground (UG) access testing* (53), which varies with option, depending on the combination of *ramps versus shafts.*

Of the two contributors to the costs of the *underground accesses* (45), the *contingency cost of technology uncertainty* (49) is the major factor. This factor reflects the high cost estimates that are attached to construction phases that rely on unproven mining technology. Some of the alternative designs are based on mining machines that are still in the prototype stage of development. Experienced architects and engineers realize

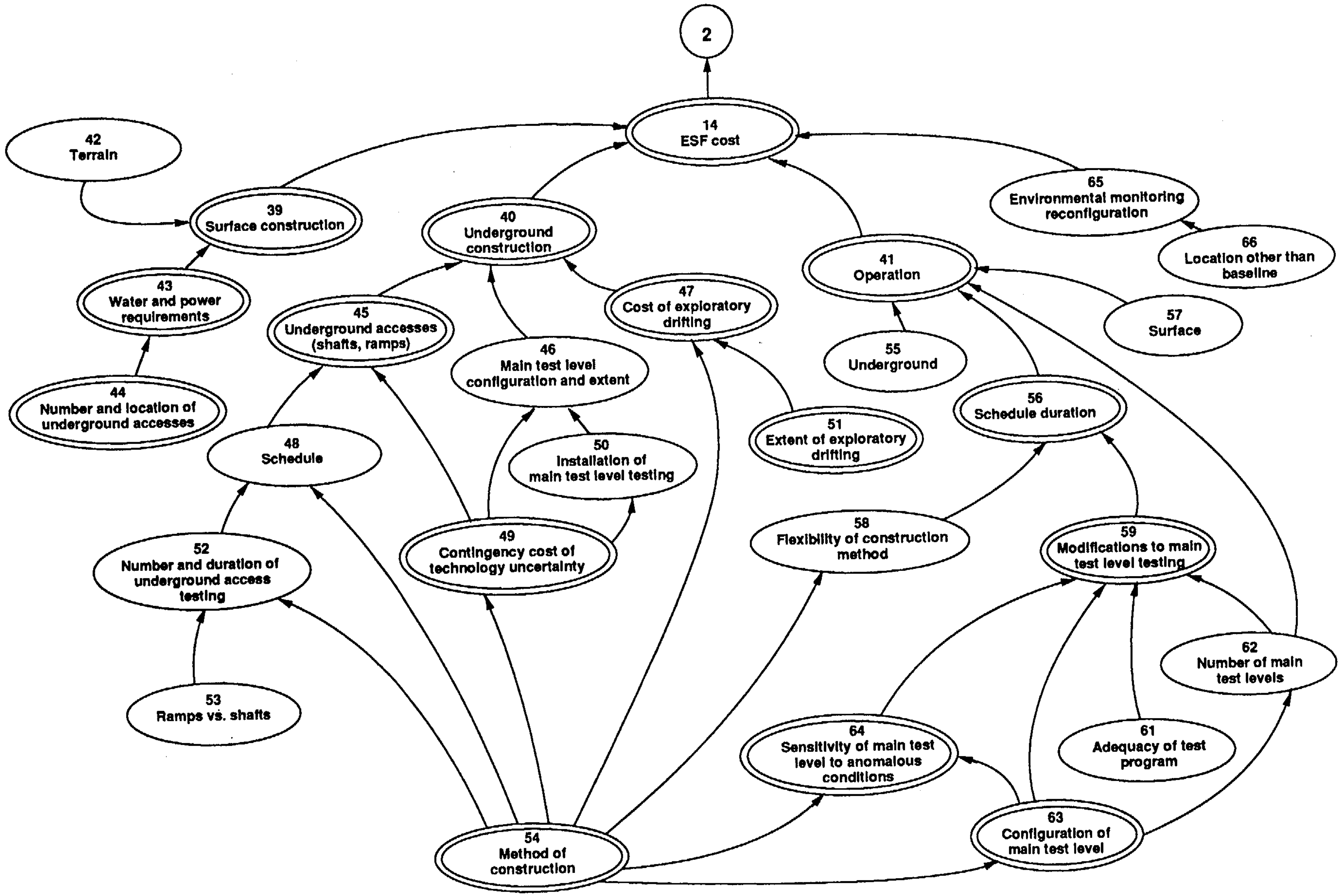

Figure B-22. Factors That Influence the ESF Cost (Page 3 of 3).

that the ultimate costs for construction projects using new technology will be higher than those projects that use conventional technology. The resulting contingency costs are directly related to the *method of construction* (54) that is proposed for the design. Drill and blast techniques of construction are well understood and the cost estimates are reliable. Some mechanical mining techniques are less understood and contingency costs must be added to the cost estimates. The *contingency cost of technology uncertainty* (49) also affects the costs associated with the construction of the MTL. Those costs include the costs of *installing the MTL tests* (50) and the costs that increase in proportion to the *configuration and extent of the MTL* (46). However, the costs associated with the MTL are minor compared with the costs of constructing *underground accesses* (45) and *exploratory drifting* (47). These costs may vary significantly depending on the *extent of exploratory drifting* (51) that is included in the design.

Rock hardness impacts the *contingency cost of technology uncertainty* (49) but was not included in the influence diagram because rock hardness does not vary from ESF-repository option to ESF-repository option. For the purpose of the ESF-AS, rock hardness is a determined quantity. The value provided by the Yucca Mountain Site Characterization Project Reference Information Base (RIB) will be used for all options. Contingency costs (DOE, 1989) associated with technology uncertainty are determined by the rock hardness and the *method of construction* (54), more specifically, the mining method. Even though the rock hardness is the same for all options, it is used in conjunction with the mining method to determine the contingency cost of technology uncertainty. For example, the technology uncertainty associated with mining a very strong rock (uniaxial compressive strength = 200 MPa) is likely to be lower for drill-and-blast technology than for blind-shaft boring.

The *operation cost* (41) of the ESF has four main components. The cost of the *underground* operation (55), the cost of operating the *surface* facilities (57), and the cost of operating the *MTL levels* (62) are relatively minor compared to the costs caused by increases in *schedule duration* (56). The number of people working at the ESF (about 300 persons) is only about 15 percent of the total people involved in the ESF (about 2,000 persons). *Modifications to the MTL testing program* (59) that cause schedule delays cause cost increases that overwhelm the costs of operating the underground and surface facilities. The factors that cause *modifications to the MTL* (59) are such things as *anomalous conditions* (60) that may be encountered during the testing program, identification of *inadequate tests* (61) in the MTL testing program, the *number of MTL levels* (62) that are required, and the overall configuration of MTL (63). If the MTL is not configured adequately, it may require modifications during the operation of the ESF. These modifications will increase the cost of operations. The *configuration of the MTL* (63) may also affect the ability of scientists and engineers working in the MTL to identify *anomalous conditions* (64). The different costs associated with different designs may reflect differences in the sensitivity of the MTL to *anomalous conditions* (64). The sensitivity of the MTL to *anomalous conditions* (64) and the *configuration of the MTL* (63) are both influenced by the *method of construction* (54) used for the design. The costs associated with reconfiguring the environmental monitoring systems (65) will become important if the ESF-repository design calls for the monitoring systems to be located in locations other than those identified for the base case (SCP-CDR).

B.1.15.3 Performance Measure and Scale

The performance measure for direct costs of the ESF-repository is the total discounted dollars required to construct and operate the ESF-repository. The performance scale for direct costs is a natural scale. The unit of measurement is discounted dollars.

B.1.16 Preclosure Indirect Cost (Schedule) Impacts, X_8

The location of summary notes and transcripts documenting the development of the influence diagram and performance-measure scales for the preclosure direct cost impacts are indicated by references in Appendix D.11.

B.1.16.1 Objective

The ESF-AS Objectives Hierarchy (ESF-AS Report, Volume 2, Section 2, Figure 2-4) identifies the one of the objectives of the ESF-AS as

minimize indirect cost (schedule) impacts.

Schedule impacts are reflected in indirect costs. Therefore, an influence diagram was developed to show the factors that impact schedule and the resulting impact on indirect costs.

Two cost impacts were identified in the objectives hierarchy. One of those impacts was the indirect costs resulting from schedule slippages resulting from the ESF-repository. Therefore, one objective of the ESF-AS was to select an option that would

minimize the indirect costs (schedule) of the ESF-repository.

B.1.16.2 Factors Influencing the Performance Measure

The performance objective is to minimize the total duration of the ESF and repository operation. The performance measure is the discounted dollar difference caused by the number of months of schedule change that will be caused by activities, design changes, or programmatic changes.

There was little reason to believe there would be significant differences among options because of the time required for the actual characterization testing. The construction time and cost is likely to vary among options but the actual time for testing is about the same as the cost of testing that is estimated for the base case. The cost of additional testing, for example, duplication of tests in the same time frame as the original tests, was not included in the cost estimates for the options. The underlying assumption used in developing the performance measure for scheduling costs was that there was no time constraint on the testing program. Testing will continue to the time when the information is obtained to determine site suitability. The cost and schedule estimates were based on incomplete plans and scopes for some of the ESF-repository designs.

The duration to the end of repository closure or retrieval of waste was considered the important factor in the performance measure. The duration of the retrieval period was estimated by a panel of experts.

To aid in the development of the indirect cost (schedule) performance measure, the factors influencing the highest level objective, minimization of total duration of the ESF and repository operation, was constructed (Figures B-23 and B-24). The criteria for selecting a factor as having major influences were that the factor would cause a significant impact on the schedule and that the factor vary enough to allow discrimination among and between options.

The following underlying assumptions were used in developing the performance measure for scheduling costs.

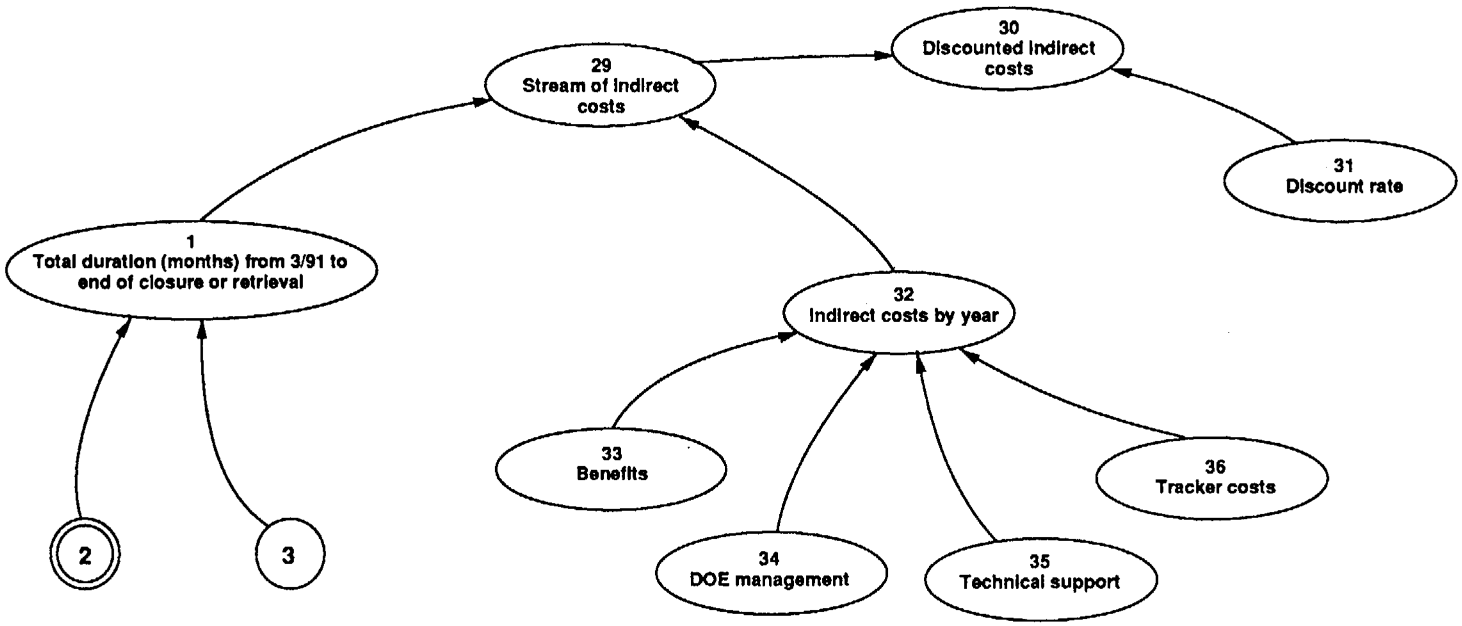

Figure B-23. Factors That Influence the Discounted Indirect Costs Due to Schedule (Page 1 of 2).

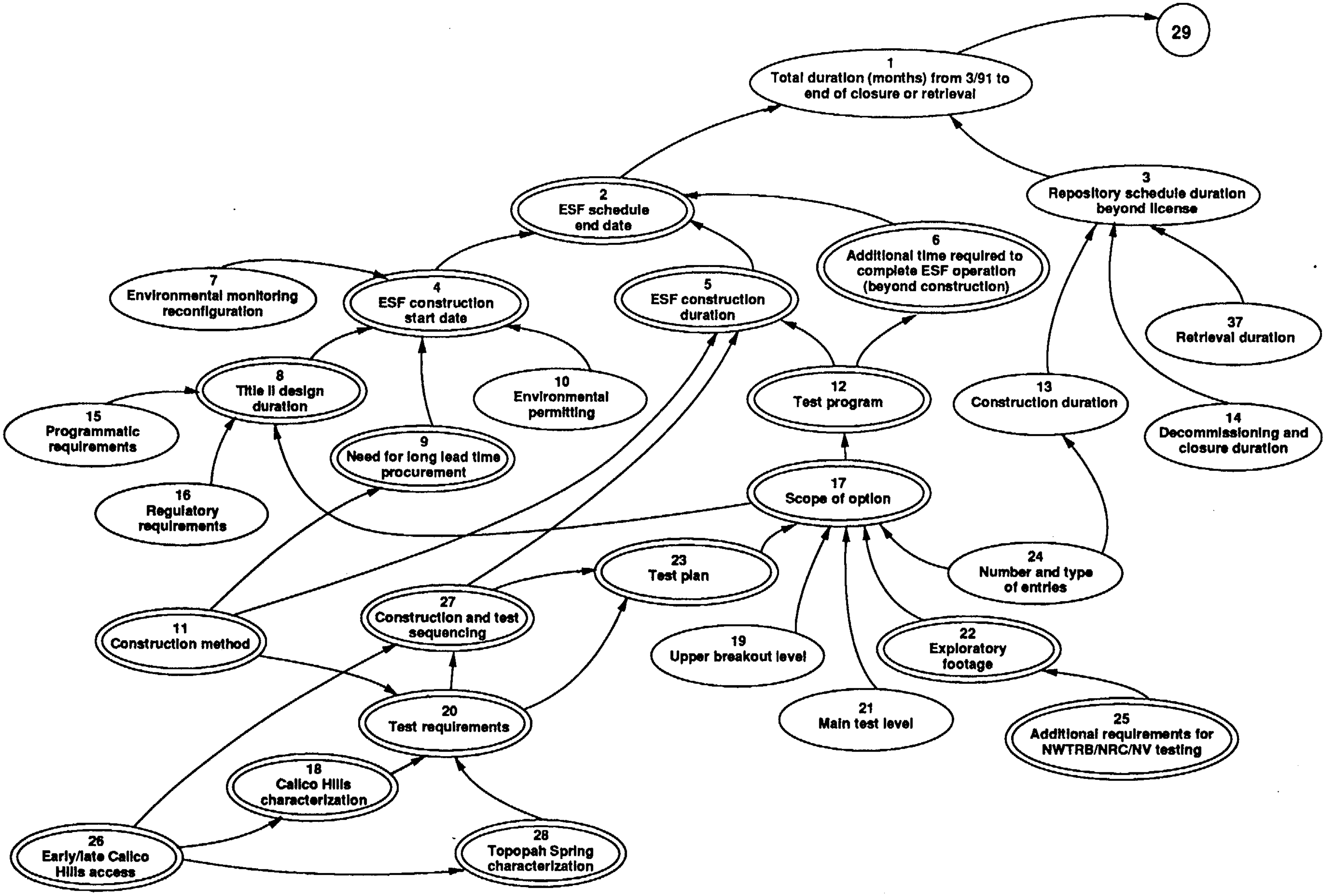

Figure B-24. Factor That Influence the Discounted Indirect Costs Due to Schedule (Page 2 of 2).

- Assume no time constraint on the testing program. Testing will continue to the time when the information is obtained to determine site suitability.

- Assume a fixed best estimate for the time required for testing. All estimates must include the recommendations from the NWTRB.

- Estimate the costs consistent with the specified schedules.

The cost and schedule estimates were based on incomplete plans and scopes for some of the ESF-repository designs.

The duration to the end of repository closure or retrieval of waste was considered the important factor in the performance measure. The duration of the retrieval period was estimated by a panel of experts.

Discounted indirect costs (30), the highest level factor in the influence diagram for schedule as reflected by indirect costs (Figure B-23), are derived from the *stream of indirect costs* (29) in constant (1989) dollars for each option and the *discount rate* (31) adopted for the study. One contribution to the *stream of indirect costs* (29) is the *total duration (months) from March 1991 to the end of closure or retrieval* (1). March 1991 was the assumed date for starting construction of the ESF. The different schedules for each option will provide discrimination among options using this performance measure. The other contributions to the *stream of indirect costs* (29) are *indirect costs by year* (32) that result from *benefits* (33) for example, reviews by states, Native American tribes and other affected parties, *DOE management* (34), *technical support* (35), and DOE inspection and tracking of progress (*tracker costs* (36)).

The total duration from March 1991 to the end of closure or retrieval (1), was subdivided to include impacts from the *ESF schedule end date* (2) and the *repository schedule duration beyond licensing* (3). Of these two components, the *repository schedule* (3) has the lesser impact on schedule because once a license is obtained, the duration of the repository is expected to be nearly constant, regardless of which ESF-repository alternative was used in the preclosure period. The *construction duration* (13), *decommission and closure duration* (14), and *retrieval duration* (28) were all considered constant. The *construction duration* (13) may be impacted to a minor degree by the *number and type of entries* (24) used in the ESF. The repository must be designed to work with whatever entries are available from the ESF.

The ESF *schedule end date* (2) is impacted to equal degrees by three major factors:

- *the ESF construction start date* (4),
- *the ESF construction duration* (5), and
- *the additional time required to complete the ESF operations beyond construction* (6).

All three of these factors are ultimately influenced by the *scope of the ESF design selected for the repository* (17). Two minor impacts on the *ESF construction start date* (4) are the *environmental monitoring reconfiguration* (7) and the *environmental permitting* (10). All options except the base case will require modification of environmental monitoring system. There will be no discrimination among the other options. Relative to the schedule aspects, the environment monitoring reconfiguration efforts are not a basis for discrimination between and among options. In addition, any actual reconfiguration of the environment monitoring programs would be undertaken in parallel with ESF design efforts; that is, during the period from the point of picking a preferred ESF-repository option to the beginning of site preparation. Because costs have already been incurred for the environmental program for the base case design, any other options will require some type of reconfiguration of the environmental monitoring program. Those costs of reconfiguring the environmental monitoring system are expected to be essentially the same for all options other than the base case. Therefore, the base case will have less cost for reconfiguring than the other options.

The factors included in the time required to obtain environmental permits (10) are

- ESF construction permits;
- Repository construction/operation permits;
- Water appropriation permits, covering such items as waterlines, pump stations, storage, and tanks; and ponds, which require a permit change[3];

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[3]The amount of water used depends on the construction methods. The SCP-CDR design requires less than 100 acre feet (123,000 m^3).

- ESF design phase (nominally 500 days);

- Air quality surface disturbance permits[4]; and

- Political decisions (Environmental Litigation by the State of Nevada and/or New Alternatives versus CDR Base Cases).

Any of these factors may delay the start of ESF construction. Environmental permitting delays are less likely than the other three factors that may delay the start of ESF construction.

The two major impacts on the *ESF construction start date* (4) are the *Title II design duration* (8) and the *need for long lead-time procurement* (9). The *scope of the option* (17) influences the *Title II design duration* (8) and the *test program* (12). The longer the *Title II design duration* (8), the longer the *ESF construction start date* (4) will be delayed. The start of ESF construction is the time between groundbreaking for the ESF and the time at which construction allows beginning of testing at the repository horizon (mineralogy and petrology tests). The *Title II design duration* (8) may be protracted by *programmatic requirements* (15) and *regulatory requirements* (16). These factors are less impacting than the scope of the option (17). Unforeseen changes in programmatic requirements (15) and regulatory requirements (16) may demand changes in the Title II design. The programmatic requirements are determined by the DOE HQ, and are included in a variety of plans, records, and procedures, as well as the QA configuration management. Regulatory requirements are determined by several agencies, including the NRC, EPA, and the State of Nevada. Regulatory requirements (for example, 10 CFR 60 and 40 CFR 191) and programmatic requirements (for example, QA Configuration) were considered to have a significant impact on the schedule but they were not considered major factors for the purposes of the ESF-AS because the impact will be the same for all options.

The need for long lead-time procurement (9) depends on the *construction method* (11) that is required by the option. Several types of equipment must be ordered several months in advance. For example, specially designed tunnel boring machines must be specially ordered and assembled before delivery. These long lead-time procurements may delay the ESF construction start date.

[4]The access road/pad construction requires more than 20 acres (8 ha).

The *ESF construction duration* (5) is impacted by three factors. The *construction method* (11) has less impact than the *test program* (12) and the *construction and test sequencing* (27).

The *test program* (12) is based on the *scope of the option* (17), which is significantly impacted by the *construction and test sequencing* (27) and the *test requirements* (20) as expressed in the *test plan* (23). The *scope of the option* (17) includes the scope of such experimental programs as the *upper level breakout level* (19), the MTL (21), and the *number and type of entries* (24). However, for the purpose of discriminating among options, the main impact on the *scope of the option* (17) is the *exploratory footage* (22). Each option provides for different approaches to exploring the subsurface for the purpose of site characterization. The exploratory footage may also be increased because of *additional requirements for the NWTRB, NRC, or State of Nevada testing* (23).

The *construction and test sequencing* (27) includes the influence of four very significant factors affecting the total duration of the project. These four factors are the *test requirements* (20), *Calico Hills* (CH) *unit characterization* (18), *Topopah Spring* (TS) *unit characterization* (28), and the *early or late CH access* (26). The *early or late CH access* (26) refers to the two scenarios under which the options were designed. One set of options was designed for early exploration of the TS unit. The other set of options was designed for early exploration of the CH unit.

B.1.16.3 Performance Measure and Scale

The performance measure for indirect costs, as they reflect the schedule impact of the ESF-repository, is the total discounted dollars incurred by schedule delays. The performance scale for indirect costs is a natural scale. The unit of measurement is discounted dollars.

B.2 Scoring

B.2.1 Probability of Programmatic Viability, P_{VIAB}

The Expert Panel on Programmatic Viability provided expert judgments on the near-term success of maintaining programmatic viability, P_{VIAB}. This probability is the first uncertainty in the ESF-AS Decision Tree (ESF-AS Report, Volume 2, Section 2, Figure 2-1) after selecting an ESF-AS option.

The panel reviewed the various uncertainties with regard to identifying an acceptable site through testing (Nature's Tree, ESF-AS Report, Volume 2, Section 2, Figure 2-2). The major paths through the influence diagram for programmatic viability (Figure B-1) were reviewed. The important factors were

- Similarity of ESF to SCP design,
- ESF test strategy, and
- Acceptability of ESF to NWTRB and NRC.

The panel reviewed nine components of information relative to the important factors for programmatic viability.

B.2.1.1 Schedule

The panel reviewed three schedules related to the site characterization testing program.

- Topopah Spring early testing and exploratory drifting
- Calico Hills early testing and exploratory drifting
- Total duration of characterization

The start date for all options is mid-1993 (June 24, 1993). The length of the design varies among options but the time to start of the ESF is the same for all options.

The Site Characterization Testing Program was reviewed by the Characterization Testing Support Group. The Panel was concerned that exploration of faults was considered a principal criterion for Calico Hills testing.

B.2.1.2 Costs

Cost was not considered an important factor for maintaining near-term programmatic viability but cost data were provided for the panel's consideration. The total costs were reviewed in three categories: design, early testing, and late testing. In addition, the panel compared the average cost per month of each option. Cost data were prepared by the Cost Support Group.

B.2.1.3 Design Similarity

The panel compared each option with the ESF original Title II design. The original Title II design did not include provisions for early characterization of the Calico Hills unit. Quantitative estimates of the similarities of the designs to the SCP-CDR Design and the potential for schedule slippage because of the dissimilarity in design were developed by the technical support staff. Each of the 34 options, including the schedules for significant milestones, were reviewed in detail with the assistance of the Design Support Group.

B.2.1.4 Resolution of Concerns

The potentials for each option to resolve the concerns expressed by the NWTRB and the NRC were addressed by reviewing six concerns raised by the NWTRB and six concerns raised by the NRC. The six concerns of the NWTRB expressed the need to:

- Maximize the use of "modern excavation techniques,"
- Cross the Ghost Dance Fault,
- Plan an east-west drift,
- Use an inclined ramp,
- Conduct geological mapping, and
- Explore the softer tuff units above and below the repository level.

The second and third items were considered to be nondiscriminating among options. All options eventually cross the Ghost Dance Fault and excavate an east-west drift. Option 8 scored highest with regard to these six concerns.

The six concerns of the NRC were the following:

- Compatibility of tests,
- Space for tests,
- Test duration,
- In-situ waste package test,
- Blast-induced fractures, and
- Drift in southern part of block.

The first five items are addressed by increasing the area of the MTL. Extended discussion of the waste isolation impact of the ESF-repository raised the point that a release calculation was not required for each option.

B.2.1.5 Residual Uncertainty

The panel members used the judgments of the Expert Panel on Characterization Testing to estimate the residual uncertainty that the site is OK. The residual uncertainty is the probability that the site is NOT OK even though the early and late testing programs indicate that the site is "OK," $P(\overline{OK} \mid \text{"OK-ET," "OK-LT"})$. The residual uncertaintities ranged from 0.5 to 2.5 percent.

The Expert Panel on Characterization Testing judged that the most highly ranked option with respect to early false negative test results showed a 12 percent chance of incorrectly abandoning a good site after the early testing program. That is, in the short time frame of early testing, some data could indicate a problem that could not be resolved in the time frame of the early testing program.

B.2.1.6 Probability of Approval

The probability for each option receiving approval from the regulatory groups, including a license from the NRC, was not included in the influence diagram but was of interest to the panel. These judgments were provided by the Expert Panel on Regulatory Considerations. The probabilities for regulatory approval ranged from 66 percent to 95 percent.

B.2.1.7 Qualitative Ranking

The panel members were provided with work sheets for qualitatively ranking the options. The scoring instruction workbook were to estimate whether each option would be judged much better, better, the same, worse, or much worse than the base case (Option 1). Option 1 is the Title I design as modified to address early and late testing issues for the ESF-AS.

The panel adjourned the meeting and each panel member scored the options. Each expert's scores were aggregated and used to initiate discussions regarding probability encoding.

The qualitative ranking of the options showed Options 24, 23, 25, and 30 as the top ranking options. Each of these options are designed for early testing in the Calico Hills unit. The panel members' discussion of the options addressed the following factors that entered into the qualitative ranking.

- Options 23, 24, 25, and 30 seemed about even.
- Options 24, 23 and 25 ranked higher with respect to P($\overline{\text{OK}}$ | "OK-ET," "OK-LT").
- Option 24
  - keeps one shaft in the same place as the base case and it has other shafts;
  - minimizes Engineer/Architect (E/A) rework, retains shafts, and ramps were planned;
  - has ramps; we learn more from ramps;
  - retains vertical shaft that will give needed information on Tiva Canyon;
  - provides E-W drift early; and
  - was downgraded by some panel members because the ramp was not a scientific ramp.
- Options 23, 24, and 25 have good schedules,
- Options 23, 24, and 25 address NRC concerns:
  - Options 24 and 25 higher with respect to mapping higher units;
  - Option 23 higher because of HLW tests, two ramp accesses; and
  - Option 23 only marginally higher than Options 24 and 25 on the scale used to rank the options with respect to NRC concerns.
- Positive and negative features of ramps and shafts approximately in balance.
- Some members of panel drove the ranking using the schedule.
- Pros and cons of schedule
  - should have heavy weight because of schedule performance to date.
  - schedule performance to date is poor anyway. Poor schedule will not influence program viability.

- Among Options 7, 8, 9, 10, and 11

  - all have similar schedules.
  - Option 8 has multiple attributes that rank high with respect to NWTRB concerns. All accesses are mechanically mined using the V-Mole.
  - Option 8 has shafts and ramps. Three steps are required for the shaft:
    * Mine to bottom of prospective ramp,
    * Drill to bottom of prospective ramp, and
    * Upream shaft.
  - Option 8 schedule is delayed by instrumentation of ramp.
  - Option 9 uses a blind boring machine, no instrumentation.

- Some panel members were strongly influenced by the fact that characterization data for all tests would be collected later in the program.

- Overly complicated options (i.e., Options 15 and 16) were rated lower by some panel members. On the other hand, Options 15 and 16 give the impression that the program is giving needed attention to the Ghost Dance Fault.

- The values of $P(\overline{OK}$ | "OK-ET," "OK-LT") lowered the ranking for Options 15 and 16.

- Options 25 and 30 ranked lower because of the cost and schedule.

B.2.1.8 Calibration for Probability Encoding

Calibration of experts is needed when the event being estimated occurs only once. Because the event cannot be repeated, the experts must rely on their degree of belief. The panel participated in a probability assessment demonstration. The objective of the demonstration was for each panel member to estimate the level of uncertainty of their judgments. The demonstration consisted of a series of questions derived from an almanac. Each panel member estimated the confidence in the correct answer by expressing the values as fractiles (Table B-6).

TABLE B-6

EXPLANATIONS OF FRACTILES

Fractiles	Explanation
0.05	1 chance in 20 that the score is less than the estimate
0.50	1 chance in 2 that the score is greater or less than the estimate
0.95	1 chance in 20 that the score is greater than the estimate

The results were typical of such demonstrations. The group has a central tendency bias, suggesting overconfidence in their estimates. The group was instructed about this and other phenomena that typically bias expert judgments. The Decision Methodology Group used this calibration exercise to condition the expert panels so as to reduce the effects of the biases. One debiasing technique used anonymous ballots to avoid personality bias; that is, yielding to persuasion of a panel member with a strong personality. The Decision Methodology Group also conducted open discussion, allowing all panel members to support their positions and judgments.

B.2.1.9 Probability Encoding

The panel provided quantitative estimates of P_{VIAB} in a series of secret ballots. The aggregated results of each ballot were discussed and a consensus of the panel was identified. The panel provided three estimates of the probability of programmatic viability.

- High estimate = 0.95
- Best judgment = 0.50
- Low estimate = 0.05

The panel balloted on Options 1 and 24 before scoring all options. The probability estimates were aggregated by calculating the arithmetic average, geometric average, the second highest high estimate, and the second lowest low estimate. The aggregated results were displayed, along with the individual estimates of each panel member without identifying which panel member was responsible for which estimate.

The reason for discarding the highest and lowest values is that experience has shown that extreme values are usually nonrepresentative outliers. They may be correct estimates and will be used in sensitivity analyses to estimate whether the ranking might be changed if the outliers are considered. This was an arbitrary approach to representing the data. The panel continued balloting until a concensus agreement was reached.

Two ballots were conducted for Option 1. The results of the first ballot showed that the arithmetic average of the panel estimates was approximately P_{VIAB} = 0.6. The discussion of the results revealed a range of opinions regarding the programmatic viability of Option 1. Arguments that the programmatic viability of Option 1 should be higher focused on the argument that the base case is a credible option because the design is not seriously flawed and it can be constructed on schedule at low cost. On the other hand, arguments for lowering the probability of programmatic viability of Option 1 pointed out that the SCP-CDR design has been criticized by the NWTRB and the NRC. The very existence of the ESF-AS testifies that the base case is flawed. Ranking Option 1 high lowers the probability of near-term success because the credibility of the DOE would be questioned for supporting a flawed design.

A third viewpoint was that the nuclear waste program was not likely to be abandoned without a reasonable alternative to waste disposal. The NWTRB and NRC will not lobby to abandon the program, regardless of the selected option.

The definition of "abandon" in the ESF-AS Decision Tree was crucial to the estimates of programmatic viability. The panel agreed that abandon means that if the DOE used an option as presented in the ESF-AS, the probability that the program would be abandoned is expressed by P_{VIAB}.

These discussions prepared the panel for the second ballot on Option 1. The arithmetic average of the panel's scores were approximately $P_{VIAB} = 0.5$ for Option 1. The panel reached a consensus agreement that the probability of maintaining programmatic viability if Option 1 were selected was

- High $P_{VIAB} = 0.9$,
- Best Judgment $P_{VIAB} = 0.55$, and
- Low $P_{VIAB} = 0.1$.

The results of the estimating P_{VIAB} for Option 24 revealed that some experts judged this option to have a programmatic viability of 1.0. Those experts reasoned that Option 24 was the best option. It can only increase the program viability.

Further discussion led to a consensus among six of the seven panel members. The subgroup of six (Subgroup A) agreed that setting P_{VIAB} high, but not equal to one, allowed for the possibility that the program might be cancelled. A minority subgroup of one (Subgroup B) maintained that $P_{VIAB} = 1.0$ for Option 24 was consistent with his professional experience and knowledge. A summary of the panel judgments regarding Option 24 are shown in Table B-7.

TABLE B-7

PROBABILITY OF NEAR-TERM SUCCESS IN MAINTAINING PROGRAMMATIC VIABILITY: OPTION 24

	Fractile		
	0.05	0.50	0.95
Majority	0.50	0.90	0.99
Minority	0.95	1.00	1.00

Judgments for all remaining options were conducted in two groups, Subgroup A (majority) and Subgroup B (minority). The results of the first ballot on all options by Subgroup A showed a preference for options that get data early and complete both testing phases early. Discussions regarding these characteristics led the Subgroup A to rescore Options 7, 28, 29. The consensus probabilities for programmatic viability (Table B-8) show that Subgroup A ranked Options 24, 30, 23, and 25 as the top options with respect to programmatic viability. The panel member forming Subgroup B rescored P_{VIAB} for all options (Table B-9).

B.2.2 Probability of Early False Negative, P_{EFN}

This section presents a description of the process used by and the discussions of the Expert Panel on Characterization Testing that lead to the estimation of P_{EFN}, the probability of an early false negative, for each of the 34 ESF-respository options. In this study, an early false negative is defined as the outcome in which the proposed repository and site are determined to be "NOT OK" at the end of the early test phase of the ESF, even though the proposed repository and site are truly OK. It was necessary for the panel to estimate P_{EFN} because it is a required datum to be used with Nature's Tree (ESF-AS Report, Volume 2, Section 2, Figure 2-2). The description in this section is a complete summary, but more details of the process and discussions used in estimating P_{EFN} are contained in the summary notes and transcripts of the meetings of the panel. The description in this section is not a strict chronological presentation of the process and discussions but is a synthesis of them. This section can be divided into two parts: the first is a description of the process and discussions that lead to a qualitative ranking of the options with respect to P_{EFN} and the second is a description of the process and discussions that lead to the estimation of P_{EFN}, given the qualitative ranking of the options. The influence diagram (Figure B-2) shows the important issues that can discriminate between and among the options with respect to P_{EFN}.

Before the panel estimated P_{EFN} for the options, the panel qualitatively ranked the options in comparison to the base case option by considering the effect that the options would have on P_{EFN}. To help them compare the options to the base case, the panel members received *Instruction Workbook for Characterization Testing Panel Members: Preparation for the ESF-repository Option Scoring Sessions* (hereinafter the *Instruction Workbook*) and explanations of the important features of each of the options. In the *Instruction Workbook* were four statements that were related to the most important

TABLE B-8

PROBABILITY OF NEAR-TERM SUCCESS IN MAINTAINING PROGRAMMATIC VIABILITY, P_{VIAB}, MAJORITY CONSENSUS

Option	Fractile 0.05	0.50	0.95
24	0.50	0.90	0.99
30	0.40	0.89	0.99
23	0.50	0.87	0.99
25	0.40	0.84	0.99
27	0.40	0.83	0.95
13	0.40	0.81	0.95
7	0.40	0.79	0.99
28	0.40	0.79	0.99
6	0.30	0.78	0.95
19	0.20	0.77	0.99
22	0.30	0.77	0.95
21	0.25	0.77	0.99
4	0.20	0.74	0.95
29	0.30	0.73	0.95
2	0.20	0.73	0.95
31	0.10	0.70	0.95
20	0.10	0.67	0.95
8	0.10	0.64	0.90
32	0.10	0.62	0.90
33	0.10	0.59	0.90
5	0.10	0.58	0.90
10	0.10	0.58	0.90
12	0.10	0.58	0.90
11	0.10	0.56	0.90
17	0.10	0.56	0.90
Base Case	0.10	0.55	0.90
26	0.05	0.55	0.90
15	0.10	0.54	0.90
16	0.05	0.53	0.90
34	0.10	0.53	0.90
18	0.10	0.52	0.90
3	0.10	0.52	0.90
14	0.10	0.51	0.90
9	0.05	0.45	0.90

TABLE B-9

PROBABILITY OF NEAR-TERM SUCCESS IN MAINTAINING PROGRAMMATIC VIABILITY, P_{VIAB}, MINORITY JUDGMENT

	Fractile		
Option	0.05	0.50	0.95
24	1.00	1.00	1.00
23	1.00	1.00	1.00
25	0.90	0.95	1.00
30	0.70	0.85	1.00
7	0.90	0.95	1.00
13	1.00	1.00	1.00
19	1.00	1.00	1.00
21	1.00	1.00	1.00
28	0.90	0.95	1.00
29	1.00	1.00	1.00
4	1.00	1.00	1.00
22	1.00	1.00	1.00
6	0.90	0.95	1.00
20	0.90	0.95	1.00
2	0.90	0.95	1.00
27	0.50	0.80	1.00
8	0.80	0.90	1.00
31	1.00	1.00	1.00
32	0.70	0.85	1.00
33	0.70	0.85	1.00
Base Case	0.70	0.85	1.00
5	1.00	1.00	1.00
11	0.80	0.90	1.00
12	1.00	1.00	1.00
17	0.80	0.90	1.00
18	0.80	0.90	1.00
3	0.80	0.90	1.00
10	0.80	0.90	1.00
14	1.00	1.00	1.00
26	0.60	0.80	1.00
34	0.70	0.80	1.00
9	0.90	0.95	1.00
15	0.70	0.85	1.00
16	0.70	0.85	1.00

issues of the influence diagram (Figure B-2), which shows the important factors that can discriminate between and among options with respect to the effect that the options have on P_{EFN}. The more important factors on the influence diagram are shown enclosed within double ellipses. Each of the four statements required the panels members to consider the issue described in the statement and for each option to qualitatively compare the effect this issue would have on P_{EFN} to the effect of the base case. After considering the four statements of the *Instruction Workbook* separately, the panel members considered all their responses and produced a summary final qualitative comparison of the ESF-repository options based on the effect the options would have on P_{EFN} in comparison to the effect the base case option would have on P_{EFN}. By combining the panel members' responses to the summary statement, a qualitative ranking of the options with respect to P_{EFN} was obtained. The following section contains a synthesis of the discussions that the panel members had in determining this initial qualitative ranking. The discussions will be presented in approximately the same order in which they occurred. Changes in the order of presentation have been made to show how the discussion evolved, to minimize redundancies, and to make this section more readable. A complete record of the discussions is contained in the transcripts of the panel meetings (Appendix D.13).

B.2.2.1 Qualitative Ranking With Respect to P_{EFN}

One of the statements in the *Instruction Workbook* was concerned with the effect of the construction method on the natural barrier tests, which in turn might affect P_{EFN}. The panel was principally concerned with the introduction of construction water. Larger quantities of water increase the estimates of P_{EFN}. The construction methods of Options 18 through 34 could lead to a draining of water from the Topopah Spring unit.

The panel was also instructed to consider how the omission of tests described in the SCP would affect the ability to adequately characterize both the Calico Hills unit and the rocks above the Calico Hills, two factors that affect P_{EFN}. The amount of rock exposed in construction was considered to have an important effect. The increased drifting and a mixture of ramps and shafts exposed more rock, and therefore, should reduce the estimates of P_{EFN}.

After discussing the statements in the *Instruction Workbook*, the panel members qualitatively ranked all the options. The ranking is shown in Table B-10. In the ranking, an option having a relative score less than zero was considered to have a

TABLE B-10

PROBABILITY OF EARLY FALSE NEGATIVE, P_{EFN}, MAJORITY REPORT (entire panel)

		Fractile		
Option	Relative Score	0.05	0.05	0.95
4	-0.9	0.01	0.13	0.60
21	-0.9	0.01	0.12	0.60
30	-0.9	0.01	0.12	0.60
3	-0.8	0.01	0.13	0.60
13	-0.8	0.01	0.12	0.60
12	-0.7	0.01	0.13	0.60
22	-0.7	0.01	0.12	0.60
31	-0.7	0.01	0.13	0.60
5	-0.6	0.01	0.13	0.60
14	-0.6	0.01	0.13	0.60
29	-0.6	0.01	0.13	0.60
2	-0.4	0.01	0.13	0.60
17	-0.4	0.01	0.14	0.60
19	-0.4	0.01	0.13	0.60
28	-0.4	0.01	0.14	0.60
11	-0.3	0.01	0.14	0.60
20	-0.3	0.01	0.14	0.70
23	-0.3	0.01	0.14	0.60
7	-0.2	0.01	0.14	0.60
8	-0.2	0.01	0.14	0.60
25	-0.2	0.01	0.14	0.60
34	-0.2	0.01	0.13	0.60
6	-0.1	0.01	0.14	0.60
15	-0.1	0.01	0.14	0.60
24	-0.1	0.01	0.14	0.60
33	-0.1	0.01	0.14	0.60
Base Case	0.0	0.01	0.14	0.60
16	0.0	0.01	0.16	0.65
18	0.2	0.01	0.15	0.70
27	0.2	0.01	0.18	0.75
32	0.2	0.01	0.17	0.75
10	0.4	0.01	0.19	0.75
9	0.8	0.01	0.23	0.80
26	0.9	0.01	0.23	0.80

smaller P_{EFN} than the base case and an option having a relative score greater than zero was considered to have a greater P_{EFN} than the base case. The relative score was developed by averaging the qualitative ratings assigned by the panel members. Considering the complete option compared to the base case, if it appeared that an option would have a much lower P_{EFN}, then a score of -2 was assigned; if it appeared that it would have a lower P_{EFN}, then a score of -1; the same P_{EFN}, a score of zero; a higher P_{EFN}, a score of 1; and a much higher P_{EFN}, a score of 2.

B.2.2.2 Estimation of P_{EFN}

Before estimating P_{EFN}, the panel discussed the relationships among three probabilities related to false negatives; P_{EFN}, probability of an early false negative, P_{LFN}, the probability of a late false negative, and P_{FN}, the probability of a false negative, which is a function of P_{EFN} and P_{LFN}. Of these three probabilities, only two are independent. The panel also discussed whether P_{FN} should be the same for all options because the amount of testing in all options is the same. After the discussions, the panel decided that P_{EFN} and P_{LFN} would be the two probabilities that the panel would estimate because studies have shown that it would probably be more accurate to estimate P_{EFN} and P_{LFN}, rather than estimating P_{FN}.

The panel estimated P_{EFN} on two occasions, September and November. The estimates made in September were based on invalid schedule assumptions. The estimates of September were replaced by those of November. Although the estimates of September were incorrect, some of the discussions that took place at that time were still applicable in November when the new estimates were made. This section contains a summary of the applicable discussions of both September and November.

The panel had recurring discussions on whether acquiring more data in an option would lower or increase P_{EFN}. One group of panel members stated that as more data are gathered, the likelihood of finding data that would raise questions that could not be explained would increase, and therefore, P_{EFN} should be larger if more data are gathered. This group said that because of the intense review by many groups that the repository program receives, that it is not unlikely that an OK site would be incorrectly rejected. Another group of panel members stated that as more data are gathered, the ability to correctly characterize the site will improve, and therefore, P_{EFN} should be less for those options that gather more data in the early test program. This difference in views was apparent, in particular, in discussions regarding whether it was beneficial or not to intensively investigate the Ghost Dance fault, considering that a repository can be built that largely avoids the fault.

The entire panel of nine experts provided judgments of P_{EFN} for the baseline calculations in the decision methodology (Table B-10). The probabilities were estimated at three levels: high (0.95), best judgment (0.50), and low (0.05). The panel divided into two subpanels and each panel provided an additional set of probability judgments. These probabilities were intended to express the differing opinions among the panel with respect to the impact of additional data on estimates of P_{EFN}. The two sets of probabilities were intended for sensitivity studies to determine the influence of P_{EFN} on the ESF-repository selection process.

Seven experts provided judgments (Table B-11) based on the assumption that more data reduce P_{EFN}. Two experts provided judgments (Table B-11) based on the assumption that more data would increase P_{EFN}.

B.2.3 Probability of Late False Negative, P_{LFN}

This section presents a description of the process used by and the discussions of the Expert Panel on Characterization Testing that lead to the estimation of P_{LFN}, the probability of a late false negative, for each of the 34 ESF-repository options. In this study, a late false negative is defined as the outcome in which the proposed repository and site are determined to be "NOT OK" at the end of the late test phase of the ESF even though the proposed repository and site were found to be "OK" at the end of the Early Test phase and the proposed repository and site are truly OK. It was necessary for the panel to estimate P_{LFN} because it is a required datum to be used with the Nature's Tree (ESF-AS Report, Volume 2, Section 2, Figure 2-2). The description in this section is a complete summary but more details of the process and discussions regarding the estimation of P_{EFN} are contained in the summary notes and transcripts of the meetings of the panel. The description in this section is not a strict chronological presentation of the process and discussions but is a synthesis of them. This section can be divided into two parts: the first is a description of the process and discussions that lead to a qualitative ranking of the options with respect to P_{LFN}, and the second is a description of the process and discussions that lead to the estimation of P_{LFN}, given the qualitative ranking of the options. The influence diagram (Figures B-3 and B-4) shows the important issues that can discriminate between and among the options with respect to P_{LFN}.

TABLE B-11

PROBABILITY OF EARLY FALSE NEGATIVE, P_{EFN}, MINORITY* REPORTS

	Fractile (7 Experts)			Fractile (2 Experts)		
Option	0.05	0.50	0.95	0.05	0.50	0.95
4	0.01	0.09	0.60	0.02	0.28	0.73
21	0.01	0.09	0.60	0.02	0.21	0.73
30	0.01	0.08	0.60	0.02	0.25	0.73
3	0.01	0.10	0.60	0.02	0.25	0.73
13	0.01	0.09	0.60	0.02	0.23	0.70
12	0.01	0.10	0.60	0.02	0.23	0.70
22	0.01	0.10	0.60	0.02	0.23	0.70
31	0.01	0.10	0.60	0.02	0.23	0.70
5	0.01	0.10	0.60	0.02	0.23	0.70
14	0.01	0.11	0.60	0.01	0.22	0.70
29	0.01	0.10	0.60	0.01	0.22	0.70
2	0.01	0.12	0.60	0.01	0.18	0.70
17	0.01	0.12	0.60	0.01	0.19	0.70
19	0.10	0.12	0.60	0.01	0.19	0.70
28	0.01	0.12	0.60	0.01	0.21	0.65
11	0.01	0.12	0.60	0.01	0.21	0.65
20	0.01	0.13	0.60	0.01	0.16	0.65
23	0.01	0.12	0.60	0.01	0.21	0.65
7	0.01	0.13	0.60	0.01	0.21	0.65
8	0.01	0.12	0.60	0.01	0.21	0.65
25	0.01	0.12	0.60	0.01	0.20	0.65
34	0.01	0.12	0.60	0.01	0.16	0.65
6	0.01	0.12	0.60	0.01	0.20	0.65
15	0.01	0.13	0.60	0.01	0.20	0.65
24	0.01	0.13	0.60	0.01	0.20	0.65
33	0.01	0.13	0.60	0.01	0.20	0.65
Base Case	0.01	0.14	0.60	0.01	0.14	0.60
16	0.01	0.15	0.65	0.01	0.20	0.60
18	0.01	0.15	0.70	0.01	0.15	0.60
27	0.01	0.18	0.75	0.01	0.20	0.60
32	0.01	0.17	0.75	0.01	0.19	0.60
10	0.01	0.19	0.75	0.01	0.19	0.60
9	0.02	0.24	0.80	0.01	0.19	0.60
26	0.03	0.24	0.80	0.01	0.19	0.58

*This table represents two minority reports. See Subsection B.2.2.2, paragraph three for a description of the basis for these reports.

Before the panel estimated P_{LFN} for the options, the panel qualitatively ranked the options in comparison to the base case option by considering the effect that the options would have on P_{LFN}. To help them compare the options to the base case, the panel members received *Instruction Workbook for Characterization Testing Panel Members: Preparation for the ESF-Repository Option Scoring Sessions* (hereinafter the *Instruction Workbook*) and explanations of the important features of each of the options. In the *Instruction Workbook* were eleven statements that were related to the most important issues of the influence diagram, (Figures B-3 and B-4), which shows the important factors that can discriminate between and among options with respect to the effect that the options have on P_{LFN}. The more important factors on the nfluence diagram are shown enclosed within double ellipses. Each of the eleven statements required the panels members to consider the issue described in the statement, and for each option to qualitatively compare the effect this issue would have on P_{LFN} to the effect of the base case. After considering the eleven statements of the *Instruction Workbook* separately, the panel members considered all their responses and produced a summary final qualitative comparison of the ESF-repository options based on the effect the options would have on P_{LFN} in comparison to the effect the base case option would have on P_{LFN}. By combining the panel members' responses to the summary statement, a qualitative ranking of the options with respect to how the options affect P_{LFN} was obtained. The following section contains a synthesis of the discussions that the panel members had in determining this initial qualitative ranking. The discussions will be presented in approximately the same order in which they occurred. Changes in the order of presentation have been made to show how the discussion evolved, to minimize redundancies, and to make this section more readable. A complete record of the discussions is contained in the transcripts of the panel meetings (Appendix D.13).

B.2.3.1 Qualitative Ranking With Respect to P_{LFN}

The panel discussed a statement that concerned the influence of the construction method on the ability to refute erroneous observations and interpretations, which in turn would affect P_{LFN}. Some options might have limited access to the rock or restrict data acquisition which would tend to increase P_{LFN}.

Discussions regarding the adequacy of the space, concluded that the options with the blind-bore shaft excavation method were options that increased the potential for having a greater P_{LFN}.

Two statements concerned the influence that testing in degraded conditions might have on the ability to adequately characterize both the Calico Hills unit and the rocks above the Calico Hills. Water introduced during construction may tend to increase P_{LFN} and because ramps introduce less water, ramps are better than shafts. However, shafts had an advantage over ramps regarding the rocks above the Calico Hills because they revealed the rocks above the repository block.

Inadequate duration of early tests might affect the ability to adequately characterize both the Calico Hills unit and the rocks above the Calico Hills. Options 18-34 might cause water to drain from the Topopah Spring unit, which could affect the duration of the early tests.

The SCP tests included in the late test program might provide an inadequate basis for characterizing both the Calico Hills unit and the rocks above the Calico Hills. This inadequate characterization might provide an inadequate basis for refuting erroneous observations and interpretations. The panel concurred that those options that provide more late drifting would tend to decrease P_{LFN}.

The late test program of an option may provide an inadequate basis for characterizing the Calico Hills unit and the rocks above the Calico Hills unit, and also provide an inadequate basis for changing and expanding the test program. These considerations also led the panel to conclude that those options with more late drifting would tend to have lower values of P_{LFN}.

After discussing the statements in the *Instruction Workbook*, the panel members qualitatively ranked all the options. The ranking is shown in Table B-12. In the ranking, an option having a relative score less than zero was considered to have a smaller P_{LFN} than the base case and an option having a relative score greater than zero was considered to have a greater P_{LFN} than the base case. The relative score was developed by averaging the qualitative ratings assigned by the panel members. Considering the complete option compared to the base case, if it appeared that an option would have a much lower P_{LFN}, then a score of -2 was assigned; if it appeared that it would have a lower P_{LFN}, then a score of -1; the same P_{LFN}, a score of zero; a higher P_{LFN}, a score of 1; and a much higher P_{LFN}, a score of 2.

TABLE B-12

PROBABILITY OF LATE FALSE NEGATIVE, P_{LFN}

Qualitative Ranking		Fractile		
Option	Relative Score	0.05	0.50	0.95
4	-1.1	0.01	0.08	0.40
13	-1.1	0.01	0.09	0.40
21	-1.0	0.01	0.09	0.40
32	-1.0	0.01	0.10	0.40
2	-0.9	0.01	0.09	0.40
15	-0.9	0.01	0.09	0.40
25	-0.9	0.01	0.10	0.40
30	-0.9	0.01	0.09	0.40
3	-0.8	0.01	0.09	0.40
5	-0.8	0.01	0.09	0.40
6	-0.8	0.01	0.10	0.40
7	-0.8	0.01	0.09	0.40
8	-0.8	0.01	0.10	0.40
10	-0.8	0.01	0.10	0.40
11	-0.8	0.01	0.09	0.40
12	-0.8	0.01	0.09	0.40
14	-0.8	0.01	0.09	0.40
16	-0.8	0.01	0.10	0.40
22	-0.8	0.01	0.10	0.40
28	-0.8	0.01	0.09	0.40
33	-0.8	0.01	0.10	0.40
17	-0.7	0.01	0.09	0.40
29	-0.7	0.01	0.10	0.40
31	-0.7	0.01	0.10	0.40
19	-0.6	0.01	0.11	0.40
20	-0.6	0.01	0.11	0.40
23	-0.6	0.01	0.11	0.40
24	-0.6	0.01	0.10	0.40
27	-0.6	0.01	0.11	0.40
34	-0.4	0.01	0.11	0.40
18	-0.2	0.01	0.12	0.40
Base Case	0.0	0.01	0.11	0.40
9	0.4	0.01	0.15	0.60
26	0.6	0.01	0.16	0.60

B.2.3.2 Estimation of P_{LFN}

The panel estimated P_{LFN} on two occasions, September and November. The estimates made in September were based on invalid schedule assumptions. The estimates of September were replaced by those of November, which are based on valid schedules. Although the estimates of September were incorrect, some of the discussions that took place at that time were still applicable in November when the new estimates were made. This section contains a summary of the applicable discussions of both September and November.

There were recurring discussions on whether acquiring more data in an option was going to decrease P_{LFN} or increase P_{LFN}. One group of panel members stated that as more data were gathered, the likelihood of finding data that would raise questions that could not be explained would increase, and therefore, P_{LFN} should be larger if more data are gathered. This group said that because of the intense review that the repository program receives by many groups, that it is not unlikely that an OK site would be incorrectly rejected. Another group of panel members stated that as more data are gathered, the ability to correctly characterize the site will improve, and therefore, P_{LFN} should be less for those options that gather more data.

The expert panel provided judgments on P_{LFN} shown in Table B-12.

B.2.4 Probability of Early False Positive Test Results, P_{EFP}

This section presents a description of the process used by and the discussions of the Expert Panel on Characterization Testing that lead to the estimation of P_{EFP}, the probability of an early false positive, for each of the 34 ESF-repository options. In this study, an early false positive is defined as the outcome in which the proposed repository and site are determined to be "OK" at the end of the Early Test phase of the ESF, even though the proposed repository and site are truly NOT OK. It was necessary for the panel to estimate P_{EFP} because it is a required datum to be used with Nature's Tree (ESF-AS Report, Volume 2, Section 2, Figure 2-2). The description in this section is a complete summary, but more details of the process and discussions regarding the estimation of P_{EFP} are contained in the summary notes and transcripts of the meetings of the panel. The description in this section is not a strict chronological presentation of the process and discussions but is a synthesis of them. This section can be divided into two parts: the first is a description of the process and discussions that lead to a qualitative ranking of the options with respect to P_{EFP} and the second is a description of the process and discussions that lead to the estimation of P_{EFP}, given the qualitative ranking of the options.

Before the panel estimated P_{EFP} for the options, the panel qualitatively ranked the options in comparison to the base case option by considering the effect that the options would have on P_{EFP}. To help them compare the options to the base case, the panel members received *Instruction Workbook for Characterization Testing Panel Members: Preparation for the ESF-Repository Option Scoring Sessions* (hereinafter, the *Instruction Workbook*) and explanations of the important features of each of the were six statements that were related to the most important issues of the influence diagram (Figure B-5), which shows the important factors that can discriminate between and among options with respect to the effect that the options have on P_{EFP}. The more important factors on the influence diagram are shown enclosed within double ellipses. Each of the six statements required the panels members to consider the issue described in the statement and for each option to qualitatively compare the effect this issue would have on P_{EFP} to the effect of the base case. After considering the six statements of the *Instruction Workbook* separately, the panel members were asked to consider all their responses and to produce a summary final qualitative comparison of the ESF-repository options based on the effect the options would have on P_{EFP} in comparison to the effect the base case option would have on P_{EFP}. By combining the panel members' responses to the summary statement, a qualitative ranking of the options with respect to how the options affect P_{EFP} was obtained. The following section contains a synthesis of the discussions that the panel members had in determining this initial qualitative ranking. The discussions will be presented in approximately the same order in which they occurred. Changes in the order of presentation have been made to show how the discussion evolved, to minimize redundancies, and to make this section more readable. A complete record of the discussions is contained in the transcripts of the panel meetings (Appendix D.13).

B.2.4.1 Qualitative Ranking With Respect to P_{EFP}

One of the statements in the *Instruction Workbook* was concerned with how the construction method might affect the natural barrier tests and how this in turn might affect P_{EFP}. The panel discussed that the following factors might have an important effect on P_{EFP}: access to the excavation surface during construction (easier access is desirable), construction materials and how they are used (less water is desirable), the quality of the excavation surface (very smooth surfaces are less desirable), the characteristics of the excavated materials (larger pieces are desirable), and the spatial distribution of data (clustering is less desirable).

Another statement concerned how the number and location of shafts and ramps might affect the natural barrier tests and how this in turn would affect P_{EFP}. The panel discussed that the following factors could have an important effect on P_{EFP}: the spatial distribution of data (clustering is less desirable), location of accesses, size of accesses (larger is more desirable), the number of accesses (more is better), and the amount of data (more are better). Some panel members preferred ramps because of the off-block data that are gathered. Other panel members preferred shafts because of the data gathered above the repository.

Another statement concerned the potential for locational non-representativeness and how it might affect P_{EFP}. The following factors would tend to cause P_{EFP} to be smaller: seeing more real estate, having multiple fault exposures, having more drifting, having data from off the repository block, and using accesses located in the south.

A fourth statement concerned the effect of omitting some tests described in the SCP on the ability to characterize the Calico Hills unit, and in turn, P_{EFP}. Both ramps and shafts were considered to have both positive and negative effects on this factor.

The last statement in the *Instruction Workbook* regarding P_{EFP} concerned the effect of omitting some tests described in the SCP on the ability to characterize the rocks above the Calico Hills unit, and in turn, P_{EFP}. Exposure of more rock, in particular, in areas off the repository block, would tend to cause P_{EFP} to be smaller.

After discussing the statements in the *Instruction Workbook*, the panel members qualitatively ranked all the options. The ranking is shown in Table B-13. In the ranking, an option having a relative score less than zero was considered to have a smaller P_{EFP} than the base case and an option having a relative score greater than zero was considered to have a greater P_{EFP} than the base case. The relative score was developed by averaging the qualitative ratings assigned by the panel members. Considering the complete option compared to the base case, if it appeared that an option would have a much lower P_{EFP}, then a score of -2 was assigned; if it appeared that it would have a

TABLE B-13

PROBABILITY OF EARLY FALSE POSITIVE, P_{EFP}

Qualitative Ranking		Fractile		
Option	Relative Score	0.05	0.50	0.95
4	-1.9	0.03	0.17	0.60
13	-1.6	0.03	0.18	0.65
30	-1.6	0.03	0.19	0.65
3	-1.4	0.03	0.19	0.80
29	-1.3	0.04	0.20	0.80
21	-1.2	0.03	0.20	0.80
31	-1.2	0.04	0.20	0.80
33	-1.2	0.04	0.20	0.80
2	-1.1	0.04	0.20	0.80
7	-1.0	0.04	0.21	0.80
8	-1.0	0.04	0.21	0.80
15	-1.0	0.03	0.18	0.75
19	-1.0	0.04	0.21	0.80
22	-1.0	0.04	0.21	0.80
5	-0.9	0.04	0.21	0.80
11	-0.9	0.04	0.20	0.80
12	-0.9	0.04	0.21	0.80
14	-0.9	0.04	0.21	0.80
28	-0.9	0.04	0.20	0.80
32	-0.9	0.04	0.20	0.80
16	-0.8	0.03	0.20	0.80
17	-0.8	0.04	0.20	0.80
25	-0.8	0.04	0.20	0.80
6	-0.7	0.04	0.22	0.80
23	-0.7	0.04	0.23	0.80
20	-0.6	0.04	0.22	0.80
24	-0.6	0.04	0.22	0.80
27	-0.3	0.04	0.23	0.80
34	-0.2	0.05	0.24	0.81
18	-0.1	0.04	0.24	0.81
Base Case	0.0	0.05	0.25	0.80
10	0.0	0.05	0.27	0.85
9	0.8	0.05	0.35	0.90
26	0.8	0.05	0.34	0.95

lower P_{EFP}, then a score of -1; the same P_{EFP}, a score of zero; a higher P_{EFP}, a score of 1; and a much higher P_{EFP}, a score of 2.

B.2.4.2 Estimation of P_{EFP}

The panel estimated P_{EFP} on two occasions, September and November. The panel reconvened in November because the estimates made in September were based on invalid schedule assumptions. Although the estimates of September were incorrect, some of the discussions that took place at that time were still applicable in November when the new estimates were made. This section summarizes the applicable discussions of September and November.

One recurring topic of discussion for the panel concerned whether it was better to obtain data from the Topopah Spring unit in the repository block or from the Topopah Spring unit at locations away from the repository block. While all panel members felt that it was important to obtain some data from the Topopah Spring unit, some panel members stated that it might be sufficient to observe some processes outside of the Topopah Spring unit because knowledge of the process was critical, not where this knowledge was gained. Other panel members stated that off-block data, while helpful, could not replace first-hand knowledge of the Topopah Spring unit. Related to these discussions was the question of whether shafts or ramps were more useful because shaft accesses typically give on-block Topopah Spring data and ramps typically give more off-block data.

The differences between ramps and shafts were also the topics of discussions concerning the differences between drill-and-blast excavation and mechanical, non-drill-and-blast excavation methods. Some panel members stated that an advantage of drill-and-blast excavation is that it more easily permits data gathering and inspection of the excavation. On the other hand, the drill-and-blast accesses are typically smaller and also may tend to obscure some data by damaging the rock.

Based on the discussions described above, some panel members preferred options with a mixture of ramps and shafts. These options typically provide data from both on and off the block data, Topopah Spring and Calico Hills data, and use both drill-and-blast and mechanical excavation.

Another discussion concerned the water that would be introduced by the construction method. Some panel members stated that the introduction of too much construction water may mask important data.

The panel members also discussed that generally, more data would be helpful. In particular, the number of fault crossings and the amount of drifting are important.

The quantitative estimates of the panel for P_{EFP} are shown in Table B-13.

B.2.5 Probability of Late False Positive Test Results, P_{LFP}

This section presents a description of the process used by and the discussions of the Expert Panel on Characterization Testing that lead to the estimation of P_{LFP}, the probability of a late false positive, for each of the 34 ESF-repository options. In this study, a late false positive is defined as the outcome in which the proposed repository and site are determined to be "OK" at the end of the late test phase of the ESF after also having been found to be "OK" at the end of the early test phase, even though the proposed repository and site are truly NOT OK. It was necessary for the panel to estimate P_{LFP} because it is a required datum to be used with the Nature's Tree (ESF-AS Report, Volume 2, Section 2, Figure 2-2). The description in this section is a complete summary but more details of the process and discussions used in estimating P_{LFP} are contained in the summary notes and transcripts of the meetings of the panel. The description in this section is not a strict chronological presentation of the process and discussions but is a synthesis of them. This section can be divided into two parts. The first part is a description of the process and discussions that lead to a qualitative ranking of the options with respect to P_{LFP}, and the second is a description of the process and discussions that lead to the estimation of P_{LFP}, given the qualitative ranking of the options. The influence diagram (Figure B-6) shows the important issues that can discriminate between and among the options with respect to P_{LFP}.

Before the panel estimated P_{LFP} for the options, the panel qualitatively ranked the options in comparison to the base case option by considering the effect that the options would have on P_{LFP}. To help them compare the options to the base case, the panel members received *Instruction Workbook for Characterization Testing Panel Members: Preparation for the ESF-Repository Option Scoring Sessions* (hereinafter the *Instruction*

Workbook), Appendix D.13, and explanations of the important features of each of the options. In the *Instruction Workbook* were ten statements that were related to the most important issues of the influence diagram (Figure B-6), which shows the important factors that can discriminate between and among options with respect to the effect that the options have on P_{LFP}. The more important factors on the influence diagram are shown enclosed within double ellipses. Each of the ten statements required the panels members to consider the issue described in the question and for each option, to qualitatively compare the effect this issue would have on P_{LFP} to the effect of the base case. After considering the ten statements of the *Instruction Workbook* separately, the panel members were asked to consider all their responses and to produce a summary final qualitative comparison of the ESF-repository options based on the effect the options would have on P_{LFP} in comparison to the effect the base case option would have on P_{LFP}. By combining the panel members' responses to the summary statement, a qualitative ranking of the options with respect to how the options affect P_{LFP} was obtained. The following section contains a synthesis of the discussions by the panel members in determining this initial qualitative ranking. The discussions will be presented in approximately the same order in which they occurred. Changes in the order of presentation have been made to show how the discussion evolved, to minimize redundancies, and to make this section more readable. A complete record of the discussions is contained in the transcripts of the panel meetings (Appendix D.13).

B.2.5.1 Qualitative Ranking With Respect to P_{LFP}

One of the statements in the *Instruction Workbook* concerned the influence of construction method on the ability to conduct the natural barrier tests, which in turn affect P_{LFP}. The panel discussed that drill-and-blast excavation will tend to produce more rock fragments and more rock surfaces that can be examined than other excavation methods. This will tend to give more data, which some panel members stated would tend to cause lower values of P_{LFP}.

Another statement concerned the effect that the number and/or location of shafts and ramps might have on the natural barrier tests, which in turn affects P_{LFP}. The panel discussed that those options that have shaft access and an MTL in the south will provide access to the vitric part of the Calico Hills unit, helping to reduce P_{LFP}.

The panel discussed how an inadequate duration for the early tests might lead to conducting late tests in degraded conditions so that the rocks above the Calico Hills might not be adequately characterized. Shafts allow vertical sampling above the Calico Hills unit and provide data about the repository block, which would lower P_{LFP}.

The panel also discussed how an inadequate duration for the early tests might lead to conducting late tests in degraded conditions so that rock in the Calico Hills unit might not be adequately characterized, which in turn would affect P_{LFP}. Shafts tend to provide data such that P_{LFP} would be smaller.

The panel discussed how delays in the tests described in the SCP might affect the ability to characterize both the Calico Hills unit and the rocks above the Calico Hills and how this might affect P_{LFP}. It was not readily apparent to the panel that there would be delays and also that data gathered from separate areas would tend to produce lower estimates of P_{LFP}.

The panel also discussed two other statements concerned with how the possible omission of some of the SCP tests might affect the ability to characterize both the Calico Hills unit and the rock above the Calico Hills, which in turn would affect P_{LFP}. The panel discussed that those construction methods that introduce a lot of construction water may tend to produce larger values of P_{LFP}.

Considerations of other factors that were not necessarily on the influence diagram led one panel member to state that inadequate space to conduct tests would tend to produce larger values of P_{LFP}.

After discussing the statements in the *Instruction Workbook*, the panel members qualitatively ranked all the options. The ranking is shown in Table B-14. In the ranking, an option having a relative score less than zero was considered to have a smaller P_{LFP} than the base case and an option having a relative score greater than zero was considered to have a greater P_{LFP} than the base case. The relative score was developed by averaging the qualitative ratings assigned by the panel members. Considering the complete option, compared to the base case, if it appeared that an option would have a much lower P_{LFP}, then a score of -2 was assigned; if it appeared that it would have a lower P_{LFP}, then a score of -1; the same P_{LFP}, a score of zero; a higher P_{LFP}, a score of 1; and a much higher P_{LFP}, a score of 2.

TABLE B-14

PROBABILITY OF LATE FALSE POSITIVE

Qualitative Ranking		Fractile		
Option	Relative Score	0.05	0.50	0.95
4	-0.8	0.05	0.51	0.95
5	-0.8	0.05	0.52	0.95
12	-0.8	0.05	0.51	0.94
14	-0.8	0.05	0.53	0.92
16	-0.8	0.05	0.51	0.90
21	-0.8	0.05	0.58	0.90
2	-0.7	0.05	0.55	0.90
34	-0.7	0.05	0.59	0.90
6	-0.6	0.05	0.59	0.90
11	-0.6	0.05	0.60	0.90
18	-0.6	0.05	0.61	0.90
20	-0.6	0.05	0.62	0.90
13	-0.4	0.05	0.72	0.95
15	-0.4	0.05	0.55	0.90
17	-0.4	0.05	0.63	0.90
19	-0.4	0.05	0.63	0.90
29	-0.4	0.05	0.66	0.95
33	-0.4	0.05	0.63	0.95
22	-0.3	0.05	0.66	0.95
23	-0.3	0.05	0.66	0.95
28	-0.3	0.05	0.63	0.95
31	-0.3	0.05	0.67	0.95
7	-0.2	0.05	0.59	0.90
8	-0.2	0.05	0.62	0.95
10	-0.2	0.05	0.67	0.90
27	-0.2	0.05	0.70	0.95
32	-0.2	0.05	0.64	0.95
30	-0.1	0.05	0.76	0.95
Base Case	0.0	0.05	0.60	0.90
3	0.1	0.05	0.66	0.95
24	0.1	0.05	0.67	0.95
25	0.2	0.05	0.72	0.95
26	0.4	0.05	0.65	0.95
9	0.9	0.05	0.68	0.90

B.2.5.2 Estimation of P_{LFP}

The panel estimated P_{LFP} on two occasions, September and November. The estimates made in September were based on invalid schedule assumptions. The estimates of September were replaced by those of November, which are based on valid schedules. Although the estimates of September were incorrect, some of the discussions that took place at that time were still applicable in November when the new estimates were made. This section contains a summary of the applicable discussions of both September and November.

The panel discussed whether to estimate P_{LFP}, or instead to estimate P_{FP}, the probability of a false positive, which is the product of P_{EFP} and P_{LFP}. The panel discussed that there are three probabilities (P_{FP}, P_{EFP}, and P_{LFP}), only two of which are independent. Some members stated that they would estimate P_{LFP}, while other members stated that they would estimate P_{FP}, and use the estimates of P_{EFP} to calculate what P_{LFP} must be.

The panel members discussed that they should not be overconfident in their estimates of P_{LFP}, particularly regarding the high and low estimates that are used in sensitivity calculations.

The panel discussed whether P_{LFP} should be greater than P_{EFP} or vice versa. On the one hand, a problem that escapes detection during the early test program must be subtle and P_{LFP} should be larger than P_{EFP}. On the other hand, data gathered during the Late Test program could only help to increase knowledge about the site, and therefore, P_{LFP} should be less than P_{EFP}. If the early test program was relatively poor in comparison to the late test program, then P_{EFP} might be large but P_{LFP} would then be small. Similarly, if the early test program was relatively good in comparison to the late test program, then P_{EFP} might be small but P_{LFP} would then be large.

The panel also discussed that the more data that are gathered in the late test program, then the smaller P_{LFP} would be. The panel also discussed that the locations of the data collection are important. Some panel members stated that they preferred options that had ramps as well as shafts because such options would gather data over a wide area. Some panel members stated that they did not prefer those options without shafts because there would be a lack of data from the block above the repository. Those options that might introduce significant quantities of water during shaft construction would tend to have larger values of P_{LFP} because the water might mask an important feature or reduce the detection of subtle problems.

The quantitative best estimates of P_{LFP} by the panel are shown in Table B-14.

B.2.6 Probability That the Site is OK, P_{OK}

The Expert Panel on Postclosure Health provided judgments on the probability that the Yucca Mountain site is suitable, P_{OK}. The probability that the Yucca Mountain site is OK (P_{OK}) is used in Nature's Tree (ESF-AS Report, Volume 2, Section 2, Figure 2-2) and is based on the current understanding of the site. The definition of "site is OK" that was used for the ESF-AS (See ESF-AS Report, Volume 2, Section 2.3) includes the possibility that the site may be degraded as a result of constructing an ESF and repository. A site that is OK is one at which the releases will meet the EPA standard for releases of radionuclide for 10,000 years after closure, EPA_S [40 CFR 191]. That is,

$$\text{Release} \leq EPA_S$$

The panel estimated the complement of P_{OK} i.e., $P_{OK} = 1 - P_{\overline{OK}}$ by considering the probability that radionuclide releases would exceed EPA limits. The probability that the site is NOT OK was visualized in terms of a cumulative probability distribution describing the probability of release as a function of total released radionuclides. The EPA standard can be as a vertical line on such a probability plot. The probability that the site is NOT OK is the area under the curve that extends to values greater than the EPA standard.

The panel reviewed the influence diagram for postclosure health effects (Figures B-10, B-11, B-12, and B-13). Specific attention was given to the major factors that influence radionuclide releases (Table B-2). Based on guidance provided in a scoring workbook entitled *ESF-ACS Instruction Workbook for Postclosure Panel Members, Preparation for ESF-Repository Option Scoring Sessions* (see Appendix D.4), the panel qualitatively ranked the options. The qualitative ranking (i.e., much worse, worse, same, better, or much better than the base case) provided the ordinal ranking of the options shown in Table B-15.

TABLE B-15

CONSENSUS JUDGMENT OF $P_{\overline{OK}}$ AND P_{OK}: ALL OPTIONS

	$P_{\overline{OK}}$			$P_{OK} = 1 - P_{\overline{OK}}$		
	Fractile			Fractile		
Option	0.05	0.50	0.95	0.95	0.50	0.05
9	0.001	0.070	0.300	0.999	0.930	0.700
26	0.001	0.070	0.300	0.999	0.930	0.700
4	0.001	0.055	0.250	0.999	0.945	0.750
21	0.001	0.055	0.250	0.999	0.945	0.750
17	0.001	0.057	0.250	0.999	0.945[a]	0.750
34	0.001	0.057	0.250	0.999	0.945[a]	0.750
3	0.001	0.051	0.250	0.999	0.950[a]	0.750
14	0.001	0.051	0.250	0.999	0.950[a]	0.750
18	0.001	0.050	0.250	0.999	0.950	0.750
20	0.001	0.051	0.250	0.999	0.950[a]	0.750
31	0.001	0.051	0.250	0.999	0.950	0.750
Base Case	0.001	0.050	0.250	0.999	0.950	0.750
2	0.001	0.049	0.250	0.999	0.950[a]	0.750
11	0.001	0.053	0.250	0.999	0.945[a]	0.750
19	0.001	0.049	0.250	0.999	0.950[a]	0.750
28	0.001	0.053	0.250	0.999	0.945[a]	0.750
5	0.001	0.048	0.250	0.999	0.950[a]	0.750
8	0.001	0.050	0.250	0.999	0.950	0.750
10	0.001	0.050	0.250	0.999	0.950	0.750
12	0.001	0.050	0.250	0.999	0.950	0.750
22	0.001	0.048	0.250	0.999	0.950[a]	0.750
25	0.001	0.048	0.250	0.999	0.950[a]	0.750
27	0.001	0.050	0.250	0.999	0.950	0.750
29	0.001	0.050	0.250	0.999	0.950	0.750
7	0.001	0.050	0.250	0.999	0.950	0.750
24	0.001	0.050	0.250	0.999	0.950	0.750
13	0.001	0.045	0.250	0.999	0.955	0.750
30	0.001	0.045	0.250	0.999	0.955	0.750
6	0.001	0.043	0.250	0.999	0.955[a]	0.750
23	0.001	0.043	0.250	0.999	0.955[a]	0.750
15	0.001	0.040	0.250	0.999	0.960	0.750
16	0.001	0.039	0.250	0.999	0.960[a]	0.750
32	0.001	0.040	0.250	0.999	0.960	0.750
33	0.001	0.039	0.250	0.999	0.960[a]	0.750

[a]Best judgments were rounded to the nearest 0.005 interval.

The panel agreed that the testing schedule defining 17 sets of option pairs (Testing Schedule 1 for Options 1 through 17 and Testing Schedule 2 for Options 18 through 34) should make no difference in the radionuclide release estimates. For that reason, identical scores were estimated for each option-pair (for example, Options 9 and 26). The same basic assumptions related to the conditions for failure of the waste package used for estimating radionuclide releases (Section B.2.9) were agreed upon before scoring P_{OK}.

The elicitation of panel judgments of P_{OK} proceeded as a series of ballots (see the Records Package referenced in Appendix D.4). Each panel member estimated the condfidence in P_{OK} by estimating the values at three confidence intervals (Table B-15).

The panel estimated the probability that the site is NOT OK for the base case before considering the other options. The consensus best judgment of the panel (0.50 confidence interval in Table B-13) for the base case was that there is a 5 percent chance that the site is NOT OK. The probability estimates ranged as high as 25 percent at the 0.95 interval and as low as 0.1 percent at the 0.05 interval.

Balloting to determine the best judgment for the other options led to the quantitative scores shown in Table B-15. The low estimate for all cases (P_{OK} = 0.001) was considered to be an extremely low value, but it was retained in an attempt to avoid a central-tendency bias.

B.2.7 Probability of Construction/Operation Approval, P_{APP}

Estimates of P_{APP} and its complementary probability, $P_{\overline{APP}}$, the probability of disapproval, were required data for analysis of the ESF-AS Decision Tree (ESF-AS Report, Volume 2, Section 2, Figure 2-1). The Expert Panel on Regulatory Consideration provided judgments of $P_{\overline{APP}}$ for each of the 34 ESF-repository options. For the purpose of the ESF-AS, approval refers not only to that granted by the NRC, but also includes and is not solely limited to, approvals by the DOE, the President, and the Congress. The description in this section is a complete synthesis, but more details of the process and discussions regarding the estimation of $P_{\overline{APP}}$ are contained in the summary notes and transcripts of the meetings of the panel (Appendix D.12). This section is divided into two parts: the first is a description of the process and discussions that led to a qualitative ranking of the options with respect to P_{APP} and the second is a description of the process and discussions that led to the quantitative judgments of P_{APP}. The panel agreed that because it has been found to be generally more reliable to estimate very small probabilities than to estimate very large probabilities, and P_{APP} is much closer to 1 than to zero, estimates of P_{APP} would be more reliable. All scoring of P_{APP} was based on the influence diagram (Figure B-7) that shows the important issues that can discriminate between and among the options with respect to P_{APP}.

Before the panel estimated P_{APP} for the options, the panel qualitatively ranked the options in comparison to the base case option by considering the effect that the options would have on P_{APP}. To help them compare the options to the base case, the panel members received *Instruction Workbook for Regulatory Panel Members: Preparation for the ESF-Repository Option Scoring Sessions* (hereinafter the *Instruction Workbook*) and explanations of the important features of each of the options. In the *Instruction Workbook* were six questions that were related to the most important issues of the influence diagram, Figure B-7, which shows the important factors that can discriminate between and among options with respect to the effect that the options have on P_{APP}. The more important factors on the influence diagram are shown enclosed within double ellipses. Each of the six questions required the panels members to consider the issue described in the question and, for each option, to qualitatively compare the effect this issue would have on P_{APP} to the effect of the base case. After answering the six questions of the *Instruction Workbook*, the panel members were asked to consider all their answers and to produce a summary final qualitative comparison of the ESF-repository options based on the effect the options would have on P_{APP} in comparison to the effect the base case option would have on P_{APP}. By combining the panel members' answers to the summary question, a qualitative ranking of the options with respect to how the options affect P_{APP} was obtained. The following section contains a synthesis of the discussions that the panel members had in determining this initial qualitative ranking. The discussions will be presented in approximately the same order in which they occurred. Changes in the order of presentation have been made to show how the discussion evolved, to minimize redundancies, and to make this section more readable. A complete record of the discussions is contained in the transcripts of the panel meetings.

B.2.7.1 Qualitative Ranking With Respect to P_{APP}

The panel discussed that the influence diagram did contain the important issues that affect P_{APP} and that also can be used to discriminate between and among the options. The panel discussed that the ESF costs should not be on the influence diagram because those costs represent money that has already been spent, and as such, should not influence whether approval is granted to construct and operate the repository.

One of the questions in the *Instruction Workbook* dealt with how the ability to conduct HLW tests in an option affects P_{APP}. The panel discussed that although the DOE does not currently plan on conducting any HLW tests, the ability to conduct the tests would be considered in estimating P_{APP} because the NRC may like to see such a test conducted. The panel considered the four factors as important regarding the ability to conduct HLW tests: the amount of space available for the tests, whether shafts or ramps are used for access, the representativeness of the geology, and the time available for testing.

Another one of the questions in the *Instruction Workbook* dealt with how the estimates of the Expert Panel on Postclosure Health affect P_{APP}. The panel discussed that the lower the estimated releases, the larger P_{APP} would be. Similarly for the question in the *Instruction Workbook* concerning the estimates of the Expert Panels on Characterization Testing and Postclosure Health regarding the residual uncertainty about the site, the panel discussed that the smaller the estimate that the site is NOT OK, even though it has been found to be OK, the larger the estimate of P_{APP} will be.

Another one of the questions in the *Instruction Workbook* dealt with how the estimates of the Expert Panels on Preclosure Health and Safety affect P_{APP}. The panel discussed the following factors as important regarding P_{APP}: the preclosure radiation doses estimated by the Expert Panel on Preclosure Radiologic Health, the cost and schedule estimates of the Expert Panel on Cost and Schedule, the estimates of the Expert Panel on Socioeconomics, and for environmental concerns, land access, air quality, endangered species, noise, and transportation.

Another one of the questions in the *Instruction Workbook* dealt with how extended duration tests could affect P_{APP}. The panel discussed that the following factors could be used to determine how the ability to conduct extended duration tests affects P_{APP}: the MTL location, the MTL size, the relative location of the shops area to the test area, construction interference with tests, interference from other tests, the amount of water used in construction, and the reamability of shafts.

The final question in the *Instruction Workbook* dealt with how the ability to conduct early tests for site suitability could affect P_{APP}. The panel discussed that both technical confidence and procedural confidence regarding early tests for site suitability could affect P_{APP} and that it is difficult to separate technical and procedural confidence. The panel also discussed that the starting and ending dates of the test programs are important factors that affect how the procedural confidence affects P_{APP}.

After discussing the questions in the *Instruction Workbook*, the panel members qualitatively ranked all the options. In the ranking, if an option has a relative score greater than zero, that option probably has a greater P_{APP} than the base case, and if an option has a relative score less than zero, that option probably has a smaller P_{APP} than the base case. The relative score was developed by averaging the qualitative ratings assigned by the panel members. Considering the complete option, compared to the base case, if it appeared that an option would have a much lower P_{APP}, then a score of -2 was assigned; if it appeared that it would have a lower P_{APP}, then a score of -1; the same P_{APP}, a score of zero; a higher P_{APP}, a score of 1; and a much higher P_{APP}, a score of 2. The panel ranked ESF-repository Options 9 and 26 poorly because those options will have large residual uncertainties whether the site truly is OK and they have larger estimated releases than the other options.

B.2.7.2 Estimation of P_{APP}

The proposition that P_{APP} is exactly 1 for all options was considered. The site already will have been found to be "OK" and it is likely that whatever conditions are imposed to meet approval will be met. On the other hand, P_{APP} may not be the same for all options because of the differences between the options and also because it is not certain that approval to construct and operate a repository will be given, even though the site has been found to be "OK." Furthermore, the magnitude of P_{APP} indicates the uncertainty regarding approval. The probability of approval, P_{APP}, was not equated with P_{OK}, the probability the site is OK, because P_{OK} was not conditioned on certain data, such as costs and politics. The residual uncertainty that the site is truly NOT OK, even though characterization testing indicates the site to be "OK," $P(\overline{OK}$ | "OK-ET," "OK-LT"), may be a more important estimate than P_{OK} because approval will only be sought after the site has been found to be "OK." If an option would receive approval only by meeting conditions that essentially change the option, then that option was viewed as disapproved. The panel considered using the percentage of nuclear reactors that have not received approval as an indication of $P_{\overline{APP}}$. However, estimates of $P_{\overline{APP}}$ assume the site has been found to be "OK."

Although the panel recognized deficiencies in the base case option, they did not consider P_{APP} to be zero. The known deficiencies could be corrected. When the base case was created, the design was considered likely to win approval. The base case may not have as large a difference between the high and low estimates of P_{APP} as some of the other options because the base case has been studied more intensively and has less uncertainty.

Some panel members estimated relatively larger values of $P_{\overline{APP}}$ for Options 17 and 34 because the muck piles will be visible and the estimated releases are larger for those options than for other options.

Option 24 was assigned a larger P_{APP} than Option 7 because Option 24 probably may not be able to accommodate the HLW tests and extended duration tests as well as Option 7. Option 24 also has a larger residual uncertainty than Option 7.

Options 16 and 33 tend to have lower values of $P_{\overline{APP}}$ because the releases should be low and the residual uncertainty should be low. However, the visible muck piles and the test schedules increase the $P_{\overline{APP}}$. In the discussions, it was clear that the panel members did not weight the factors being considered in exactly the same way. The panel also noted that the Expert Panel on the Aesthetic Properties used a highly non-linear scale and that small differences in the estimates can represent large differences in utility. The final estimates of $P_{\overline{APP}}$ are shown in Table B-16.

B.2.8 Probability of Retrieval, P_{RET}

The Expert Panel on Regulatory Considerations provided expert judgments on the probability of waste retrieval, P_{RET}.

TABLE B-16

PROBABILITY OF DISAPPROVAL FOR REPOSITORY CONSTRUCTION/OPERATION, $P_{\overline{APP}}$

Qualitative Ranking		Fractile		
Option	Relative Score	0.05	0.50	0.95
15	2.0	0.01	0.05	0.50
32	1.6	0.01	0.06	0.50
6	1.4	0.01	0.07	0.50
16	1.4	0.01	0.10	0.51
2	1.3	0.01	0.07	0.50
7	1.3	0.02	0.08	0.50
3	1.1	0.02	0.11	0.50
19	1.1	0.01	0.10	0.50
23	1.1	0.01	0.10	0.50
33	1.1	0.02	0.12	0.52
4	1.0	0.02	0.13	0.50
13	1.0	0.01	0.11	0.50
30	1.0	0.01	0.13	0.50
5	0.9	0.02	0.15	0.53
8	0.9	0.02	0.15	0.53
20	0.9	0.03	0.17	0.55
21	0.9	0.03	0.16	0.55
24	0.9	0.03	0.14	0.53
11	0.7	0.03	0.17	0.55
12	0.7	0.03	0.19	0.55
28	0.7	0.03	0.18	0.55
25	0.6	0.03	0.20	0.55
14	0.3	0.04	0.22	0.60
29	0.3	0.04	0.21	0.55
31	0.1	0.04	0.23	0.60
Base Case	0.0	0.04	0.22	0.55
18	0.0	0.04	0.23	0.55
22	0.0	0.04	0.22	0.56
10	-0.1	0.04	0.26	0.60
27	-0.1	0.04	0.27	0.60
17	-0.4	0.05	0.30	0.65
9	-0.9	0.05	0.33	0.75
26	-1.0	0.05	0.34	0.75
34	-1.0	0.06	0.31	0.75

The probability of closure (P_{CLO}) is based on the current understanding plus the understanding that the site has gone through testing, approval, and operation. The two release estimates that are required are the releases that we would estimate given our current understanding of the site and the releases that we would estimate given the understanding that we expect to have after testing, license approval, construction, operation, and monitoring.

This section presents a description of the process used by and the discussions of the Expert Panel on Regulatory Considerations that lead to the estimation of P_{RET}, the probability of waste retrieval, for each of the 34 ESF-repository options. In this study, retrieval is defined as removing any and all waste stored underground in the repository at Yucca Mountain. It was necessary for the panel to estimate P_{RET} because it and its complementary probability, P_{CLO}, the probability of repository closure, are required data to be used with the Decision Tree (ESF-AS Report, Volume 2, Section 2, Figure 2-1). The description in this section is a complete summary but more details of the process and discussions concerning the estimation of P_{RET} are contained in the summary notes and transcripts of the meetings of the panel. The description in this section is not a strict chronological presentation of the process and discussions, but is a synthesis of them. This section can be divided into two parts: the first is a description of the process and discussions that lead to a qualitative ranking of the options with respect to P_{RET} and the second is a description of the process and discussions that lead to the estimation of P_{RET}, given the qualitative ranking of the options.

B.2.8.1 Qualitative Ranking With Respect to P_{RET}

Before the panel estimated P_{RET} for the options, the panel qualitatively ranked the options in comparison to the base case option by considering the effect that the options would have on P_{RET}. To help them compare the options to the base case, the panel members received *Instruction Workbook for Regulatory Panel Members: Preparation for the ESF-Repository Option Scoring Sessions* (hereinafter the *Instruction Workbook*) and explanations of the important features of each of the options. In the *Instruction Workbook* were two questions that were related to the most important issues of the influence diagram, Figure B-12, which shows the important factors that can discriminate between and among options with respect to the effect that the options have on P_{RET}. The more important factors on the influence diagram are shown enclosed within double ellipses. Each of the two questions required the panels members to consider the issue described in the question and to qualitatively compare each ESF-repository option to the base case option, considering the effect this issue would have on P_{RET} for each option. After answering the two questions of the *Instruction Workbook*, the panel members were asked to consider all their answers and to produce a summary final qualitative comparison of the ESF-repository options based on the effect the options would have on P_{RET} in comparison to the effect the base case option would have on P_{RET}. By combining the panel members' answers to the summary question, a qualitative ranking of the options with respect to how they affect P_{RET} was obtained. The following section contains a synthesis of the discussions that the panel members had in determining this initial qualitative ranking. The discussions will be presented in approximately the same order in which they occurred. Changes in the order of presentation have been made to show how the discussion evolved, to minimize redundancies, and to make this section more readable. A complete record of the discussions is contained in the transcripts of the panel meetings.

The panel discussed whether retrieval and closure were the correct mutually exclusive outcomes for the final decision in the ESF-AS Decision Tree. It was discussed whether closure and non-closure might be better choices for the two outcomes. After discussions, the panel decided to keep closure and retrieval as the outcomes because non-closure should eventually lead to either closure or retrieval.

The panel discussed the issues shown on the influence diagram and although there was some disagreement among the panel as to the relative importance of some of the issues, the panel discussed that agreement about the relative importance of the issues was not the purpose of the influence diagram, but that the influence diagram served as a tool for helping the panel discuss important issues. The panel did decide that cost was probably not one of the most important issues on the influence diagram that affects P_{RET}.

One of the questions in the *Instruction Workbook* concerned how the amount of real estate examined in each ESF-repository option affects P_{RET} for the options. The amount of real estate can affect P_{RET} because an option that examines less real estate in the ESF, even though it is approved for repository construction/operation, is more likely to miss important information than is an option that examines more real estate.

Examining a greater amount of real estate leads to increased procedural confidence in an option. However, at least one panel member considered the amount of real estate examined to be non-discriminatory among options. The linear feet of drifting in the ESF, the number of independent ramps and shafts, and the number of faults penetrations affects how the amount of real estate examined affects P_{RET}. The panel discussed the area of the MTL, the location of the MTL, the shape of the drifted areas, the timing of the tests, and the shaft construction method do not affect how the real estate examined affects P_{RET}.

The panelists also discussed the effects of estimates by the Expert Panel on Postclosure Health on P_{RET}. The panel considered that the lower the estimated releases, the smaller P_{RET} would be. Similarly, for the question in the *Instruction Workbook* concerning the estimates of the Expert Panels on Characterization Testing and Postclosure Health regarding the residual uncertainty about the site, the panel considered that the smaller the residual uncertainty about the site, the smaller the estimate of P_{RET} would be.

The panel also discussed how P_{APP} affects P_{RET}, including whether there might be some simple functional relationship between P_{APP} and P_{RET}. Some possible functional relationships that also include the estimates of residual uncertainty developed by the Expert Panels on Characterization Testing and Postclosure Health were discussed. Some functional forms included terms representing procedural confidence and technical confidence, both of which do affect P_{RET}, as shown on the influence diagram. The panel decided to estimate P_{RET} independently because the functions that were proposed would not have allowed for more input from the panel. Some of the variables that would have been used in the functions were at least partly based on factors, such as aesthetic impacts, that have no bearing on retrieval of the waste. A ranking of the options based on the functional results would not agree with the ranking based on the qualitative results. The functional results could be interpreted as implying that performance confirmation is of little use or the regulations regarding releases will be changed in the future.

After discussing the questions in the *Instruction Workbook*, the panel members qualitatively ranked all the options (Table B-17). The qualitative ranking resulted from judgments provided by each of six panel members. Each panel member judged each option to have a much lower, lower, the same, higher, or much higher probability of retrieval than the base case. A relative score of -2, -1, 0, +1, or +2 was assigned to

TABLE B-17

PROBABILITY OF RETRIEVAL, P_{RET}

Qualitative Ranking		Fractile			
Option	Relative Score	Option	0.05	0.50	0.95
4	-1.5	13	0.0001	0.0012	0.05
6	-1.5	16	0.0001	0.0013	0.05
13	-1.5	6	0.0001	0.0013	0.05
30	-1.5	4	0.0001	0.0014	0.05
5	-1.3	15	0.0001	0.0014	0.05
12	-1.3	30	0.0001	0.0015	0.05
8	-1.2	5	0.0001	0.0015	0.05
21	-1.2	12	0.0001	0.0017	0.05
23	-1.2	32	0.0001	0.0019	0.05
25	-1.2	23	0.0001	0.0019	0.05
29	-1.2	2	0.0001	0.0019	0.05
15	-1.0	14	0.0001	0.0022	0.05
16	-1.0	7	0.0001	0.0022	0.05
22	-1.0	33	0.0001	0.0022	0.05
2	-0.8	8	0.0001	0.0023	0.05
3	-0.8	21	0.0001	0.0023	0.05
7	-0.8	3	0.0001	0.0024	0.05
14	-0.8	19	0.0001	0.0027	0.05
32	-0.8	25	0.0001	0.0027	0.05
33	-0.8	29	0.0001	0.0027	0.05
10	-0.7	20	0.0001	0.0030	0.05
11	-0.7	22	0.0001	0.0030	0.05
19	-0.7	11	0.0001	0.0031	0.05
20	-0.7	24	0.0001	0.0032	0.05
24	-0.7	17	0.0001	0.0033	0.05
27	-0.7	28	0.0001	0.0034	0.05
28	-0.7	31	0.0001	0.0035	0.05
31	-0.7	10	0.0001	0.0041	0.05
17	-0.5	27	0.0001	0.0042	0.05
18	-0.3	18	0.0001	0.0049	0.05
34	-0.3	Base Case	0.0001	0.0049	0.05
Base Case	0.0	34	0.0001	0.0053	0.05
9	0.3	26	0.0001	0.0087	0.05
26	0.3	9	0.0001	0.0088	0.05

each option, depending on whether the P_{RET} was judged to be respectively much lower, lower, the same, higher, or much higher than the base case. The relative scores shown in Table B-17 resulted from arithmetically averaging the relative scores provided by the six panel members.

B.2.8.2 Estimation of P_{RET}

After a qualitative ranking was obtained for the options, the panel discussed the estimates of P_{RET} for the options. The estimates elicited in the pilot study were approximately 1 percent to 2 percent. It was discussed whether P_{RET} should be essentially equal to 1 or significantly less than 1. It was discussed that too low an estimate of P_{RET}, as well as too large an estimate, could be damaging to the DOE. In the discussions, the panel decided that the best course was to make the best estimate possible for P_{RET} based on the information and discussions that the panel had. The panel also discussed that caution should be taken to not make too small an estimate of P_{RET} by being overconfident in their knowledge and by not taking into account unlikely events. The panel also discussed whether every option should have the same P_{RET}, which although perhaps acceptable, was in disagreement with the qualitative ranking of the options with respect to P_{RET}.

The panel made the estimates of P_{RET} for all the options. Although there were some reservations about some of the estimates (in particular, it was discussed that P_{RET} may be very small after all the testing, approvals, construction, operation, and emplacement, but there are still unforeseen events that could cause retrieval), all the panel members except one agreed with the estimates of P_{RET}. The panel member in disagreement stated that the causes of retrieval are so speculative that it is not productive to try and estimate P_{RET}. This panel member instead chose to use the residual uncertainty that the site is NOT OK, even though it has been found to be "OK," as an indication of P_{RET}. The panel member stated that if the site were truly NOT OK, then if one assumes that the probability of discovering this is 1, then P_{RET} is simply the residual uncertainty. It was discussed by the panel that such an approach puts a lot of weight on the estimate of residual uncertainty.

The consensus estimates of six panel members (Table B-17) used the geometric mean as the best estimate. The estimates of the panel member who disagreed are 0.5 percent for the low estimate, 1 percent for the best estimate, and 2.6 percent for the high estimate. The geometric mean was considered more useful in estimating central tendencies among small numbers, such as the P_{RET}.

B.2.9 Radionuclide Releases to the Accessible Environment, X_1

The Expert Panel on Postclosure Health provided expert judgments on the postclosure releases of radionuclides from each ESF-repository option to the accessible environment during the first 10,000 years after closure. All releases were expressed in terms of the EPA standard (EPA_S) for release 10,000 years after repository closure [40 CFR 191].

B.2.9.1 Basic Assumptions

The panel was guided by a set of scoring instructions in reviewing the factors in the influence diagram and establishing basic assumptions for the scoring process. The scoring instructions are included in Record Packages (Appendix D.5). As a basis for beginning consideration of the radionuclide release estimates for the base case, the panel considered published estimates. Three reports were consulted: Sinnock et al. [1987], Sinnock et al. [1984], and DOE [1986]. The results are summarized below.

- Sinnock et al. [1984]
  - Assumed flux: 0.5 mm/yr
  - Release rates
    - Matrix flow: Release $\approx 10^{-7}$ EPA_S
    - Fracture flow: 0.001 < Release < 0.002 EPA_S

- Sinnock et al. [1987, Figure 15]
  - Assumptions
    - Flux: 5 mm/yr
    - No retardation
    - Waste package life: 300 yrs
    - Water available for interaction with waste: 5 mm/yr x 5.5 x 10^6 m^2
    - Water reaching canisters: 0.25 percent of water available

Release rates

* Fracture flow: Release ≈ 10^{-7} EPA_S

- DOE/RW-0074 [DOE, 1986]

  Assumptions --- Table B-18
  Releases --- Release estimates (Release ≈ 10^{-4} EPA_S were based on judgments of experts who reviewed calculations.

The SCP-CDR [SNL, 1987] waste package design was the reference design for all options. The reference design uses a stainless steel that is 1 cm thick. The reference waste volume was 68,000 metric tons of uranium (MTU) in a mixture of 60 percent pressurized water reactor (PWR) and 40 percent boiling water reactor (BWR) spent fuel.

The assumptions regarding the conditions for failure of the waste package (Table B-19) were agreed upon before the scoring exercise began.

The panel scored each option twice. The two scoring tasks were

- to estimate all radionuclide releases: gaseous plus aqueous releases; and

- to estimate only aqueous radionuclide releases.

Estimated releases of carbon-14 (gaseous transport) are expected to be large compared with releases carried by fluids (aqueous transport). On the one hand, site is considered a poor barrier against gaseous releases and a very good barrier against aqueous releases. On the other hand, the gaseous radionuclides represent only 1 percent of the total inventory. The site will contain 99 percent of the inventory of radionuclides. Gaseous releases of carbon-14 could lead to estimated accumulations greater than 1 EPA_S.

The issue of carbon-14 accumulations must be addressed either by new developments in technology or by updates to the requirements regarding the acceptable releases of carbon-14. The releases of carbon-14 will not vary with option, and therefore do not

TABLE B-18

SITE CHARACTERISTICS AND PERFORMANCE FACTORS FOR EXPECTED CONDITIONS AT YUCCA MOUNTAIN [DOE, 1986]

Parameter	Range of Parameter Values: 0 to 10,000 Years After Closure	Range of Parameter Values: 10,000 to 100,000 Years After Closure
Q - Volume of Water Available for Dissolution of Waste (m^3/1,000 MTHM)[a]	0 to 44,000	0 to 400,000
No. of Radionuclides		
$i = 1$ $\frac{C_i}{RL_i}$ (1,000 MTHM/m^3)[b]	2.2×10^{-8} to 2.2×10^{-4}	9.4×10^{-10} to 9.4×10^{-6}
F - Radionuclide Release From Engineered Barrier System[c]	0.001 to 9.7	0.0001 to 3.8
T - Median Groundwater Travel Time (Years)	42,000 to 200,000	42,000 to 200,000
R - Retardation Factor	100 to 1,000	100 to 1,000
T_i - Median Radionuclide Travel Time (Years)	4.3×10^6 to 2×10^8	$>4.3 \times 10^6$
Waste Package Lifetime (Years)	3,000 to 30,000	

[a]MTHM = Metric Tons of Heavy Metal.
[b]C_i = Predicted cumulative release of the i^{th} radionuclide to accessible environment after closure.
RL_i = Release limit for i^{th} radionuclide listed in 40 CFR 191.
[c]Multiple of EPA release limits for 10,000 years.

TABLE B-19

ASSUMPTIONS REGARDING WASTE PACKAGE FAILURE

	Fractile			
	0.999	0.95	0.50	0.05
Percent of Waste Package Failures	≃100	< 100	≃10	< 10
Flux (mm/yr) Flow Mode (See Notes)	> 5[a]	≃5[b]	$\leq$ 1[c]	~Zero[d]
		←Decreasing matrix diffusion		
Retardation	Much less than expected (colloids)	Expected	Expected	Better than expected
Effective Porosity	←Decreasing		Expected	Better than expected
Water in Contact With Waste (percent of total volume flow)[e]	$\geq$ 2.5	0.2 to 2.5	< 0.2 (Expected)	Better than expected
Waste Form Dissolution	←Increasing Gain Exposure ←Increasing Solubility Higher pH		Congruent plus solubility limited	

[a]Fracture flow over substantial portion of the site for a substantial portion of 10,000 years.
[b]Same as 0.95 fractile but retardation is less than expected.
[c]Below fracture-flow threshold. Zero net flux means a very low net percolation to the Topopah Spring.
[d]Strictly confined to matrix flow.
[e]Unsaturated conditions: divergence of flow around waste canisters; Saturated conditions: drifts and holes may be sinks.

represent a discriminating performance measure for the purpose of selecting one option over another. The panel provided estimates for both cases so that these data would be available for future studies.

B.2.9.2 Scoring

Each panel member estimated the radionuclide releases to the accessible environment at four confidence levels (Table B-20).

The elicitation of panel judgments of the radionuclide releases was facilitated by a series of ballots (See Appendix D.4). The first balloting considered only the base case. Two ballots led to a consensus judgment of the panel for the base case (Tables B-21 and B-22).

The best judgment (0.50 confidence fractile) was that Option 1 would release radionuclide levels that were within 2 percent of the EPA standards if gaseous transport were considered. If only aqueous transport were considered, the radionuclide releases are likely to be 10^{-6} of the EPA standard at the 0.50 confidence level. The lowest estimate of releases for Option 1 was for aqueous transport only. The panel considered that under the best circumstances, the releases would be almost zero. A numerical value of 10^{-12} EPA_S was used in the calculations to represent zero releases from the repository.

A consensus of the panel regarding radionuclide releases from all the options was reached after two ballots (Tables B-23 and B-24).

The characterization testing schedule defining 17 sets of option pairs (Testing Schedule 1 for Options 1 through 17 and Testing Schedule 2 for Options 18 through 34) should make no difference in the release estimates. For that reason, identical scores were estimated for each option pair (for example, Options 9 and 26).

B.2.10 Preclosure Radiological Health Effects: Workers, X_2

The performance measure for radiologic health effects to repository workers was

premature cancer deaths among workers during the preclosure period and attributable to radiation from radionuclides that escaped within the repository facility.

TABLE B-20

EXPLANATIONS OF CONFIDENCE INTERVALS

Fractile	Explanation
0.05	5 chances in 100 that the release is less than the estimated value
0.50	Equal probability that the release is greater or less than the estimated value
0.95	5 chances in 100 that the release is greater than the estimated value
0.999	1 chance in 1,000 that the release is greater than the estimated value

TABLE B-21

CONSENSUS JUDGMENT OF RADIONUCLIDE RELEASES FOR BASE CASE (OPTION 1): GASEOUS PLUS AQUEOUS TRANSPORT

Fractile	Release/EPA_S
0.999	2
0.95	0.2
0.50	0.02
0.05	10^{-5}

TABLE B-22

CONSENSUS JUDGMENT OF RADIONUCLIDE RELEASES FOR BASE CASE (OPTION 1): AQUEOUS TRANSPORT

Fractile	Release/EPA_S
0.999	1
0.95	0.01
0.50	10^{-6}
0.05	10^{-12}

TABLE B-23

CONSENSUS JUDGMENT OF RADIONUCLIDE RELEASES FOR ALL OPTIONS: GASEOUS AND AQUEOUS TRANSPORT (RELEASE/EPA_S)

	Fractile			
Option	0.05	0.50	0.95	0.999
1, 18	10^{-5}	0.020	0.2	2
2, 19	10^{-5}	0.019	0.2	2
3, 20	10^{-5}	0.020	0.2	2
4, 21	10^{-5}	0.019	0.2	2
5, 22	10^{-5}	0.017	0.2	2
6, 23	10^{-5}	0.017	0.2	2
7, 24	10^{-5}	0.020	0.2	2
8, 25	10^{-5}	0.020	0.2	2
9, 26	10^{-5}	0.023	0.2	2
10, 27	10^{-5}	0.020	0.2	2
11, 28	10^{-5}	0.020	0.2	2
12, 29	10^{-5}	0.017	0.2	2
13, 30	10^{-5}	0.017	0.2	2
14, 31	10^{-5}	0.017	0.2	2
15, 32	10^{-5}	0.017	0.2	2
16, 33	10^{-5}	0.017	0.2	2
17, 34	10^{-5}	0.020	0.2	2

TABLE B-24

CONSENSUS JUDGMENT OF RADIONUCLIDE RELEASES FOR ALL OPTIONS: AQUEOUS TRANSPORT (RELEASE/EPA_S)

	Fractile			
Option	0.05	0.50	0.95	0.999
1, 18	10^{-12}	1.0×10^{-6}	0.010	1
2, 19	10^{-12}	6.7×10^{-7}	0.010	1
3, 20	10^{-12}	6.3×10^{-7}	0.010	1
4, 21	10^{-12}	2.0×10^{-6}	0.010	1
5, 22	10^{-12}	7.9×10^{-7}	0.010	1
6, 23	10^{-12}	5.5×10^{-7}	0.010	1
7, 24	10^{-12}	8.1×10^{-7}	0.010	1
8, 25	10^{-12}	9.4×10^{-7}	0.010	1
9, 26	10^{-12}	5.1×10^{-6}	0.020	1
10, 27	10^{-12}	9.4×10^{-7}	0.010	1
11, 28	10^{-12}	8.1×10^{-7}	0.010	1
12, 29	10^{-12}	8.5×10^{-7}	0.010	1
13, 30	10^{-12}	6.4×10^{-7}	0.010	1
14, 31	10^{-12}	2.2×10^{-6}	0.010	1
15, 32	10^{-12}	3.1×10^{-7}	0.010	1
16, 33	10^{-12}	2.3×10^{-7}	0.010	1
17, 34	10^{-12}	2.3×10^{-6}	0.010	1

The Expert Panel on Preclosure Radiological Health Effects estimated the doses to workers in the ESF-repository and the surface facilities within 1 mile of the ESF. The doses were converted to potential premature deaths as part of the aggregation of the utility and expected net benefit of each option. The doses were estimated in person-rems over the 25-year emplacement period of the repository. The influence diagram for radiological worker health (Figure B-14) was reviewed and it was agreed to use the same approach for scoring the 34 options that was used to score the options relative to radiological public health (Section B.2.10).

Experts in health physics, mining operations, and safety estimated the total person-rems resulting from accidents in the ESF-repository using the following steps:

- Compute estimates of radiation doses resulting from each option, considering the five major influencing factors;

- Adjust the calculated releases to account for other factors that are included in the influence diagram for radiological worker health (Figure B-14); and

- Use best judgments to estimate high and low doses for each option.

The estimated worker fatality rate was

$$500 \text{ premature fatalities per } 10^6 \text{ person-rems.}$$

The assumptions used to estimate the risk of radiation exposure to the workers were similar, except for some slight changes, to the accident scenarios presented in the SCP-CDR [SNL, 1987].

- A transporter runs away or two transporters collide.
- A waste container breaches.
- A spent fuel pellet fractures and fragments become airborne.
- Fuel rod particles are released to the ventilation system.
- Radiation monitoring alarm systems fail.
- Workers are exposed to radiation.

B.2.10.1 Accident Scenario

The scenario for accidents that might cause radiation doses to workers was basically the same scenario considered for public doses. Two mechanisms that influence the radionuclide concentrations that reach the public were not included when calculating doses to workers. Those mechanisms are

- Dispersion caused by airborne transport to the boundary of the controlled area of the repository, and

- Deposition of fuel particles on the ground.

The dilution of concentrations to workers was based on the mine ventilation airflow rate rather than atmospheric dilution. Ground particles were not considered when calculating cases to workers. The calculations considered two types of workers.

- Workers downstream from an accident are subject to airflow velocities of 45,000 cubic feet per minute (cfm).

- Workers in the surface facilities and development area are subject to exhaust air flow velocities of 70,000 cfm.

The dominant impact is to workers downstream from an accident that breaches a waste container and releases particles of radionuclides to the air.

B.2.10.2 Doses and Risks

The estimated typical dose to underground workers under the assumed accident scenario was

$$\text{Dose}_{typ} = 1800 \text{ person-rems per accident.} \qquad \text{(B-2)}$$

This dosage was combined with the estimated probabilities of a runaway transporter accident (P_{RT} = 10^{-2} per year) and a container breach (P_{CB} = 10^{-4} per accident) to obtain the annual risk to underground workers.

$$\text{Risk}_{ug}\text{ per year} = P_{RT}\, P_{CB}\, \text{Dose}_{typ} \approx 2 \times 10^{-3} \text{ person-rem/year.} \qquad \text{(B-3)}$$

The risk of radiologic doses to workers over the operational life of the repository was obtained by multiplying the annual risk by the 25-year emplacement period:

$$\text{Risk}_{ug} \approx 5 \times 10^{-2} \text{ person-rem.} \qquad \text{(B-4)}$$

This underground risk estimate was considered to be accurate only to the nearest order-of-magnitude. The panel considered other factors in the influence diagram than might cause variations from this estimate. Perturbations such as downstream or upstream monitors were considered to cause less than one order-of-magnitude variation from the underground risk estimate.

Air flow in the ventilation systems also vary among options and within the SCP-CDR base case. The air flow velocities in the main drift range from 300,000 cfm to 500,000 cfm (Table B-25). The number of people in the vicinity of an accident may also vary. A typical number of five people in the vicinity of an accident was adopted for the purpose of the scoring exercise.

B.2.10.3 Scoring

The panel scored options by groups as indicated in Table B-26. Each option was assigned a score corresponding to the panel's best estimate of the risk to underground workers. The panel also estimated the optimistically low estimates of risk and pessimistically high estimates of risk to radiation doses resulting from underground accidents.

The approach was to scale the scores estimated for public health and adjust the resulting scores to account for variations in air flow rates. The factor that scales the public risk to the underground worker risk resulting in the doses shown in Table B-26 was approximately

$$\text{Scale}_{\text{public to worker}} \approx \text{x } 10^{4} \qquad \text{(B-5)}$$

TABLE B-25

GROUPING OF ESF-REPOSITORY OPTIONS FOR RADIONUCLIDE HEALTH SCORING

ESF/Repository Option	Grades (Percent) Waste Ramp	Grades (Percent) Waste Main	Grades (Percent) Empl. Drift	Facility Locations Empl. Shops	Facility Locations ESF Location	Main Splits	Air Flow (10^3 cfm) (Percent Base Case)
Base Case	8.9	2.5 - 8	2.5 - 9	ESF[b]	N	No	500 (100)
A1, A2, A4-R1, A7	8.9	2.5 - 8	2.5 - 9	ESF	N	No	500 (100)
A5	8.9	2.5 - 8	2.5 - 9	North[c]	S	Yes[a]	500 (100)
B3 (Rev. 2-6)	8.9	2.5 - 8	3.5 - 7.5	ESF	N	Yes[d]	300 (60)
B4, B7, B8	8.9	2.5 - 8	4 - 8.5	North	S	Yes	300 (60)
C1, C2	10 MAX	<1	<1	ESF/ North	N/S	Yes[e]	550 (110)
R11	8.9	2.5 -8	3.5 - 7.5	ESF	N	Yes[d]	300 (60)

[a]Two waste-emplacement main drifts, both flat.
[b]If shops are located at the ESF, ventilation air is split between emplacement area and shop area.
[c]If shops are located in the North, ventilation systems of emplacement area and shop area are not connected.
[d]Bottom of ramp.
[e]Upper and lower levels.

TABLE B-26

PRECLOSURE RISK OF RADIOLOGIC DOSES TO UNDERGROUND WORKERS

	Person-Rems Over the 25-Year Emplacement Period		
Design Option	0.05 Fractile	0.50 Fractile	0.95 Fractile
Base Case, 1, 18	10^{-5}	$5x10^{-2}$	10
2, 3, 4, 6, 19, 20, 21, 23	10^{-5}	$5x10^{-2}$	10
5, 22	10^{-5}	10^{-1}	20
7-11, 24-28	10^{-5}	10^{-1}	20
12-14, 29-31	10^{-5}	$2x10^{-1}$	40
15, 16, 32, 33	10^{-5}	10^{-2}	2
17, 34	10^{-5}	10^{-1}	20

B.2.11 Preclosure Radiological Health Effects: Public, X_3

The performance measure for radiologic health effects to the public was

> *premature cancer deaths among members of the public at risk during the preclosure period and attributable to radiation from radionuclides that escaped from the repository facility.*

The Expert Panel on Preclosure Radiological Health Effects estimated the radiation doses that members of the public at risk are likely to receive as a result of each ESF-repository option. The doses were converted to potential premature deaths as part of the aggregation of the utility and expected net benefit of each option. The doses were estimated in person-rems over the 25-year emplacement period of the repository. The estimations required three steps.

- Compute estimated radiation doses to the public resulting from each option.

- Adjust the calculated doses for each option to account for other factors that are included in the influence diagram (Figure B-15).

- Use expert judgment to estimate high and low doses for each option.

The assumptions used to estimate the risk of radiation exposure to the public are similar, except for some slight changes, to the accident scenarios presented in the SCP-CDR [SNL, 1987]. The scenarios used for the ESF-AS were

- A transporter runs away or two transporters collide.
- A waste container breaches.
- A spent fuel pellet fractures and fragments become airborne.
- Fuel rod particles are released to the ventilation system.
- Radiation monitoring alarm systems fail.
- Radionuclides are carried to the site boundary 5 km away and expose a population of 10,000 persons within an 80-km (50-mile) radius from the controlled area of the repository site.

A typical dose per accident was calculated for the stated scenario. The typical dose was judged to be

$$Dose_{typ} = 0.03 \text{ person-rems/accident.}$$

This dosage was combined with the estimated probabilities of a runaway transporter accident ($P_{RT} = 10^{-2}$ per year) and a container breach ($P_{CB} = 10^{-4}$ per accident) to obtain the annual risk to the public.

$$Risk_{public} \text{ per year} = P_{RT}\, P_{CB}\, Dose_{typ} = 3 \times 10^{-8} \text{ person-rem/year}$$

The risk of radiologic doses to the public over the operational life of the repository was obtained by multiplying the risk per year by the 25-year emplacement period.

$$Risk_{public} \approx 8 \times 10^{-7} \approx 10^{-6} \text{ person-rem}$$

For the purposes of estimating radiation doses, the options were grouped according to the features that might influence accidents resulting in the release of radionuclides (Table B-25). These features correspond to the major influencing factors shown in the influence diagram (Figure B-15).

The radiation doses (person-rem doses over the 25-year emplacement period of the repository) are summarized in Table B-27. The major judgments regarding the estimates are summarized in the following sections.

B.2.11.1 Base Case --- SCP-CDR

After considering the dosage risk calculation in light of other factors in the influence diagram (Figure B-15), The expert panel decided to use the approximate calculated doses associated with the repository conceptual design (SNL, 1987). A radiation dose of 10^{-6} person-rem was adopted as the best estimate of the dosage to the public for the base case. The expert panel attached greater importance to transporter slides than indicated on the influence diagram (Figure B-15) because when the influence diagram was being developed, the panel was under the impression that the emplacement rooms were flat. The SCP-CDR design includes sloping floors in the emplacement rooms.

TABLE B-27

PRECLOSURE RISK OF RADIOLOGIC DOSES TO PUBLIC

	Person-Rems Over the 25-Year Emplacement Period		
Design Option	0.05 Fractile	0.50 Fractile	0.95 Fractile
Base Case, 1, 18	10^{-4}	10^{-6}	10^{-9}
2, 3, 4, 6, 19, 20, 21, 23	10^{-4}	10^{-6}	10^{-9}
5, 22	$2x10^{-4}$	$2x10^{-6}$	10^{-9}
7-11, 24-28	10^{-4}	10^{-6}	10^{-9}
12-14, 29-31	$2x10^{-4}$	$2x10^{-6}$	10^{-9}
15, 16, 32, 33	$2x10^{-5}$	$2x10^{-7}$	10^{-9}
17, 34	10^{-4}	10^{-6}	10^{-9}

The panel decided to base their judgments on the calculations for the SCP-CDR and their expert judgments of the effects of transporter slides. The panel adjusted the estimates when scoring options with slopes greater or less than those in the SCP-CDR design. The judgment was that the range of uncertainty in the expected value of 10^{-6} person-rem for the base-case estimate exceeded the variation in the caused by transporter slides.

B.2.11.2 Options 2, 3, 4, 6, 19, 20, 21, and 23

These options were considered to be indistinguishable from the base case so the base-case estimates were assigned to these options.

B.2.11.3 Options 5 and 22

The principal differentiating features of Options 5 and 22 were the following:

- mining and emplacement proceed in a different direction;
- the waste ramp splits;
- the ESF is isolated; and
- shops are on the waste emplacement ventilation system.

The split ramp was considered to increase the risk of a transporter accident by less than a factor of 2. The more complicated arrangement of the repository was considered to increase the probability of human error.

B.2.11.4 Options 7 Through 11 and 24 Through 28

These options were considered to be simpler; thus, reducing the probability of human error. On the other hand, mining is planned for two sides simultaneously. This case was to be similar to Option 5 except that the grades are more similar to the base-case grades. The final judgment was to score these options the same as the base case.

B.2.11.5 Options 12 Through 14 and 29 Through 31

This option was similar to Options 5 and 22 except that the split in the waste ramp was in a sloping portion of the ramp rather than on a flat portion.

B.2.11.6 Options 15, 16, 32, and 33

The principle distinctions in these options are the flat grades. These options have longer emplacement rooms than Options 7 through 14 and Options 24 through 31. These options also assume a thicker section of Topopah Spring unit than the other options. This assumption must be confirmed by site characterization.

The argument for higher scores is

The lower grades for the waste mains and emplacement drifts should significantly reduce the probability for a runaway transporter accident.

The arguments for lower scores are

Overall designs are more complicated, and
Split ramp decreases score.

B.2.11.7 Options 17 and 34

This option was considered to be about the same as the base case, although the panel recognized some similarities with Options 7 through 14 and 24 through 31. The final judgment was to score it the same as the base case.

B.2.11.8 Remarks

The panel noted that the identical high scores for all options represented the irreducible risk that cannot be eliminated.

B.2.12 Preclosure Nonradiological Safety: Workers, X_4

The performance measure for nonradiologic safety effects to workers was the

estimated number of fatal accidents among ESF-repository workers.

The preclosure nonradiological safety panel provided judgments of the number of worker fatalities that will occur as a consequence of each of the six paths through the Decision Tree (ESF-AS Report, Volume 2, Section 2, Figure 2-1). These estimates were required for each of the 34 options under consideration. The estimates included fatalities incurred during environmental restoration if the site were abandoned. The number of fatalities was the same for Paths C and D in the ESF-AS Decision Tree. The same number of fatalities were expected whether site abandonment results from lack of license approval (Path C) or unsatisfactory results from late testing (Path D).

B.2.12.1 Assumptions and Basic Data

B.2.12.1.1 Backfilling. The level of effort required to backfill an underground access is estimated to be approximately 50 percent of the level of effort required to construct the access. Thus, for Scenarios D and E, the total worker-hours for construction and backfilling are estimated as follows:

$$LOE_D = LOE_{const} \times 1.5 \quad \text{(B-6)}$$

$$LOE_E = LOE_{const} \times 1.5 \quad \text{(B-7)}$$

where

LOE_D = Level of effort for Scenario D
LOE_E = Level of effort for Scenario E
LOE_{const} = Level of effort for construction.

B.2.12.1.2 Fatality Rates. The Expert Panel for Nonradiologic Safety estimated of fatality rates for drill-and-blast mining and mechanical mining methods (Table B-28).

B.2.12.1.3 Review of Worker-Hours. Estimates of the total man-hours required for the repository operation are subdivided into four phases (Table B-29). The four phases are

- Phase 1: Initial Construction (5 years),
- Phase 2: Emplacement Operations (25 years),
- Phase 3: Caretaker Operations (25 years), and
- Phase 4: Backfill and Closure (12 years).

The estimated worker-hours of effort required to retrieve waste canisters (Table B-30) were required for estimates of fatalities in Scenario B.

TABLE B-28

ESTIMATED FATALITY AND INJURY RATES (PER MILLION WORKER-HRS)

Fatalities		
	Mining Method	
Fractile	Drill & Blast	Mechanical Mining
0.95	0.45	0.4
0.50	0.3	0.25
0.05	0.2	0.2

Non-Fatal Days Lost Injuries		
	Mining Method	
Fractile	Drill & Blast	Mechanical Mining
0.95	35	25
0.50	15	12
0.05	3	3

TABLE B-29

TOTAL WORKER HOURS FOR ALL PHASES OF REPOSITORY LIFE (1,000 HRS)

Options	Initial Construction Phase 1 (5 Years)	Emplacement Operations Phase 2 (25 Years)	Caretaker Operations Phase 3 (25 Years)	Backfill & Closure Phase 4 (12 Years)	Total
1, 18	5,064	35,185	6,547	6,325	53,122
2, 19	5,931	35,546	6,885	6,919	55,281
3, 20	6,166	35,595	6,948	6,932	55,642
4, 21	5,944	35,546	6,885	6,919	55,295
5, 22	5,353	35,047	6,601	6,554	53,550
6, 23	5,730	35,477	6,821	6,910	54,939
7, 24	5,310	33,528	6,456	8,012	53,306
8, 25	5,310	33,528	6,456	8,012	53,307
9, 26	5,310	33,528	6,456	8,012	53,306
10, 27	5,310	33,528	6,456	8,012	53,306
11, 28	5,310	33,528	6,456	8,012	53,306
12, 29	4,244	34,456	6,424	7,937	53,060
13, 30	4,059	34,386	6,355	7,920	52,720
14, 31	3,978	34,138	6,213	7,792	52,122
15, 32	5,040	37,206	7,487	10,082	59,817
16, 33	4,981	38,365	7,904	11,013	62,263
17, 34	5,235	33,874	6,496	7,919	53,523

TABLE B-30

ESTIMATED WORKER HOURS REQUIRED FOR WASTE CANISTER RETRIEVAL (1,000 HRS)

Options	Surface Worker Hours	Underground Worker Hours	Total Expected Worker Hours
1,18	17,817	14,324	32,141
2,19	17,817	14,874	32,691
3,20	17,817	14,930	32,747
4,21	17,817	14,874	32,691
5,22	17,817	14,445	32,262
6,23	17,817	13,444	31,261
7-11,8-28	17,817	14,354	32,171
12,29	17,817	14,305	32,122
13,30	17,817	14,244	32,061
14,31	17,817	14,334	32,151
15,32	17,817	16,049	33,866
16,33	17,817	16,668	34,485
17,34	17,817	14,374	32,191

NOTES: Worker-hour calculations based upon the retrieval costs estimated on 10/18/91.

Estimated range of estimated cost spread ranges from +30 percent higher to -5 percent lower. This is the same spread as the estimated costs.

Surface worker hours include all personnel located above ground except for personnel involved in shaft and/or ramp operation.

Underground worker hours include retrieval personnel, supply/maintenance personnel, as well as personnel required for emplacement drift clean-up, repair, and maintenance. No drilling/blasting operations are expected; however, some drilling and rock bolting will be required.

Retrieval time is 25 years.

The level of effort, expressed in worker-hours, for nonconstruction phases were summarized in Table B-31.

The estimates of worker-hours by mining method (Table B-32) revealed the options that are predominately drill-and-blast methods and those that are predominately mechanically mined.

- Drill-and-Blast Options: Options 1 through 6 and 18 through 23
- Mechanically Mined Options: Options 7 through 17 and 24 through 34

B.2.12.2 Nonmining Fatality Rates

The fatality rate for nonmining work underground is likely to be lower than the fatality rate for miners. Typical nonmining underground work is experiment support at the Nevada Test Site. Retrieval of waste canisters will be nonmining underground work. Estimates of the worker-hours required for waste canister retrieval (Table B-30) suggest little variation in the level of effort among options during the retrieval period. Even if the expected fatality rates for mining activities (Table B-28) were accepted for nonmining activities, the nonmining activities would not discriminate among the options (Table B-33).

The minimum fatality rate for mining activities was adopted as the fatality rate for nonmining phases. The fatality rate for activities other than mining, R_{OT} was judged to be 0.2 fatalities per million worker-hours of nonmining activities.

B.2.12.3 Early Testing vs Late Testing

After reviewing the distinctions between early testing and late testing the breakdown of worker-hours required for underground personnel at the mining face (Table B-34) were considered. The worker-hours required for other activities during early testing and late testing is ten times greater than the mining-face worker-hours. The level of effort (LOE) in worker-hours for early testing, LOE_{ET}, and late testing, LOE_{LT}, were estimated using the assumption that the level of effort (worker-hours) varied in direct proportion to the costs during each testing phase. Thus, the worker-hours for each phase were calculated as follows:

TABLE B-31

RANGES IN HOURS FOR NONCONSTRUCTION PHASES OF REPOSITORY

Phase	Minimum (Million Hours)	Maximum (Million Hours)
Emplacement: Phase 2	33.5	38.0
Caretaker[a]	6.2	7.9
Decommission and Closure[b]	6.3	11.0
Retrieval[c]	13.4	16.6

[a]Caretaker - Maintenance and Replacement of Ground Support.
[b]Decommission - Retrieve Equipment.
[c]Retrieval - No Drill and Blast.

TABLE B-32

ESTIMATED WORKER HOURS IN MINING, PHASES 1 AND 2 (1,000 HRS)

	Phase 1			Phase 2		
Options	Mechanical	Drill & Blast	Total	Mechanical	Drill & Blast	Total
1, 18	608	2,026	2,633	5,630	8,093	13,722
2, 19	830	2,253	3,084	5,687	8,175	13,863
3, 20	863	2,343	3,206	5,695	8,187	13,882
4, 21	832	2,259	3,091	5,687	8,175	13,863
5, 22	749	2,034	2,784	5,607	8,060	13,666
6, 23	802	2,178	2,980	5,676	8,160	13,836
7, 24	2,496	212	2,708	11,064	134	11,198
8, 25	2,496	212	2,708	11,064	134	11,198
9, 26	2,496	212	2,708	11,064	134	11,198
10, 27	2,496	212	2,708	11,064	134	11,198
11, 28	2,496	212	2,708	11,064	134	11,198
12, 29	1,995	170	2,165	11,370	138	11,384
13, 30	1,907	162	2,070	11,347	138	11,485
14, 31	1,870	159	2,029	11,266	137	11,402
15, 32	2,369	202	2,571	12,278	149	12,427
16, 33	2,341	199	2,540	12,660	153	12,814
17, 34	2,461	209	2,670	11,178	135	11,314

TABLE B-33

LEVEL OF EFFORT AND INFERRED FATALITIES DURING THE RETRIEVAL PERIOD

Base Case:	32.1 million worker-hours ⇒ 1 fatality
Minimum:	31.3 million worker-hours ⇒ 0.98 fatality
Maximum:	34.5 million worker-hours ⇒ 1.07 fatalities

TABLE B-34

ESF TESTING FACE WORKER HOURS (1,000 HRS)

Option	End Early Testing	End Late Testing	Predominant Mining Method
1	165	241	Drill-and-Blast
2	252	331	Drill-and-Blast
3	252	301	Drill-and-Blast
4	283	348	Drill-and-Blast
5	297	380	Drill-and-Blast
6	270	344	Drill-and-Blast
7	286	368	Mechanical Mining
8	329	368	Mechanical Mining
9	298	368	Mechanical Mining
10	308	368	Mechanical Mining
11	292	373	Mechanical Mining
12	349	407	Mechanical Mining
13	346	418	Mechanical Mining
14	337	386	Mechanical Mining
15	280	378	Mechanical Mining
16	339	453	Mechanical Mining
17	310	430	Drill-and-Blast
18	134	250	Drill-and-Blast
19	266	340	Drill-and-Blast
20	184	310	Drill-and-Blast
21	255	348	Drill-and-Blast
22	335	392	Drill-and-Blast
23	270	355	Drill-and-Blast
24	299	378	Mechanical Mining
25	225	379	Mechanical Mining
26	243	377	Mechanical Mining
27	236	383	Mechanical Mining
28	279	382	Mechanical Mining
29	343	419	Mechanical Mining
30	279	441	Mechanical Mining
31	337	398	Mechanical Mining
32	239	389	Mechanical Mining
33	340	465	Mechanical Mining
34	274	439	Drill-and-Blast

$$LOE_{ET} = \frac{C_{ET}}{C_T} \times LOE_T \qquad \text{(B-8)}$$

$$LOE_{LT} = LOE_T - LOE_{ET} \qquad \text{(B-9)}$$

where

C_{ET} = cost of early testing (dollars)

C_T = total cost to end of late testing (dollars)

LOE_{ET} = level of effort by underground personnel through the end of early testing (worker-hours)

LOE_{LT} = level of effort by underground personnel from the end of early testing through the end of late testing (worker-hours)

LOE_T = total level of effort by underground personnel through the end of late testing (worker-hours).

B.2.12.4 Fatalities During Backfill Operations

Backfilling safety varies with mining method. The fatality rates used for mining activities (Table B-35) were also applied to the backfilling phase.

B.2.12.5 Formulas for Estimating Fatalities for Each Scenario

The fatalities, F, estimated for each scenario in the Decision Tree (ESF-AS, Report, Volume 2, Section 2, Figure 2-1) are indicated by a subscript. For example, F_A = fatalities estimated for Scenario A.

The estimates of fatalities resulting from each scenario were computed by multiplying the level of effort, LOE, expressed in worker-hours for each activity, by the fatality rate, R, estimated for that activity. The fatalities were calculated based on the estimated statistical fatality rates for the two predominant mining methods under consideration for the ESF-repository (Table B-35). Fatality rates for underground activities that do not involve mining were considered to be lower than the mining fatality rates (Section B.2.11.2).

TABLE B-35

FATALITY RATES FOR ESF-REPOSITORY MINING METHODS AND OTHER UNDERGROUND ACTIVITIES

Activity	Fatality Rate (Fatalities per Worker-Hour)
Drill-and-Blast Mining	$R_{DB} = 3.0 \times 10^{-7}$
Mechanical Mining	$R_{MM} = 2.5 \times 10^{-7}$
Other	$R_{OT} = 2.0 \times 10^{-7}$

B.2.12.5.1 Scenario A, Closure. Scenario A is the decision path that leads to closure of a satisfactorily functioning repository. The total number of fatalities resulting from Scenario A is the sum of fatalities during five time periods.

$$F_A = F_{LT} + F1 + F2 + F3 + F4 \qquad \text{(B-10)}$$

where

F_{LT} = Fatalities at the end of Late Testing

F1 = Fatalities during repository construction, Phase 1

F2 = Fatalities during emplacement of waste, Phase 2

F3 = Fatalities during the caretaker period, Phase 3

F4 = Fatalities during closure, Phase 4.

F_{LT}--The fatalities at the end of late testing is the product of the level of effort to the end of late testing, LOE_{LT}, and the appropriate fatality rate for the mining method used.

$$F_{LT} = LOE_{LT} \times \begin{cases} R_{DB} \text{ Drill and Blast Mining (Options 1 through 6, 18 through 23)} \\ R_{MM} \text{ Mechanical Mining (Options 7 through 17, 24 through 34)} \end{cases} \qquad \text{(B-11)}$$

F1--The fatalities during Phase 1 of the repository are attributable to three types of activities: drill-and-blast mining, mechanical mining, and other activities.

$$\begin{aligned} F1 &= F1_{DB} + F1_{MM} + F1_{OT} \\ &= (LOE1_{DB} \times R_{DB}) + (LOE1_{MM} \times R_{MM}) + (LOE1_{OT} \times R_{OT}) \end{aligned} \qquad \text{(B-12)}$$

where

LOE1 = Level of effort by underground personnel during Phase 1 (worker-hours)

R	=	Fatality rate (fatalities per worker-hour)
DB		Denotes drill-and-blast mining activity
MM		Denotes mechanical mining activity
OT		Denotes other underground activity.

F2--The fatalities during Phase 2 of the repository are attributable to three types of activities: drill-and-blast mining, mechanical mining, and other underground activities.

$$F2 = F2_{DB} + F2_{MM} + F2_{OT}$$
$$= (LOE2_{DB} \times R_{DB}) + (LOE2_{MM} \times R_{MM}) + (LOE2_{OT} \times R_{OT}) \qquad \text{(B-13)}$$

where

LOE2 = Level of effort by underground personnel during Phase 2 (worker-hours).

F3--During the caretaker period, approximately 20 percent of the activities will require a combined usage of drill-and-blast mining and mechanical mining. Approximately 80 percent of the activities will require personnel to work underground at activities other than mining. The fatalities during Phase 3 are therefore calculated as follows:

$$F3 = (0.20)(LOE3)(R_{COMP}) + (0.80)(LOE3)(R_{OT}) \qquad \text{(B-14)}$$

where

LOE3 = Total level of effort by underground personnel during Phase 3 (worker-hours)

R_{COMP} = $R_{DB}LOE2_{DB} + R_{MM}LOE2_{MM}/(LOE2_{DB} + LOE2_{MM})$

= Composite fatality rate based on combined mining activities during Phase 2 (fatalities per man-hour).

F4--During the closure period, the activities will require a combined usage of drill-and-blast mining and mechanical mining. The fatalities are calculated using the total worker-hours estimated for Phase 4 and a composite fatality rate, R_{COMP}, based on the proportions of drill-and-blast and mechanical mining during Phase 2.

$$F4 = LOE4 \times R_{COMP} \tag{B-15}$$

where

LOE4 = Total level of effort by underground personnel during Phase 4 (worker-hours).

B.2.12.5.2 Scenario B, Retrieval. The path to retrieval involves the same periods as Scenario A except for closure. Rather than closing and decommissioning the facility, the waste will be retrieved and the repository will be backfilled and decommissioned.

The formula for the fatalities resulting from Scenario B must therefore include all the fatalities in Scenario A except the fatalities incurred during Closure, F4. Scenario B must account for fatalities during mining activities during retrieval, F5, and backfill, F6.

$$F_B = F_A - F4 + F5 + F6 \tag{B-16}$$

Approximately 20 percent of the retrieval effort will require mining by a combination of mining methods. It was assumed that the proportion of time devoted to each mining method would be the same as the proportion used during the emplacement period. Approximately 80 percent of the effort during retrieval will be nonmining activities. The fatalities during retrieval were therefore calculated as follows:

$$F5 = (0.20)(LOE5)(R_{COMP}) + (0.80)(LOE5)(R_{OT}). \tag{B-17}$$

The level of effort required to backfill the repository after the waste is retrieved was estimated to be approximately 50 percent of the effort required to construct the repository and emplace the waste during Phases 1 and 2. The resulting fatalities would be 50 percent of the fatalities resulting from mining activities during Phases 1 and 2 (See Equations B-12 and B-13).

$$F6 = 0.50 [(F1_{DB} + F2_{DB}) + (F1_{MM} + F2_{MM})] \qquad (B-18)$$

B.2.12.5.3 Scenarios C and D, Abandon After Late Testing

In the event that the ESF is abandoned after late testing, the site will be environmentally restored. The estimated level of effort required to restore the site was estimated to be approximately 50 percent of the effort through the end of late testing. Because of the additional effort required for environmental restoration, the fatalities are estimated to be 50 percent greater than the fatalities at the end of late testing, F_{LT} (See Equation B-11).

$$F_C = F_D = 1.5 \times F_{LT} \qquad (B-19)$$

B.2.12.5.4 Scenario E, Abandon After Early Testing

In the event that the ESF is abandoned after early testing, the site will be environmentally restored. The estimated level of effort required to restore the site was estimated to be approximately 50 percent of the effort through the end of early testing.

$$F_E = 1.5 \times LOE_{ET} \times \begin{cases} R_{DB} & \text{Drill and Blast Mining (Option 1-6, 18-23)} \\ R_{MM} & \text{Mechanical Mining (Options 7-17, 24-34)} \end{cases} \qquad (B-20)$$

B.2.12.5.5 Scenario F, Abandon Because of Programmatic Viability

No fatalities will result from the ESF-repository if the program viability is poor, and construction does not begin.

B.2.12.5.6 Fatality Estimates

The panel provided judgments for three fractiles for the number of fatalities that could be expected to result from each option.

The best estimates of numbers of fatalities (Table B-36), based on the best judgments of fatality rates (Table B-35) and the worker-hours estimated for the ESF-AS Decision Tree Scenarios A through E, were calculated using the algorithms described in Section B.2.12.5. The estimates for the 0.05 fractile and the 0.95 fractile result from the

TABLE B-36

FATALITY ESTIMATES: BEST JUDGMENT (0.50 FRACTILE)

Option	Scenario A (Closure)	Scenario B (Retrieval)	Scenario C, D (LT Abandon)	Scenario E (ET Abandon)
31	12.33	15.08	1.14	0.97
14	12.34	15.09	1.16	1.02
30	12.55	15.26	1.27	0.80
13	12.56	15.27	1.28	1.06
26	12.58	15.34	1.11	0.72
24	12.58	15.34	1.11	0.88
25	12.59	15.34	1.11	0.66
27	12.59	15.34	1.11	0.68
9	12.60	15.35	1.13	0.92
7	12.60	15.35	1.13	0.88
10	12.60	15.35	1.13	0.95
28	12.60	15.35	1.13	0.83
8	12.60	15.36	1.13	1.01
11	12.61	15.37	1.15	0.90
34	12.67	15.46	1.17	0.73
17	12.69	15.48	1.20	0.86
29	12.73	15.47	1.13	0.93
12	12.75	15.48	1.15	0.99
18	13.19	16.81	0.95	0.51
1	13.20	16.83	0.97	0.67
22	13.54	17.13	1.31	1.12
5	13.55	17.15	1.34	1.04
23	13.85	17.18	1.27	0.97
20	13.85	17.54	1.02	0.61
19	13.87	17.52	1.17	0.92
3	13.87	17.55	1.04	0.87
6	13.87	17.20	1.30	1.02
2	13.88	17.54	1.19	0.91
21	13.97	17.63	1.32	0.97
4	13.98	17.64	1.34	1.09
32	14.13	16.86	1.22	0.73
15	14.15	16.87	1.24	0.92
33	14.66	17.33	1.18	0.86
16	14.67	17.34	1.20	0.90

corresponding fractiles for the number of worker-hours in the various phases of the preclosure period (Tables B-37 and B-38).

Analysis of the fatality estimates should consider that the fatality rate assumptions (Table B-35) were based on relatively few mining accidents in the United States in the last 25 years. One mining accident may account for a majority of the mining accident fatalities in the statistics used to determine the fatality rates. However, the estimates by the expert panel indicated that the fatalities resulting from the ESF-repository are likely to be low enough that statistical variation is not likely to significantly impact the selection of an ESF-repository option.

Another factor that must be considered in analyzing the fatality estimates is the fact that most underground accidents are catastrophic. The most dangerous accidents, for example, fires and rock falls, are localized. Three approaches have been used to analyze events such as mining accidents.

- Examine a range of risk factors (sensitivity analysis).
- Examine accident models. Binomial models are useful for cases when accidents affect only one or two people.
- Use professional judgment.

The panel chose to use the third approach and judged the estimates in Tables B-37 and B-38 to be reasonable.

B.2.13 Preclosure Environmental Impacts: Aesthetics, X_5

The Expert Panel on Aesthetic Properties provided judgments on the aesthetic impact of the ESF-repository options on the Yucca Mountain site.

The panel reviewed the influence diagram developed for the objective of minimizing degradation of aesthetic impacts to the environment (Figure B-17). Since Amargosa Valley is 20 miles distant from the Yucca Mountain site, the influence of the *Amargosa Valley community location* (18) is less important than the influence of *roads and rest*

TABLE B-37

FATALITY ESTIMATES: HIGH VALUES (0.95 FRACTILE)

Option	Scenario A (Closure)	Scenario B (Retrieval)	Scenario C, D (LT Abandon)	Scenario E (ET Abandon)
1	20.71	26.07	1.18	0.81
2	22.09	27.52	1.45	1.10
3	22.10	27.58	1.26	1.06
4	22.21	27.65	1.63	1.32
5	21.51	26.88	1.62	1.26
6	22.04	27.01	1.57	1.23
7	20.04	23.86	1.37	1.06
8	20.04	23.87	1.37	1.23
9	20.03	23.86	1.37	1.11
10	20.04	23.86	1.37	1.14
11	20.05	23.88	1.39	1.09
12	20.51	24.38	1.39	1.19
13	20.23	24.06	1.55	1.28
14	19.92	23.81	1.41	1.23
15	22.62	26.07	1.50	1.12
16	23.54	26.81	1.45	1.08
17	20.44	24.40	1.45	1.04
18	20.69	26.05	1.15	0.62
19	22.07	27.50	1.42	1.11
20	22.08	27.57	1.24	0.73
21	22.19	27.63	1.60	1.17
22	21.49	26.87	1.59	1.36
23	22.02	26.98	1.54	1.17
24	20.02	23.85	1.34	1.06
25	20.02	23.85	1.34	0.80
26	20.02	23.85	1.34	0.87
27	20.02	23.85	1.34	0.83
28	20.04	23.87	1.37	1.00
29	20.49	24.36	1.37	1.12
30	20.22	24.06	1.54	0.97
31	19.90	23.80	1.39	1.17
32	22.60	26.06	1.48	0.88
33	23.53	26.79	1.43	1.04
34	20.42	24.38	1.42	0.89

TABLE B-38

FATALITY ESTIMATES: LOW VALUES (0.05 FRACTILE)

Option	Scenario A (Closure)	Scenario B (Retrieval)	Scenario C, D (LT Abandon)	Scenario E (ET Abandon)
1	10.31	13.17	0.93	0.64
2	10.63	13.46	1.15	0.87
3	10.60	13.45	1.00	0.84
4	10.73	13.56	1.29	1.05
5	10.41	13.19	1.28	1.00
6	10.64	13.21	1.25	0.98
7	10.23	12.45	1.08	0.84
8	10.23	12.45	1.09	0.97
9	10.23	12.45	1.08	0.88
10	10.23	12.45	1.09	0.91
11	10.24	12.46	1.11	0.87
12	10.16	12.31	1.11	0.95
13	10.01	12.14	1.23	1.02
14	9.83	11.99	1.12	0.98
15	11.50	13.80	1.19	0.88
16	11.91	14.18	1.15	0.86
17	10.10	12.29	1.15	0.83
18	10.30	13.15	0.91	0.49
19	10.62	13.45	1.12	0.88
20	10.59	13.44	0.98	0.58
21	10.72	13.55	1.27	0.93
22	10.40	13.18	1.26	1.08
23	10.62	13.19	1.22	0.93
24	10.22	12.43	1.07	0.84
25	10.22	12.44	1.07	0.63
26	10.22	12.43	1.07	0.69
27	10.22	12.44	1.07	0.66
28	10.23	12.45	1.09	0.79
29	10.15	12.29	1.09	0.89
30	10.00	12.13	1.22	0.77
31	9.82	11.97	1.10	0.93
32	11.49	13.78	1.17	0.70
33	11.90	14.17	1.13	0.83
34	10.08	12.28	1.13	0.70

stops (17) on the *location of impact relative to vantage points on the ground* (5). The most important road vantage points among those listed on the influence diagram are the vantage points along U.S. Highway 95 (20).

The performance-measure scale for visual impacts (Table B-5) was used to score all options. The panel provided three judgments of the visual impact scores. The judgments correspond to level of confidence in the estimated visual impact.

The options were scored by determining whether major, intermediate, or minor visual impacts were visible from one or both of the vantage points along U.S. Highway 95. One of the vantage points was at the picnic ground at Amargosa Valley. The other vantage point was at a location where a viewer might see representative visual impacts from the surface facilities at the ESF-repository.

Tabulation of the scores (Table B-39) indicates that the scores were nearly bimodally distributed. The designs scored either close to eight or close to one. The panel judged that the possible variance in scores for each option would be small (usually less than one point). The potential for a slight increase to a higher score resulted from consideration of the possibility of routing roads or constructing surface facilities so they were not visible.

B.2.14 Preclosure Environmental Impacts: Historical Properties, X_6

The Expert Panel on Archaeological and Historical Properties provided expert judgments of the consequences of the ESF-repository on the historical properties at the Yucca Mountain site.

The performance measure for historical properties is the weighted areal extent of historical properties sites within the area of an ESF-repository site.

$$X_6 = \sum_{i=1}^{N} \text{Area}_i \times F_i \qquad \text{(B-21)}$$

TABLE B-39

VISUAL IMPACT SCORES

ESF-Repository Option	Fractile		
	0.95	0.50	0.05
1, 18	9	8	8
2, 19	9	8	8
3, 20	9	8	8
4, 21	9	8	8
6, 23	9	8	8
7-11, 24-28	9	8	8
15, 32	9	8	8
5, 22	1	0.5	0
12, 29	1	0.5	0
13, 30	1	1	0.5
14, 31	1	1	0.5
16, 33	1	0.5	0
17, 32	1	1	0.5

where

N = Total number of historical properties sites within the ESF-repository boundaries that are not common to all ESF-repository sites

Area = Areal extent of site i

$$F_i = \begin{cases} 5 \text{ if the } i^{th} \text{ site is subsurface} \\ 1 \text{ if the } i^{th} \text{ site is surface only.} \end{cases}$$

The areal extent of the historical properties site is more precisely defined as the areal extent of artifacts identified (area of minimum convex encompassing surface) where the definition of the historical properties site is based on judgment. The historical properties sites have been identified and were established at the time of the ESF-AS.

Scoring of each option with respect to the performance measure for historical properties was completed by compiling the areal extent of each historical property and determining the multiplier for the subsurface extent of the historical property site. The area of each historical site encompassed by the area of each option and the factor for each site indicating whether the site is subsurface was compiled and the multiplication of the two factors for each site represented the 0.50 fractile for each site.

The scoring of 17 of the options was completed on May 24, 1990 (See Appendix D.9). The options were rescored after the number of options was doubled from 17 to 34 to accommodate two scenarios for the Characterization Testing Program. The revised scores were transmitted for implementation in the decision methodology by the Expert Panel on Historical Properties (Appendix D.9).

B.2.15 <u>Preclosure Direct and Indirect (Schedule) Cost Impacts, X_7 and X_8</u>

The Decision Tree (ESF-AS Report, Volume 2, Section 2, Figure 2-1) required the cumulative costs at the termination of the paths (scenarios) labeled A through F on the ESF-AS Decision Tree. Estimated costs of the consequences of each option along each path were developed by the Design and Testing Support Group. The Expert Panel on

Cost and Schedule provided guidance to the Design and Testing Support Group by reviewing the bases for cost estimates. The bases for the costs of important factors in the influence diagram for direct costs and indirect (scheduling) costs were especially considered by the panel. In addition to reviewing data provided by the Design and Testing Support Group (included in documents referenced in Appendix D.11), the panel reviewed several specific aspects of the costing basis and factor in the influence diagrams.

B.2.15.1 Discounting

Costs were estimated in constant (1989) dollars. The estimates were discounted to accomplish the objective of giving more weight to near-term expenditures than to long-term expenditures. The panel was more concerned with the representativeness of the cost estimates than the precision of the estimates. That is, the estimates need to be realistic estimates of the ESF and repository costs but estimates to the nearest million dollars were sufficient.

B.2.15.2 Cash Flow Assumptions

Cash flow estimates for the options were based on the assumption that the start date of March 1991 for the ESF is constant for all options. The length of time for ESF testing varies from option to option but in all cases, License Application Design (LAD) begins approximately 30 months before the end of ESF testing and a 3-year period for NRC approval follows ESF testing.

For the purposes of the ESF-AS, the end of ESF testing coincides with the license application submittal date.

Repository engineering costs included:

- LAD,
- Title II Design,
- Construction, and
- Final Procurement and Construction Design (FPCD).

The FPCD, physical construction, and certain other activities after the completion of ESF testing were assumed to require fixed periods of time that are the same for all options.

During a formal panel meeting, the expert panel reviewed the preliminary cash flow estimates for the base case (Option 1) as well as the estimates of annualized costs for repository operations and the repository engineering costs.

B.2.15.3 Probabilistic Judgments

Probabilistic judgments were used in the cost-estimating process. Three estimates are required: (1) a high estimate, (2) a best estimate, and (3) a low estimate. These three estimates correspond to fractiles.

B.2.15.4 Major Influences on Cost

The panel focused attention on the major factors that were reflected in the influence diagrams for the total system life cycle costs (Figures B-20, B-21, and B-22) and the indirect costs (Figures B-23 and B-24) caused by scheduling delays. The panel did not think that the waste emplacement schedules differed sufficiently among options to allow this factor to discriminate among options. Emplacement takes place during the repository operation period. During this time, the discounted costs are so small that the different schedules have minimal impact on the cost consequences of the option.

The panel considered adding Calico Hills testing to the influence diagram for ESF costs (Figure B-21). However, because Calico Hills testing is included in the influence diagrams for schedule (Figures B-23 and B-24), the panel agreed that Factor 7, *Environmental Monitoring Reconfiguration*, does not represent a significant factor compared with the other factors contributing to Factor 4, the *ESF Construction Start Date*.

B.2.15.5 Environmental Restoration Costs

The high, best, and low estimates of cost for environmental restoration were calculated as

$$C_R = \begin{Bmatrix} 35\% \\ 20\% \\ 10\% \end{Bmatrix} \times C_{ET}$$

where

C_R = Restoration cost

C_{ET} = Total cost through the end of Early Testing.

The estimated time required for environmental restoration was judged to be 70 percent of the construction time.

The environmental restoration for Scenario D will consist of filling shafts with mine muck and restoring surface. Assume the costs for restoration under Scenario C are the same as for Scenario D. Some mobilization costs will be incurred and they may be significant.

B.2.15.6 Environmental Monitoring System

All options except the base case will require modification of the airflow environmental monitoring system. There will be no discrimination among the other options. The base case will have less cost than the other options.

B.2.15.7 Retrieval

The cost estimators will assume the decision to retrieve will be made at the end of the caretaker period, the third of four basic periods between start of construction and end of retrieval.

B.2.15.8 Mining Methods

The ESF-repository options incorporate several excavation methods for the accesses to the ESF and the underground drifts in the repository. The panel reviewed and summarized the excavation methods for the ESF. Shafts and ramps will be excavated for access to the ESF.

- Shaft Excavation Methods (excavated diameter = 18 feet)

  - Shaft Boring Machine
  - V-Mole Boring Machine
  - Blind Boring Machine
  - Raise Bore Mining (Internal shafts excavated by raise bore mining will have an excavated diameter of 9 feet)
  - Drill-and-Blast Mining (Some shafts will be excavated to a diameter of 14 feet)

- Ramp Excavation Methods

  - From Surface (excavated diameter = 25 feet)

    * Tunnel Boring Machine (TBM)

  - From Underground (excavated diameter = 18 feet)

    * Drill and Blast in combination with Road Header
    * Tunnel Boring Machine

Underground drift construction will utilize mining methods as follows:

- Topopah Spring

  - Exploratory Drifting

    * Drill and Blast (14 x 16 feet)
    * Mobile Miner (12 x 24 feet)
    * Tunnel Boring Machine (18 x 25 feet)

  - Main Test Level

    * Drill and Blast (14 x 16 feet to 25 x 19 feet)
    * Mobile Miner (12 x 24 feet)

- Calico Hills
  - Exploratory Drifting
    - * Tunnel Boring Machine (excavated diameter = 18 feet)
    - * Road Header (10 feet high by 16 feet wide)

B.2.15.9 <u>Mining Advance Rates</u>

The mining advance rates for the ESF construction (Table B-40) and for repository construction (Table B-41) were summarized for consideration by the panel.

B.2.15.10 <u>Work Schedule</u>

The ESF schedule estimates assumed a 7-day work week, three shifts per day. The cost basis for the labor rates were tied to Nevada Test Site (NTS) rates.

B.2.15.11 <u>Contingencies</u>

Contingency allowances ranged from 15 to 45 percent. The lowest contingencies were used for Options 2 through 6 and 19 through 23. The highest contingencies were used for Options 15, 16, 32, and 33. Options 7 through 14 and 24 through 31 were assigned intermediate contingencies. The contingencies cover the potential increase in costs required by

- Increasing the QA levels from QA Level 2 to QA Level 1.

- Construction, for example, allowances for tunnel boring machines operating on a downhill grade.

No schedule contingency is included in the estimates. The Design and Testing Support Group considered 25 percent to be a reasonable contingency for schedule uncertainties. The project could miss the schedule by as much as 2 years. Options 16, 17, 33, and 34 could delay the project more than 2 years.

TABLE B-40

ADVANCE RATES FOR ESF CONSTRUCTION TECHNIQUES

Technique	Duration[a] (Days)	Basis of Estimate	Advance Rate Feet/Day
Raise Bore	186	Nevada Test Site Data	14
Drill and Blast	221	Title II Design Data	Not provided
V-Mole	207	Data From Manufacturer	21[b]
Double Blind Bore	190	Data From Manufacturer	40
Shaft Bore[c]	218	Data From Drilling Specialist	16

[a]Duration calculated for 16-foot-diameter access at 1,185 feet depth.
[b]In rock having uniaxial compression strength of 200 MPa.
[c]Blind bore with surface based machine = large oil field drill.

TABLE B-41

ASSUMED ADVANCE RATES FOR REPOSITORY CONSTRUCTION TECHNIQUES

Technique	Application	Advance Rate (Feet/Day)
TBM	Ramps and Drifts[a]	37
Mobile Miner	Materials and Exploration Drifting in TS	14
Road Header	Ramps to CH CH Drifting	24
Drill and Blast	All Accesses	8 to 20

Mechanical mining methods have the highest uncertainty. Drill-and-blast methods have the lowest uncertainty. The mining industry has more experience with drill-and-blast technology.

The panel provided the following comments regarding the contingencies.

- The schedule is optimistic and "success oriented." Some schedule items have been omitted.

- The costs are probably high (conservative).

- As long as the basis was consistent for all options, the estimates are valid for comparing options.

An elicitation of the panel's confidence in the shaft-sinking schedule revealed the following judgments:

- Drill-and-Blast --- moderately high confidence,
- V-Mole --- low confidence,
- Blind Boring Machine --- low confidence,
- Surface-Based Boring Machine --- high confidence, and
- Raise Bore --- very high confidence.

The advance rates shown in Tables B-40 and B-41 do not include time for testing. The first entry science-shaft in the base case requires 415 days of constant excavation advance and 512 days are scheduled for testing. The test program impacts schedule components corresponding to the locations of testing. The testing locations are

- Accesses,
- Exploratory Drifting,
- MTL, and
- Calico Hills.

The philosophy in designing the base case (Option 1) was to test only one access. The philosophy changed when the alternative options were designed. The emphasis shifted from the Topopah Spring to the Calico Hills. This caused the test program to change and schedule changes accommodated the test program. Underground testing durations during access construction (including construction support) impact the tests only if the tests are conducted in the accesses. Options 1 through 17 and Options 18 through 34 represent two scenarios. The impact of testing on the schedule is different with each scenario.

B.2.15.11.1 Scenario 1, Options 1 Through 17

The scenario is two accesses with replicated testing. The testing durations are

- 512 days to the MTL, and
- 703 days to the Calico Hills Unit.

B.2.15.11.2 Scenario 2, Options 18 Through 34

The scenario is one primary science access; nominal replication of testing. The testing durations are

- 200 days to the MTL, and
- 288 days to the Calico Hills Unit.

B.2.15.12 Repository Cost Basis

Tunnel boring machines will be used for ramp construction and drift construction in some of the options. The estimated advance rate is 55 feet per day (three shifts per day). This estimate is provided by PBQ&D and was considered more realistic than the manufacturer's estimates of 25 meters per day. PBQ&D provided data for advance rates for tunnel boring machines in a variety of projects that support the advance rate of 55 feet per day. There seems to be no sensitivity of the advance rate to the tunnel diameter.

B.2.15.13 Contingencies for Repository Construction

Contingencies will be included in the estimates of the repository schedule. The repository contingencies range from 20 to 40 percent. The panel agreed that the approach to estimating contingencies was reasonable. There was little rationale for second-guessing the technical support groups. Schedules are difficult to estimate when prototype equipment is involved; however, the approach is as good as any approach can be. The cost will probably not vary much. The schedule is most vulnerable to variation. There is little cause for confidence in the schedule. The uncertainties in the schedule will cause uncertainties in the indirect costs.

The panel reviewed the schedules for Options 8 and 25. Schedule delays in these options result from raise boring. Mining must proceed to the bottom of the shaft in order to upream for the boring to begin.

B.2.15.14 Summary

After reviewing several aspects of the assumptions and bases used for cost estimates, the expert panel agreed with the assumptions that are being used.

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APPENDIX C

DETAILS OF THE ESF-AS DECISION TREE AGGREGATION FUNCTION

APPENDIX C

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APPENDIX C

DETAILS OF THE ESF-AS DECISION TREE AGGREGATION FUNCTION

C.1 Introduction

This appendix describes the data and calculations that are required to determine the expected net benefit ENB for each of the 34 ESF-repository options. Figure 2-1, (Section 2) the ESF-AS Decision Tree, shows that there are six scenarios, labeled A through F, for each of the 34 options. Every scenario has a probability that it will occur, P_A[1] through P_F respectively; an equivalent economic benefit associated with each scenario, V_A through V_F; and an economic benefit, EB_A through EB_F, which is the product of the equivalent economic benefit of the scenario and the probability of the scenario. The equivalent economic benefit of each scenario is the aggregation of the consequences, scaling functions, and weights in the multiattribute utility function. The description of each scenario as well as the inputs and calculations for the probabilities, values, and expected values are described in the following sections.

C.2 ESF-AS Decision Tree Scenarios

Figure 2-1 (Section 2) shows that there are six possible scenarios for the ESF-AS Decision Tree. Scenario A represents a closed repository, Scenario B represents a repository where the waste is retrieved, and Scenarios C through F represent four different outcomes in which the repository is abandoned before it is constructed. Each scenario is briefly described in the following paragraphs.

Scenario A represents a closed repository because this option has maintained a viable program prior to testing (this near-term success is called programmatic viability elsewhere in this appendix), it is found to be "OK"[2] after both early and late testing, it is approved by all responsible parties, it is constructed and operated, and is successfully closed. The probability of this scenario is P_A, the equivalent economic benefit is V_A, and the expected benefit is EB_A.

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[1]P_X is an abbreviated notation for P(X), the probability of Event X.

[2]The quotation marks are used to distinguish the outcome of testing (quotes) from reality (no quotes).

Scenario B represents a constructed repository from which the waste is retrieved for some reason(s), even though the option has maintained a viable program, early and late testing indicate that the site is "OK", it is approved by all responsible parties, and it is constructed and operated. The probability of this scenario is P_B, the equivalent economic benefit is V_B, and the expected benefit is EB_B.

Scenario C represents an abandonment of the repository before construction and operation because it is not approved by the responsible parties, even though the option has maintained a viable program and both early and late testing indicate the site is "OK". The probability of this scenario is P_C, the equivalent economic benefit is V_C, and the expected benefit is EB_C.

Scenario D represents an abandonment of the repository after late testing because it is found to be "NOT OK" as a result of the late testing, even though the option has maintained a viable program and it is found to be "OK" after early testing. The probability of this scenario is P_D, the equivalent economic benefit is V_D, and the expected benefit is EB_D.

Scenario E represents an abandonment of the repository after early testing because it is found to be "NOT OK" as a result of the early testing, even though the option has maintained a viable program. The probability of this scenario is P_E, the equivalent economic benefit is V_E, and the expected benefit is EB_E.

Scenario F represents an abandonment of the repository in the near-term because the option has failed to maintain a viable program. The probability of this scenario is P_F, the equivalent economic benefit is V_F, and the expected benefit is EB_F.

C.3 Probabilities for the Scenarios

Each Scenario A through F shown in Section 2, Figure 2-1, the ESF-AS Decision Tree, has a probability associated with it, P_A through P_F, respectively. The probabilities for each scenario are calculated as the product of the probabilities along each path of the ESF-AS Decision Tree. There are five nodes in the ESF-AS Decision Tree, and therefore, five associated probabilities that are used to calculate P_A through P_F for each ESF Option. Three of these probabilities were assessed directly from expert panels; the two testing probabilities were calculated through an application of Baye's Theorem. The five probabilities that were used to calculate P_A through P_F are described in the following paragraphs.

1. The probability associated with the first node from the left in the ESF-AS Decision Tree is P_{VIAB}, the probability of programmatic viability; that is, the probability that the option will maintain near-term success. This probability was evaluated for each ESF-repository option by the Management Panel Group.

2. The probability associated with the second node in the ESF-AS Decision Tree is P("OK-ET"), the probability that the site is found to be "OK" at the end of the Early Test Program. This probability was calculated for each ESF Option based on probabilities estimated by the Expert Panels on Characterization Testing and Postclosure Health. The probabilities estimated by the Expert Panels on Characterization Testing and Postclosure Health and the function used to calculate P("OK-ET") are described in a following section regarding the ESF-AS Nature's Tree, which is shown in Section 2, Figure 2-2.

3. The probability associated with the third node in the ESF-AS Decision Tree is P("OK-LT"), the probability that the site is found to be "OK" at the end of the Late Test Program. This probability was calculated for each ESF-repository option based on probabilities estimated by the Expert Panels on Characterization Testing and Postclosure Health. These estimated probabilities and the function used to calculate P("OK-LT") are described in the following section regarding ESF-AS Nature's Tree.

4. The probability associated with the fourth node in the ESF-AS Decision Tree is P_{APP}, the probability that the repository will receive approval from all responsible parties. The complement of this probability, P_{APP}, the probability of disapproval, was evaluated for each ESF-repository option by the Expert Panel on Regulatory Considerations.

5. The probability associated with the fifth node in the ESF-AS Decision Tree is P_{CLO}, the probability that the repository will receive all the waste and will be successfully closed. The complementary probability, P_{RET}, the probability of retrieval, was evaluated for each ESF-repository option by the Expert Panel on Regulatory Considerations.

For each of the five nodes and probabilities described above, there is a complementary probability that the other possible outcome at the node will occur. That is, there are probabilities that there will not be near-term success, that the site will be found to be "NOT OK" after early testing, that the site will be found to be "NOT OK" after late testing, that the site will not gain approval, and that the repository will not be closed, but the waste will be retrieved. For each of the nodes, the complementary probability is always 1 minus the probability described for the node in the paragraphs above. For example, for the fifth node, the probability of retrieval is equal to $1\text{-}P_{CLO}$.

C.3.1 ESF-AS Nature's Tree

Of the five probabilities described above, three were estimated by expert panels, but the other two probabilities, P("OK-ET") and P("OK-LT"), are calculated from other probabilities shown on the ESF-AS Nature's Tree (Section 2, Figure 2-2) by applying Baye's Theorem. The ESF-AS Nature's Tree represents the six possible results of the testing program, based on the true condition of the site and the findings of the early and late testing programs.

The convention for expressing states and probabilities on trees is as follows. State descriptions for each node are placed on the top side of the branch emanating from that node. The probability associated with a given state is placed directly beneath the respective branch. Five probabilities are used to calculate the path probabilities for Nature's Tree. These five probabilities are P_{OK}, P_{EFP}, P_{LFP}, P_{EFN}, and P_{LFN}, which are briefly described in the following paragraphs. P_{OK} was estimated by the Expert Panel on Postclosure Health and P_{EFP}, P_{LFP}, P_{EFN}, and P_{LFN} were estimated by the Expert Panel on Characterization Testing.

1. P_{OK} is the probability that the site is OK (see Section B.1.6.1). The probability that the site is not OK is $1\text{-}P_{OK}$.

2. P_{EFP} is the probability that the site is found to be "OK" at the end of early testing even though the site is NOT OK. In this study, this is called the probability of an early false positive. The probability that the site will be found to be "NOT OK" at the end of early testing given that the site truly is NOT OK is $1\text{-}P_{EFP}$.

3. P_{LFP} is the probability that the site is found to be "OK" at the end of late testing, given that the site was found to be "OK" after Early testing and that the site is not OK. This is the probability of a late false positive. The probability that the site will be found to be not "OK" at the end of late testing given that the site was found to be "OK" after early testing and that the site is NOT OK is $1-P_{LFP}$.

4. P_{EFN} is the probability that the site is found to be not "OK" at the end of early testing even though the site is OK. This is the probability of an early false negative. The probability that the site will be found to be "OK" at the end of early testing given that the site is OK is $1-P_{EFN}$.

5. P_{LFN} is the probability that the site is found to be not "OK" at the end of late testing, given that the site was found to be "OK" after early testing and that the site is OK. This is the probability of a late false negative. The probability that the site will be found to be "OK" at the end of late testing given that the site was found to be "OK" after early testing and that the site is OK is $1-P_{LFN}$.

The probability of any complete path through Nature's Tree is calculated by multiplying the probabilities of the states along that path. For example, for the topmost path in Nature's Tree, the states are the following: the site is OK, the site is found to be "OK" at the end of early testing, and the site is found to be "OK" at the end of late testing. The probability for this complete path through Nature's Tree is then $P_{OK}(1-P_{EFN})(1-P_{LFN})$, as is shown in the column of path probabilities in Section 2, Figure 2-2.

The probabilities in the Nature's Tree are used to calculate two probabilities that are used in the ESF-AS Decision Tree shown in Section 2, Figure 2-1. These two probabilities are P("OK-ET"), the probability that the site is found to be "OK" at the end of early testing, and P("OK-LT"), the probability that the site is found to be "OK" at the end of late testing. P("OK-LT") and P("OK-ET") result from a direct application of Baye's Theorem to the probabilities in the ESF-AS Nature's Tree.

C.3.2 P("OK-ET")

This is the probability that the site is found to be "OK" at the end of early testing, regardless of whether the site is OK or not OK. Thus, P("OK-ET") is the probability that the site is OK and the site is found to be "OK" after early testing, plus the probability that the site is not OK but the site is found to be "OK" after early testing. That is,

$$P(\text{"OK - ET"}) = P_{OK}(1 - P_{EFN}) + (1 - P_{OK})\,P_{EFP}.$$

C.3.3 P("OK-LT" | "OK-ET")

P("OK-LT") is the probability that the site is found to be "OK" at the end of late testing, given that the results of early testing indicated the site was "OK." As Nature's Tree shows, the only way possible for the site to be found "OK" at the end of late testing is for the site to have also been found to be "OK" at the end of early testing, regardless of whether the site is OK or NOT OK. Without knowledge from the early tests, the probability that the site is found to be OK at the end of late testing is

$$P_{OK}(1 - P_{EFN})(1 - P_{LFN}) + (1 - P_{OK})P_{EFP}P_{LFP}.$$

However, for this study, because it is known that the site can be found to be "OK" at the end of the late tests only after it has been found to be "OK" at the end of the early tests, then P("OK-LT" | "OK-ET") is

$$\frac{P_{OK}(1 - P_{EFN})(1 - P_{LFN}) + (1 - P_{OK})P_{EFP}P_{LFP}}{P_{OK}(1 - P_{EFN}) + (1 - P_{OK})P_{EFP}}$$

C.3.4 ESF-AS Decision Tree Path Probabilities

To calculate the probabilities of the paths through the ESF-AS Decision Tree (Section 2, Figure 2-1), the values of P_{VIAB}, P_{APP}, and P_{CLO}, as estimated by the appropriate panels, and the values of P("OK-ET") and P("OK-LT" | "OK-ET"), as calculated above, are used. The probabilities that apply for a scenario are determined by examination of the ESF-AS Decision Tree and are given in the following section.

P_A, the probability of path A, can be expressed as

$$P_A = P_{VIAB}\,P(\text{"OK-ET"})\,P(\text{"OK-LT"} \mid \text{"OK-ET"})\,P_{APP}\,P_{CLO}.$$

P_B, the probability of path B, can be expressed as

$$P_B = P_{VIAB}\, P(\text{"OK-ET"})\, P(\text{"OK-LT"} \mid \text{"OK-ET"})\, P_{APP}\, (1-P_{CLO})$$

P_C, the probability of path C, can be expressed as

$$P_C = P_{VIAB}\, P(\text{"OK-ET"})\, P(\text{"OK-LT"} \mid \text{"OK-ET"})\, (1-P_{APP})$$

P_D, the probability of path D, can be expressed as

$$P_D = P_{VIAB}\, P(\text{"OK-ET"})\, (1-P(\text{"OK-LT"} \mid \text{"OK-ET"}))$$

P_E, the probability of path E, can be expressed as

$$P_E = P_{VIAB}\, (1-P(\text{"OK-ET"}))$$

P_F, the probability of path F, can be expressed as

$$P_F = (1-P_{VIAB})$$

C.4 Values for the Multiattribute Utility Function

Each of the six scenarios, A through F, shown on the ESF-AS Decision Tree (Section 2, Figure 2-1), has an equivalent economic benefit associated with it that can be calculated from variables that are called performance measures. For this project, nine performance measures, X_1 through X_8 plus B, were identified and the value of each measure for each ESF Option was estimated or calculated. The nine performance measures do not all have a common set of units (for example, one measure is scaled in deaths and another in dollars); therefore, scaling factors, k_1 through k_8, were developed by the Management Panel Group to allow the values of the performance measures to be combined and expressed in a common unit, which for this study, has been chosen to be dollars. The performance measure B, the benefit of a closed repository, is already expressed in dollars and, therefore, did not require a scaling factor. The eight performance measures and their associated scaling factors are briefly described in the following section and are described in detail in the accompanying report.

C.4.1 Performance Measure 1, X_1, and Scaling Factor 1, k_1

Performance Measure 1, X_1, is the fraction of the EPA standard for radionuclide release, as presently specified in 40 CFR 191, that would be released from the repository and is applicable only to Scenario A. The Expert Panel on Postclosure Health made the estimates of releases for any aqueous releases and also carbon-14 gas phase releases. Scaling Factor 1, k_1, is \$3.5 billion per 100 percent of the EPA standard for radionuclide releases. Thus, a repository that releases 2 percent of the EPA standard would produce a cost of \$70 million.

C.4.2 Performance Measure 2, X_2, and Scaling Factor 2, k_2

Performance Measure 2, X_2, relates to the radiological health of the repository workers and is the amount of person-rems that the workers would receive. This performance measure applies to both Scenario A and Scenario B. Scaling Factor 2, k_2, is \$4,000 per person-rem. Thus, an exposure equivalent to one person-rem represents a cost of \$4,000.

C.4.3 Performance Measure 3, X_3, and Scaling Factor 3, k_3

Performance Measure 3, X_3, relates to the radiological health of the public and is the amount of person-rems that the public would receive. This performance measure also applies to both Scenario A and Scenario B. Scaling Factor 3, k_3, is also \$4,000 per person-rem.

C.4.4 Performance Measure 4, X_4, and Scaling Factor 4, k_4

Performance Measure 4, X_4, is the non-radiological safety of the workers at the repository who will work underground. The unit of the measure is the number of deaths that would occur. This performance measure applies to Scenarios A through E, but the number of deaths is not constant per scenario. More fatalities are expected for Scenario B when the waste is emplaced, then retrieved. Fewer fatalities are expected for Scenario E. Scaling Factor 4, k_4, is \$1.25 million per death. Thus, a non-radiological worker death represents a cost of \$1.25 million.

C.4.5 Performance Measure 5, X_5, and Scaling Factor 5, k_5

Performance Measure 5, X_5, measures the aesthetic visual impact of the repository using a constructed scale developed for this study that ranges from 0 to 12. Unlike the other performance measures, the single attribute function for aesthetic impacts is not linear. The single attribute utility function elicited from the DOE and SNL Management Panel Group converts a score from the constructed scale to a utility that ranges from 0 to 100. Scaling Factor 5, k_5, is $4 million per 100 percent of the range of the utility function.

Because of the constructed scale for the performance measure and a conversion for the utility, the determination of a cost for this performance measure is slightly different from the determination of the costs of the other measures, which only require multiplication of the value of the measure and the scaling factor. The cost for this performance measure is the scaling factor times the difference between 100 percent and the utility. Thus, if an ESF-repository option has an aesthetic visual impact utility of 80 percent, then the cost of X_5 for this scenario and option is equal to $4 million x (100 % - 80 %), or $240,000.

C.4.6 Performance Measure 6, X_6, and Scaling Factor 6, k_6

Performance Measure 6, X_6, is the weighted areal extent of disturbed historical properties and is measured in hectares. This performance measure applies to Scenarios A through E, with Scenarios A and B having an equal amount of disturbed area and Scenarios C, D, and E having an equal amount of disturbed area that is not the same area as that for Scenarios A and B. Scaling Factor 6, k_6, is $20 per square meter ($200,000 per hectare). Thus, one square meter of disturbed historical properties represents a cost of $20.

C.4.7 Performance Measure 7, X_7, and Scaling Factor 7, k_7

Performance Measure 7, X_7, is the direct costs of the repository and is measured in discounted 1989 dollars. The measure applies to, and the value of it is different for, all Scenarios A through F. The discount rate is 10 percent. Because the measure is already in the selected common unit of dollars, Scaling Factor 7, k_7, is unity.

C.4.8 Performance Measure 8, X_8, and Scaling Factor 8, k_8

Performance Measure 8, X_8, is the indirect costs of the repository and is measured in discounted 1989 dollars. The measure applies to, and the value of it is different for, all Scenarios A through F. The discount rate is 10 percent. Because the measure is already in the selected common unit of dollars, Scaling Factor 8, k_8, is unity.

C.4.9 Equivalent Economic Benefit for Each Scenario

The performance measures and scaling factors allow the equivalent economic benefit to be calculated for each scenario. The multiattribute utility function is additive, so the total equivalent economic benefits for Scenarios B, C, D, E, and F are simply the summation of the costs (assumed to be negative) that apply to the scenario. The total equivalent economic benefit for Scenario A is the sum of the benefit for having a successfully closed repository and the costs related to Scenario A. A benefit of $50 billion was selected as the benefit for having a successfully closed repository. Sensitivity studies showed that the relative ranking of the options remained unchanged regardless of the benefit as long as the benefit exceeded $20 billion.

The equations used to calculate the equivalent economic benefit of the scenarios, given that the scenarios occur, are

- V_A = \$50 billion + Summation of costs for X_i, i = 1, ..., 8
- V_B = Summation of costs for X_i, i = 2, ... , 8
- V_C = Summation of costs for X_i, i = 4, ... , 8
- V_D = Summation of costs for X_i, i = 4, ... , 8
- V_E = Summation of costs for X_i, i = 4, ... , 8
- V_F = Summation of costs for X_i, i = 7,8

C.5 Expected Benefits for the Scenarios

The expected benefit for any scenario is simply the product of the probability of the scenario and the equivalent economic benefit of the scenario, given that the scenario occurred. Thus, the equations for the expected benefit of the scenarios are

$$EB_A = P_A \times V_A$$
$$EB_B = P_B \times V_B$$
$$EB_C = P_C \times V_C$$
$$EB_D = P_D \times V_D$$
$$EB_E = P_E \times V_E$$
$$EB_F = P_F \times V_F$$

C.6 Expected Net Benefit for the Options

The expected net benefit, ENB, for any option is simply the sum of the expected values of the scenarios, EB_A through EB_F, of the option. Thus, the equation for the expected net benefit for each option is

$$ENB = EB_A + EB_B + EB_C + EB_D + EB_E + EB_F$$

APPENDIX D

RECORD PACKAGES OF THE ELICITATIONS DURING THE ESF-AS

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RECORD PACKAGES OF THE ELICITATIONS DURING THE ESF-AS

	Records Management System Number (RMS)	Title	Date	Source/ Org.	File Code
1.	131156	**Planning** • Records: Notes From the ESF-ACS Decision Methodology Planning Meeting Convened During the Week of January 8--12, 1990	8/7/91	S.J. Bauer	60/12611/ DIM-245/ 1.5/NQ
2.	131157	**Pilot Study** • Records: Notes From the ESF-ACS Pilot Study Conducted During the Week of February 5--9, 1990	8/7/91	S.J. Bauer	60/12611/ DIM-245/ 1.5/NQ
3.	131158	**Department of Energy and Sandia National Laboratories Management Panel** • Study Elements: - Scaling Factors - Utility Functions • Records: - Summary Notes: * May 2, 1990 * June 6, 1990 * July 25, 1990 * August 8, 1990 * October 23, 1990 * October 24, 1990 - Transcripts: * May 2, 1990 * June 6, 1990 * July 25, 1990	8/7/91	S.J. Bauer	60/12611/ DIM-245/ 1.5/NQ

RECORD PACKAGES OF THE ELICITATIONS DURING THE ESF-AS (continued)

	Records Management System Number (RMS)	Title	Date	Source/ Org.	File Code
		* August 8, 1990 * October 23, 1990 * October 24, 1990			
4.	131159	**<u>Expert Panel on Postclosure Health</u>** • Study Elements: - Postclosure Radiologic Health, X_1 - Probability That the Site is OK, P_{OK} • Records: - Summary Notes: * March 19, 1990 * March 20, 1990 * March 21, 1990 * April 17, 1990 * May 1, 1990 * May 18, 1990 * August 15, 1990 * September 5, 1990 * October 2--3, 1990 * October 9--11, 1990 - Transcripts: * March 19, 1990 * March 20, 1990 * March 21, 1990 * April 17, 1990 * May 1, 1990 * May 18, 1990 * August 15, 1990 * September 5, 1990	8/7/91	S.J. Bauer	60/12611/ DIM-245/ 1.5/NQ

RECORD PACKAGES OF THE ELICITATIONS DURING THE ESF-AS (continued)

	Records Management System Number (RMS)	Title	Date	Source/ Org.	File Code
		* October 2, 1990 * October 3, 1990 * October 9, 1990 * October 10, 1990 * October 11, 1990 - Scoring Instructions:			
5.	131160	**Expert Panel on Preclosure Health** • Study Elements: - Preclosure Radiologic Health Effects to Workers, X_2 - Preclosure Radiologic Health Effects to Public, X_3 - Preclosure Nonradiologic Safety Effects to Workers, X_4 • Records: - Summary Notes: April 18, 1990 - Transcripts: April 18, 1990	8/7/91	S.J. Bauer	60/1211/ DIM-245/ 1.5/NQ
6.	131161	**Expert Panel on Preclosure Radiologic Health** • Study Elements: - Preclosure Radiologic Health Effects to Workers, X_2 - Preclosure Radiologic Health Effects to Public, X_3	8/7/91	S.J. Bauer	60/1211/ DIM-245/ 1.5/NQ

RECORD PACKAGES OF THE ELICITATIONS DURING THE ESF-AS (continued)

	Records Management System Number (RMS)	Title	Date	Source/ Org.	File Code
		• Records: - Summary Notes: * May 9, 1990 * June 18, 1990 - Transcripts: * May 9, 1990 * June 18, 1990			
7.	131168	**Expert Panel on Preclosure Nonradiologic Safety** • Study Element: - Preclosure Nonradiologic Safety Effects to Workers, X_4 • Records: - Summary Notes: * May 10, 1990 * October 23, 1990 - Transcripts: * May 10, 1990 * October 23, 1990	8/7/91	S.J. Bauer	60/1211/ DIM-245/ 1.5/NQ
8.	131169	**Expert Panel on Environment** • Study Elements: - Preclosure Environmental Impacts: Historical Properties, X_5	8/7/91	S.J. Bauer	60/1211/ DIM-245/ 1.5/NQ

RECORD PACKAGES OF THE ELICITATIONS DURING THE ESF-AS (continued)

	Records Management System Number (RMS)	Title	Date	Source/ Org.	File Code
		- Preclosure Environmental Impacts: Aesthetic, X_6 - Preclosure Environmental Impacts: Biota • Records: - Summary Notes: * March 22, 1990 * April 20, 1990 * April 30, 1990 - Transcripts: * March 22, 1990 * April 20, 1990 * April 30, 1990 - Correspondence: * O'Farrell, T. P., 1990, Letter to W. Dixon, Yucca Mountain Project Office, May 16			
9.	131170	**Expert Panel on Historical Properties** • Study Element: - Preclosure Environmental Impacts: Historical Properties, X_5 • Records: - Summary Notes:	8/7/91	S.J. Bauer	60/1211/ DIM-245/ 1.5/NQ

RECORD PACKAGES OF THE ELICITATIONS DURING THE ESF-AS (continued)

Records Management System Number (RMS)	Title	Date	Source/ Org.	File Code
	* May 17, 1990 * May 24, 1990 - Transcripts: * May 17, 1990 * May 24, 1990 - Correspondence: * Rhode, D., 1990, Letter to S. Bauer re: Scoring of Options From Historical Properties Perspective, October 30			
10. 131171	**<u>Expert Panel on Aesthetic Properties</u>** • Study Element: - Preclosure Environmental Impacts: Aesthetics, X_6 • Records: - Summary Notes: June 19, 1990 - Transcripts: June 19, 1990	8/7/91	S.J. Bauer	60/1211/ DIM-245/ 1.5/NQ
11. 131172	**<u>Expert Panel on Cost and Schedule</u>** • Study Elements: - Preclosure Direct Cost Impacts, X_7	8/7/91	S.J. Bauer	60/1211/ DIM-245/ 1.5/NQ

RECORD PACKAGES OF THE ELICITATIONS DURING THE ESF-AS (continued)

Records Management System Number (RMS)	Title	Date	Source/ Org.	File Code
	- Preclosure Indirect Costs Resulting From Schedule Impacts, X_8 • Records: - Summary Notes: * April 19, 1990 * May 16, 1990 * August 1, 1990 * October 15, 1990 * October 25, 1990 * October 26, 1990 - Transcripts: * April 19, 1990 * May 16, 1990 * August 1, 1990 * October 15, 1990 * October 25, 1990 * October 26, 1990			
12. 131173	**Expert Panel on Regulatory Considerations** • Study Elements: - Likelihood of Construction/Operation Approval, P_{APP} - Likelihood of Retrieval, P_{RET} • Records: - Summary Notes:	8/7/91	S.J. Bauer	60/1211/ DIM-245/ 1.5/NQ

RECORD PACKAGES OF THE ELICITATIONS DURING THE ESF-AS (continued)

Records Management System Number (RMS)	Title	Date	Source/ Org.	File Code
	* February 26, 1990 * February 27, 1990 * February 28, 1990 * May 3, 1990 * August 2, 1990 * October 11, 1990 * October 12, 1990 * October 31, 1990 * November 1, 1990 * November 7, 1990 * November 8, 1990			
	- Transcripts:			
	* February 26, 1990 * February 27, 1990 * February 28, 1990 * May 3, 1990 * August 2, 1990 * October 11, 1990 * October 12, 1990 * October 31, 1990 * November 1, 1990 * November 7, 1990 * November 8, 1990			
	- Scoring Instructions:			
13. 131174	**Expert Panel on Characterization Testing**	8/7/91	S.J. Bauer	60/1211/ DIM-245/ 1.5/NQ
	• Study Elements:			
	- Probability of Early False Positive Test Results, P_{EFP} - Probability of Late False Positive Test Results, P_{LFP}			

RECORD PACKAGES OF THE ELICITATIONS DURING THE ESF-AS (continued)

Records Management System Number (RMS)	Title	Date	Source/ Org.	File Code

- Probability of Early False Negative Test Results, P_{EFN}
- Probability of Late False Negative Test Results, P_{LFN}

• Records:

- Summary Notes:

  * February 28, 1990
  * March 1, 1990
  * May 4, 1990
  * May 14, 1990
  * May 15, 1990
  * August 13--14, 1990
  * September 5, 1990
  * September 19, 1990
  * September 20, 1990
  * September 21, 1990
  * September 24, 1990
  * September 25, 1990
  * September 26, 1990
  * September 27, 1990
  * November 5, 1990
  * November 6, 1990

- Transcripts:

  * February 28, 1990
  * March 1, 1990
  * May 4, 1990
  * May 14, 1990
  * May 15, 1990
  * August 13, 1990
  * August 14, 1990
  * September 5, 1990
  * September 19, 1990

RECORD PACKAGES OF THE ELICITATIONS DURING THE ESF-AS (continued)

Records Management System Number (RMS)	Title	Date	Source/ Org.	File Code
	* September 20, 1990 * September 21, 1990 * September 24, 1990 * September 25, 1990 * September 26, 1990 * September 27, 1990 * November 5, 1990 * November 6, 1990 - Scoring Instructions:			
14. 131175	**<u>Expert Panel on Socioeconomics</u>** • Study Elements: - Preclosure Socioeconomic Impacts • Records: - Summary Notes: March 23, 1990 - Transcripts: March 23, 1990 • Correspondence: - Bauer, S. J., 1990, Completion of Evaluations by the Expert Panel for the ESF-AS, Memorandum to Distribution, October 29, 1990. - Bauer, S. J., 1991, Final Discussion Relative to Scoioeconomic Impacts for the ESF-AS, Memorandum to File, January 15, 1991.	8/7/91	S.J. Bauer	60/1211/ DIM-245/ 1.5/NQ

RECORD PACKAGES OF THE ELICITATIONS DURING THE ESF-AS (continued)

Records Management System Number (RMS)	Title	Date	Source/ Org.	File Code
15. 131176	**Expert Panel on Programmatic Viability** • Study Elements: - Probability of Programmatic Viability, P_{VIAB} • Records: - Summary Notes: * August 23, 1990 * August 24, 1990 * November 18, 1990 * November 19, 1990 - Transcripts: * August 23, 1990 * August 24, 1990 * November 18, 1990 * November 19, 1990	8/7/91	S.J. Bauer	60/1211/ DIM-245/ 1.5/NQ
16. 131177	**Sandia Management Lead Group** • Records: - Transcripts: * March 13, 1990 * March 14, 1990 * August 13, 1990	8/7/91	S.J. Bauer	60/1211/ DIM-245/ 1.5/NQ

RECORD PACKAGES OF THE ELICITATIONS DURING THE ESF-AS (concluded)

Records Management System Number (RMS)	Title	Date	Source/ Org.	File Code
17. 131178	**Methodology Lead Group** - Transcripts: * March 22, 1990 * December 5, 1990 * December 6, 1990	8/7/91	S.J. Bauer	60/1211/ DIM-245/ 1.5/NQ

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