756

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756

Location Performance Objectives for the NNWSI Area-to-Location Screening Activity

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Abstract

Fifty-four objectives were identified to guide the screening of the Nevada Research and Development Area of the Nevada Test Site for relatively favorable locations for the disposal of nuclear waste in a mined geologic repository. The objectives were organized as a hierarchy composed of 4 upper-level, 12 middle-level, and 38 lower-level objectives. The four upper-level objectives account for broad national goals to contain and isolate nuclear waste in an environmentally sound and economically acceptable manner. The middle-level objectives correspond to topical categories that logically relate the upper-level objectives to site-specific concerns such as seismicity, sensitive species, and flooding hazards (represented by the lower-level objectives). The relative merits of alternative locations were compared by an application of decision analysis based on standard utility theory. The relative favorabilities of pertinent physical conditions at each alternative location were weighted in relation to the importance of objectives, and summed to produce maps indicating the most and the least favorable locations. Descriptions of the objectives were organized by the hierarchical format; they detail the applicability of each objective to geologic repository siting, previously published siting criteria corresponding to each objective, and the rationale for the weight assigned to each objective, and the pertinent attributes for evaluating locations with respect to each objective.

Contents

Contents (cont)

Figures

Tables

Location Performance Objectives for the NNWSI Area-to-Location Screening Activity

Introduction

Purpose and Relation to Other Screening Documents

A screening for relatively favorable locations for the permanent disposal of radioactive waste was performed by the Nevada Nuclear Waste Storage Investigations (NNWSI) in compliance with the repository siting phase of the National Waste Terminal Storage (NWTS) Program called area-to-location screening.[1] The screening was based on a comprehensive systems study to identify potential locations in the Nevada Research and Development Area (NRDA) of the Nevada Test Site (NTS) and nearby areas (Figure 1) for a geologic repository.[2] The purpose of the screening was to use information available (as of the summer of 1981) to identify such locations. The screening results were to assist in selecting where future repository exploration should be concentrated and to optimize the chances that the location chosen for characterization will actually qualify as a licensed repository site.

The purpose of this report is to provide detailed descriptions of performance objectives used in the screening activity and to make explicit the assumptions employed in defining the objectives. These objectives are generally comparable to siting criteria for repository locations published earlier by the Department of Energy (DOE),[3,4] Nuclear Regulatory Commission (NRC),[5] and others.[6-10]

This report is one of five documents that describe the NNWSI screening activity. *A Method for Screening the Nevada Test Site and Contiguous Areas for Nuclear Waste Repository Locations* was the first.[11] It provides a general description of the screening method, but contains no specific data about the screening area. Its purpose was to document the proposed screening method prior to its implementation. The second publication, *Summary and Conclusions of the NNWSI Area-to-Location Screening Activity*,[2] documents the screening results and provides additional information on how the screening calculations were performed, how the results were interpreted, and how the objectives discussed in this report are used in the ratings of alternative locations. This publication also served as the principal product of the NNWSI screening activity. The last three documents (*Location Performance Objectives for the NNWSI Area-to-Location Screening Activity* (this report), *Attributes of the NNWSI Area-to-Location Screening and Associated Favorability Graphs*,[12] and *Software for APPLICON Graphics System Support of the NNWSI Area-to-Location Screening Activity*[13]) provide detailed background information on elements of the screening method used for rating alternative locations and host rocks.

Organization of This Report

Following an introductory section that provides background material on the screening process, the body of this report is organized according to a hierarchical format corresponding to an objectives tree. There are four major sections that correspond to the four upper-level objectives of the tree. Each major section describes, in order, an upper-level objective, a component middle-level objective, and its lower-level objectives that comprise, respectively, branches and subbranches of the objective tree.

For each objective, the following information is provided, as applicable:

- A map and list showing how various locations and rock types rate with respect to the objective
- A description of the objective
- The relation of the objective to previously published DOE siting criteria and proposed NRC technical criteria
- A discussion of the relative importance of the objective in the screening analyses
- Attributes applicable for evaluating the objective.

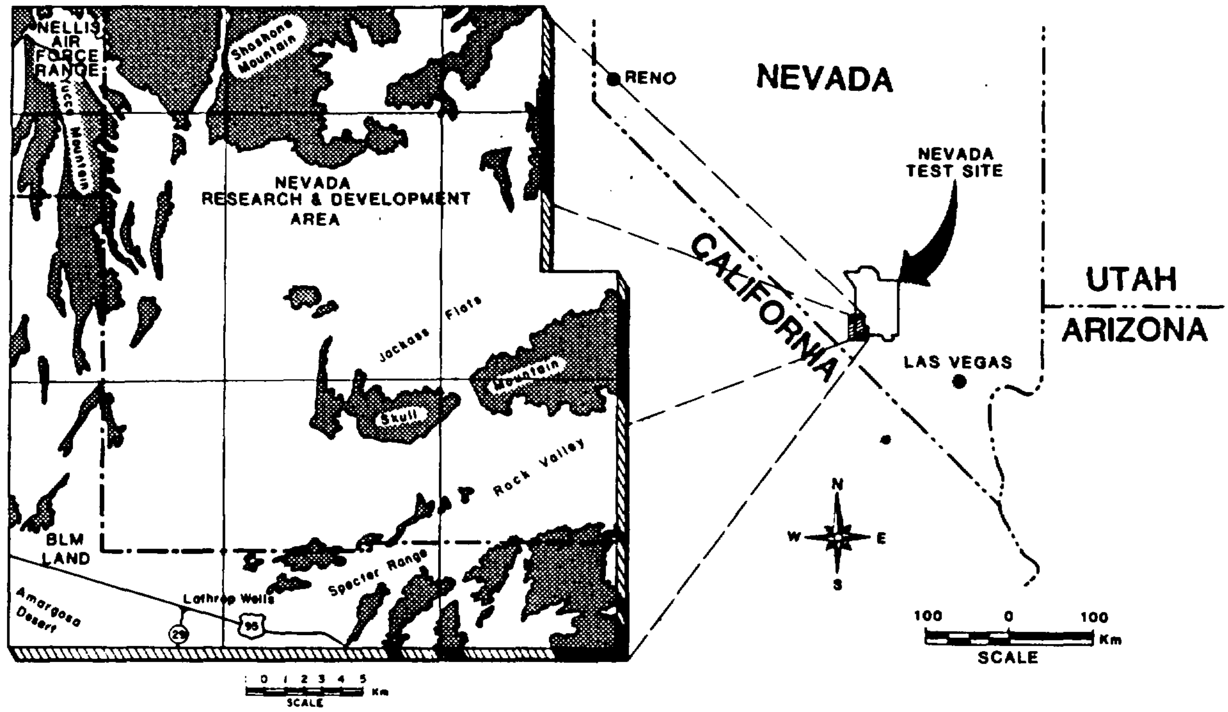


Figure 1. NNWSI Screening Area

The rating maps and lists are shown only for lower-level objectives. Reference 2 shows ratings for all upper-level and selected middle-level objectives. The descriptions explain what each objective means in terms of desirable and undesirable conditions for repository locations in the screening area. The sections relating the objectives to DOE and NRC criteria simply quote correlative requirements from References 3, 4, and 5. The relative importance of each objective is discussed, both in terms of possible consequences if it is not met and in terms of a quantitative weight assigned to the objective by a poll of NNWSI experts. The last section on each objective lists and explains why certain attributes are useful for evaluating performance with respect to that objective. These attributes and their relative weights are listed on the map of location ratings and the accompanying list of host-rock ratings for each lower-level objective. Additional information on the attributes is provided in Reference 12.

Background on Screening Method

The systems study used to screen the NRDA and contiguous areas consists of four basic elements:

- Weighted hierarchical performance objectives for ideal repository locations (the subject of this document)
- Attributes based on physical conditions that discriminate among locations or rock types in the screening area
- Relative favorability graphs, or criteria, that rate physical conditions of the attributes with respect to objectives
- Mathematical equations, expressed as computer algorithms, that calculate ratings for alternative locations and host rocks.

The first three elements are defined by a set of parameters suitable for use in equations of the fourth element. Each of the elements will be discussed in turn to provide background information about the screening method and the role of performance objectives in rating alternative locations and host rocks.

Performance Objectives

Objectives for ideal repository locations have been expressed previously (References 3 through 9). These objectives were organized for screening into a hierarchical format called an objectives tree (Figure 2). This tree ties independent desires for specific, physical characteristics of individual repository locations to the overall national goal of long-term safety, cost-effectiveness, and environmental soundness for the disposal of radioactive waste. Hierarchically organizing the objectives clarifies the logical relations between previously unstructured, site-selection criteria and the overall national program goals.

The overall national goal is divided into the four major objectives that form the upper-level of the objectives tree. The goal for long-term safety is addressed by two separate upper-level objectives: containment (Objective 1.0) and isolation (Objective 2.0). Cost-effective repository facilities are addressed by an operational or short-term objective (Objective 3.0). Environmental concerns are addressed by the last upper-level objective (Objective 4.0). These four upper-level objectives correspond to the first four of seven NWTS repository performance objectives.[10] The other three NWTS performance objectives are conservatism of approach, use of current technology, and independence of waste-disposal concepts from specific fuel-cycle options. These three objectives do not discriminate among alternative locations and, therefore, were not used in area-to-location screening.

Each upper-level objective of the tree is divided into a set of component middle-level objectives. The middle-level objectives, in turn, are divided into component lower-level objectives. The resulting tree is thereby divided into four major branches, each characterized by component middle-level and lower-level objectives independent of those in the other branches. The tree was developed during a series of iterations by the NNWSI Technical Overview Contractor of Sandia National Laboratories. Objectives of each level of the tree were correlated with NWTS and draft NRC criteria (Table 1). This correlation assured compatibility of the screening objectives developed for the NNWSI with national requirements for repository sites.

Weights were assigned to each objective to quantify them for use in computer algorithms developed to rate alternative locations and host rocks. The weighting scheme assumes a weight of 100% for the overall goal of safe, cost-effective, environmentally sound waste disposal. Each upper-level objective accounts for some fraction of this overall weight, expressed as a percentage of the overall goal (Table 2, column 2). The sum of weights for the four upper-level objectives in the tree equals 100%; i.e., the total weight of the overall goal.

To obtain weights for middle-level objectives, each upper-level objective was assumed, in turn, to equal 100%. Middle-level objectives within each branch of the tree were then assigned percentage weights equal to their presumed fractional contribution to satisfying the appropriate upper-level objective (Table 2, column 5). As a result, the sum of weights within each of the four sets of middle-level objectives is 100%. To obtain the percentage weight of a middle-level objective relative to the overall goal, its weight relative to the corresponding upper-level objective (some fraction of 100%) is multiplied by the weight of the upper-level objective relative to the overall goal, which is also some fraction of 100% (Table 2, column 6). Similarly, each lower-level objective is assigned a weight relative to the appropriate middle-level objective (Table 2, column 11). Weights of lower-level objectives with respect to the overall goal are obtained by multiplying the appropriate weights assigned to all three objective levels (Table 2 column 12).

The weights and accompanying standard deviations shown in Table 2, columns 2, 5, and 11, were obtained by averaging the responses of 15 individuals to a weighting poll. Participants in the poll were experienced and knowledgeable in the technical aspects of radioactive waste disposal. They were asked to assign weights to those objectives corresponding to their particular area of expertise. The polling form consisted of separate sheets for each branch and subbranch of the objectives tree. Thus, responses to the poll by a particular individual were a series of opinions about:

- How the weight of 100% for the overall goal should be divided among the upper-level objectives
- How the weights of 100% for each upper-level objective should be divided among its compontent middle-level objectives
- How the weights of 100% for each middle-level objective shoud be divided among its component lower-level objectives.

The participants in the poll, their affiliations, and individual responses are reproduced in the Appendix.

Because weights for middle- and lower-level objectives relative to the overall goal are obtained by multiplying average weights from the poll, each with its own standard deviation, the standard deviations in Table 2, columns 9 and 15, are obtained by a formula for propagating variance through a series of multiplications:

$$\sigma(x_1, x_2, \ldots x_n) = \left\{\left(\frac{\partial y}{\partial x_1}\right)^2 \sigma_1^2 + \left(\frac{\partial y}{\partial x_2}\right)^2 \sigma_2^2 + \ldots \left(\frac{\partial y}{\partial x_n}\right)^2 \sigma_n^2\right\}^{1/2} \quad (1$$

where σ is the standard deviation of a variable, x, and $y = f(x)$. The discrete forms of this general equation used to obtain σ's in columns 9 and 15 are given in footnotes to Table 2.

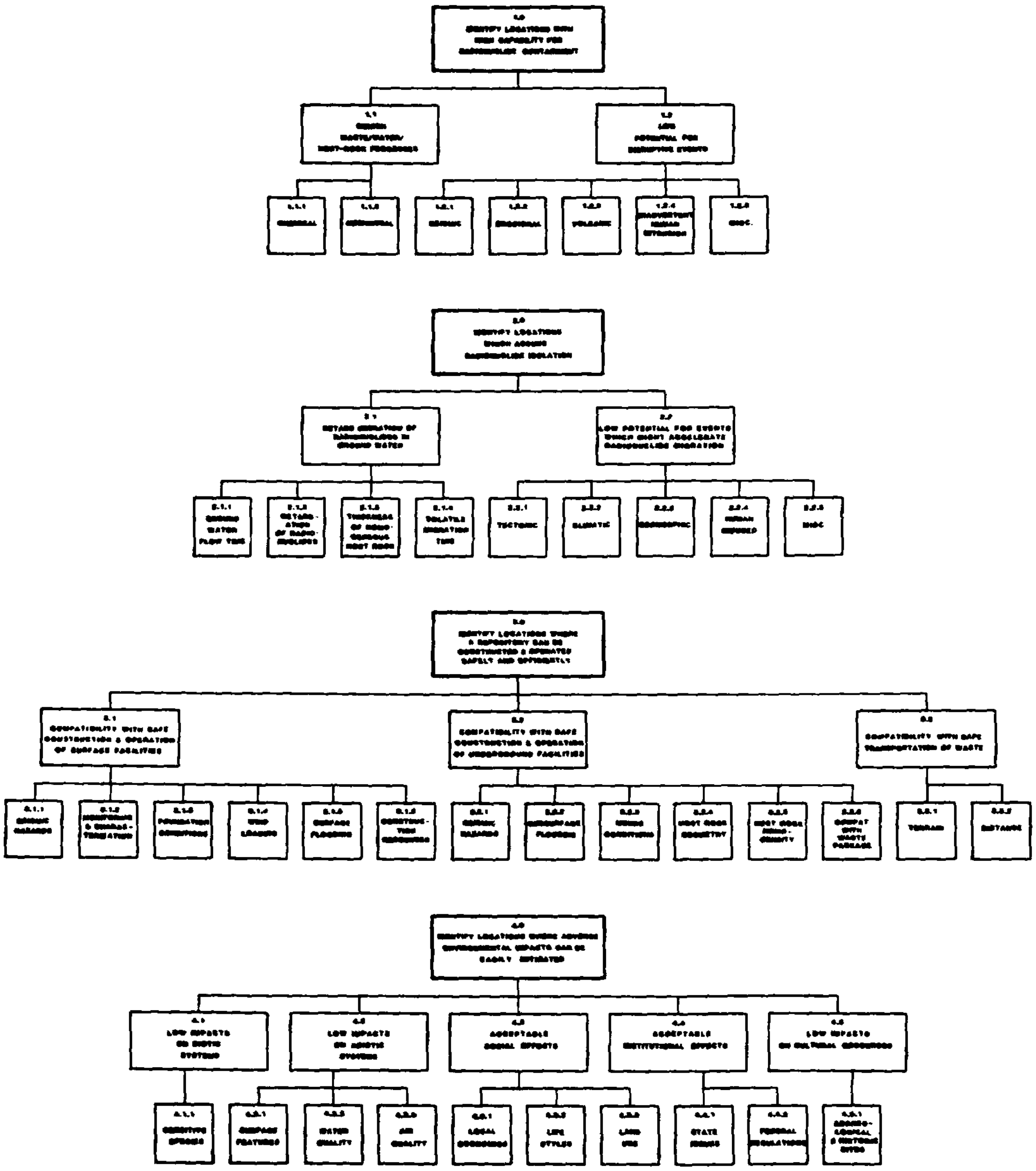


Figure 2. Hierarchical Tree of Performance Objectives for NNWSI Screening Activity

NOTES:

**NWSI PERFORMANCE OBJECTIVES FOR REPOSITORY LOCATIONS
FOR SATISFYING THE OVERALL NATIONAL GOAL**

To Provide Safe, Cost-Effective, Environmentally Sound Disposal of Heat-Generating, Commercially Produced Radioactive Waste

1.0 Identify Locations Which Permit Adequate Containment of Radionuclides in a Sealed Repository
- 1.1 Screen for Natural Systems with Potential to Resist Waste Package Disruption Processes
  - 1.1.1 Minimize Potential for Chemically Induced Release
  - 1.1.2 Minimize Potential for Mechanically Induced Release
- 1.2 Screen for Natural Systems with Minimum Potential for Waste Package Disruption Events
  - 1.2.1 Minimize Potential for Seismic Hazards to Containment in a Sealed Repository
  - 1.2.2 Minimize Potential for Erosional Disruption of Waste Packages
  - 1.2.3 Minimize Potential for Volcanic Disruption of Waste Packages
  - 1.2.4 Minimize Potential for Inadvertent Human Intrusion of a Sealed Repository
  - 1.2.5 Minimize Potential for Miscellaneous Events that Might Disrupt Containment

2.0 Identify Locations Which Permit Adequate Isolation of Radioactive Waste from the Biosphere
- 2.1 Screen for Natural Systems Which Will Retard Migration of Radionuclides
  - 2.1.1 Maximize Groundwater Flow Time to the Accessible Environment
  - 2.1.2 Maximize Retardation of Radionuclides Along Flow Paths
  - 2.1.3 Maximize Extent of Relatively Homogeneous Host Rock
  - 2.1.4 Maximize Migration Times of Volatile Radionuclides
- 2.2 Screen for Natural Systems with Low Potential for Adverse Changes to Isolation Processes
  - 2.2.1 Minimize Potential for Adverse Impacts on Isolation Due to Tectonic Changes
  - 2.2.2 Minimize Potential for Adverse Impacts on Isolation Due to Climatic Changes
  - 2.2.3 Minimize Potential for Adverse Impacts on Isolation Due to Geomorphic Changes
  - 2.2.4 Minimize Potential for Adverse Impacts on Isolation Due to Human Activities
  - 2.2.5 Minimize Potential for Miscellaneous Events Which Might Disrupt Isolation

3.0 Identify Locations Where Safe Repository Construction and Operations Can Be Implemented Effectively with Respect to Cost
- 3.1 Screen for Locations Compatible with Safe Surface Facility Construction and Operation
  - 3.1.1 Minimize Seismic Hazards to Surface Facilities
  - 3.1.2 Minimize Surface Monitoring System Cost
  - 3.1.3 Minimize Adverse Foundation Conditions
  - 3.1.4 Minimize Wind Loading on Surface Structures
  - 3.1.5 Minimize Flooding Hazards to Surface Facilities
  - 3.1.6 Assure Availability of Natural Resources to Construct and Operate the Repository
- 3.2 Screen for Locations Suitable for Subsurface Facility Construction and Safe Operation
  - 3.2.1 Minimize Seismic Hazards to Subsurface Facilities
  - 3.2.2 Minimize Flooding Hazards to Subsurface Facilities
  - 3.2.3 Minimize Adverse Mining Conditions
  - 3.2.4 Optimize the Geometry (Thickness and Lateral Extent) of the Host Rock
  - 3.2.5 Optimize Host Rock Homogeneity
  - 3.2.6 Maximize Compatability of a Host Rock with Standardized Waste Package
- 3.3 Screen for Locations with Characteristics Compatible with Safe Transport of Radioactive Waste to a Repository
  - 3.3.1 Minimize Adverse Terrain Along Potential Waste Transport Routes
  - 3.3.2 Optimize Distance from Existing Transportation Corridors

4.0 Identify Locations for Which Environmental Impacts Can Be Reasonably Mitigated
- 4.1 Minimize or Avoid Adverse Impacts on or from Sensitive Biotic Systems
- 4.2 Minimize Adverse Impacts on Abiotic Systems
  - 4.2.1 Minimize Impacts on Surface Geology
  - 4.2.2 Minimize Impacts on Water Quality and Availability
  - 4.2.3 Minimize Impacts on Air Quality
- 4.3 Minimize Adverse Impacts on the Existing Socioeconomic Status of Individuals in the Affected Area
  - 4.3.1 Minimize Adverse Impacts on Local Economies
  - 4.3.2 Minimize Adverse Impacts on Life Styles
  - 4.3.3 Minimize Conflicts with Private Land Use
- 4.4 Conduct All Activities in a Spirit of Institutional Cooperation
  - 4.4.1 Cooperate with States
  - 4.4.2 Facilitate Compliance with Federal Regulations
- 4.5 Minimize Adverse Impacts on Significant Historic and Prehistoric Cultural Resources

Figure 2. (cont)

Table 1. Correspondence Between NNWSI Screening Objectives and National Siting Criteria of DOE and NRC

NNWSI Screening Objectives		Comparable National Criteria		
Number and Title		NWTS 33(1) (Ref. 3)	NWTS 33(2) (Ref. 4)	10 CFR 60 (July 1981 Proposed Rule) (Ref. 5)
1.0	CONTAINMENT	3.1.2, 3.2.2(1), 4.2	3.2(¶1), 3.4(¶1), 3.3(¶1)	60.111(b)(2)(i), 60.111(b)(2)(ii)(A) 60.111(b)(3)(i)
1.1	Processes		3.4(2)	
1.1.1	Chemical Release		3.3(1), 3.4(2), 3.2(1), 3.2(4)	60.123(b)(5),60.123(b)(13-14)
1.1.2	Mechanical Release		3.4(2)	60.123(b)(15), 60.132(k)(1)
1.2	Events		3.5(¶1), 3.5(1)	60.123(a)(7), 60.123(b)(6,7,10)
1.2.1	Seismic		3.5(2), 3.5(5)	60.112(a), 60.123(a)(5), 60.123(b)(9)
1.2.2	Erosion		3.5(4)	60.112(b), 60.122(i), 60.123(b)(4)
1.2.3	Volcanic		3.5(3)	60.112(a), 60.123(b)(11)
1.2.4	Human Intrusion	3.2.2(3), 3.3.2(4)	3.6(¶1), 3.6(2)	60.123(b)(1-3)
1.2.5	Miscellaneous	2.3		60.122(j)
2.0	ISOLATION	2.1, 3.1.2, 3.2.2(2), 4.2	3.4(¶1), 3.1(¶1), 3.2(¶1), 3.3(¶1)	60.111(b)(1), 60.111(b)(3)(ii)
2.1	Nuclide Migration			
2.1.1	Groundwater Flow Time		3.2(1), 3.2(2)	60.112(c), 60.122(c), 60.122(f)(1-4)
2.1.2	Nuclide Retardation		3.3(1)	60.122(d), 60.122(g)(1-3), 60.122(h) 60.123(b)(13-15)
2.1.3	Host Rock Homogeneity			
2.1.4	Volatile Migration			
2.2	Changes to Existing Systems		3.5(¶1), 3.5(1)	60.123(a)(7),60.123(b)(7,12)
2.2.1	Tectonic		3.5(2-5)	60.112(a), 60.122(a,b), 60.123(a)(5), 60.123(b)(6,8,10,11)
2.2.2	Climatic		3.2(1)	60.112(b), 60.123(a)(8)
2.2.3	Geomorphic		3.1(1), 3.5(4)	60.112(b), 60.122(e,i), 60.123(b)(4)
2.2.4	Human Activities	3.3.2(4)	3.6(¶1), 3.6(2)	60.123(a)(3), 60.123(b)(1-3), 60.133(a)
2.2.5	Miscellaneous		3.4(1)	60.122(j)
3.0	CONSTRUCTION	3.1.1, 3.3.1, 4.1		60.111(a)(1,2), 60.130(b)(1), 60.130(b)(2)(ii) 60.131(e)
3.1	Surface Facilities	3.2.1	3.7(¶1)	60.123(a)(6), 60.131(a), 60.131(c)(1)
3.1.1	Seismic Hazards		3.5(5)	60.123(a)(4), 60.123(b)(9,10)
3.1.2	Monitoring and Characterization Costs	3.3.2(3)	3.7(2)	60.130(9), 60.131(c)(2)
3.1.3	Foundation Conditions		3.7(2)	
3.1.4	Wind Loads		3.7(3)	
3.1.5	Flooding		3.7(1)	60.123(a)(1)
3.1.6	Net Resource Availability	2.6	3.7(4), 3.10(2)	
3.2	Subsurface Facilities	3.1.2, 3.3.2(2)	3.4(3)	60.123(b)(16), 60.130(10), 60.132(a)(1,4) 59,133(b)(4,5)
3.2.1	Seismic Hazard		3.5(5)	60.123(a)(4), 60.123(b)(9,10)
3.2.2	Flooding		3.2(3)	60.122(f)(3), 60.132(a)(2), 60.132(i)(1) 60.132(g)(1,5)
3.2.3	Mining Conditions		3.4(3)	60.123(b)(15,17), 60.132(a)(2), 60.132(e)(1,3), 60.132(f)
3.2.4	Host Rock Geometry		3.1(¶1),3.1(2)	60.122(i), 60.132(a)(3)
3.2.5	Host Rock Homogeneity		3.4(3)	
3.2.6	Waste Package Compatibility	3.4.1, 3.4.2, 3.3.2(1,2)		60.132(a)(1,3), 60.132(i)(2), 60.135(a)(1,2) 60.135(c)(3)
3.3	Transportation			
3.3.1	Terrain		3.8(2)	
3.3.2	Distance		3.7(2)	
4.0	ENVIRONMENT	4.3	3.9(¶1), 3.9.1, 3.9(2)	60.130(b)(2)(i)
4.1	Sensitive Biotic Systems			
4.2	Abiotic Systems			
4.2.1	Geologic Quality		3.9(1)	
4.2.2	Water Quality		3.9(1)	
4.2.3	Air Quality		3.9(1)	
4.3	Socioeconomics		3.8(¶1), 3.10(¶1)	
4.3.1	Local Economies		3.10(1)	
4.3.2	Life Styles			
4.3.3	Private Land Use		3.6(2)	60.121(a)
4.4	Institutional Issues	2.2	3.9(2)	60.121(b)
4.4.1	State Issues		3.6(2), 3.9(2)	
4.4.2	Federal Regulation	4.1.1, 4.1.2	3.9(2)	
4.5	Historic & Prehistoric Res.		3.9(1)	

Table 2. NNWSI Weighting Data for the Area-to-Location Screening Objectives Tree (See Appendix for results of poll that resulted in values shown in this table.)

Level 1			Level 2						Level 3					
(1) Obj No.	(2) Average ± 1σ from Poll (Note 1)	(3) Rank	(4) Obj No.	(5) Average ± 1σ from Poll (Note 2)	(6) Relative Weight (Note 3)	(7) Rank	(8) Variance (σ^2) (Note 4)	(9) Standard Deviation (σ)	(10) Obj No.	(11) Average ± 1σ from Poll (Note 2)	(12) Relative Weight (Note 3)	(13) Rank	(14) Variance (σ^2) (Note 5)	(15) Standard Deviation (σ)
1.0	0.31 ± 0.11	2	1.1	0.68 ± 0.08	0.2108	2	0.00621	0.0788	1.1.1	0.68 ± 0.12	0.1433	1	0.00351	0.0593
									1.1.2	0.32 ± 0.12	0.0675	3	0.00128	0.0357
			1.2	0.32 ± 0.08	0.0992	5	0.00185	0.0431	1.2.1	0.37 ± 0.18	0.0367	8	0.00057	0.0239
									1.2.2	0.14 ± 0.08	0.0139	23	0.00082	0.0287
									1.2.3	0.21 ± 0.09	0.0208	16	0.00016	0.0127
									1.2.4	0.23 ± 0.15	0.0228	14	0.00032	0.0179
									1.2.5	0.05 ± 0.07	0.0050	36	0.00005	0.0073
2.0	0.34 ± 0.14	1	2.1	0.65 ± 0.11	0.2210	1	0.00968	0.0984	2.1.1	0.39 ± 0.15	0.0862	2	0.00243	0.0493
									2.1.2	0.30 ± 0.09	0.0663	4	0.00127	0.0356
									2.1.3	0.23 ± 0.13	0.0508	6	0.00133	0.0366
									2.1.4	0.08 ± 0.08	0.0177	19	0.00037	0.0194
			2.2	0.35 ± 0.11	0.1190	3	0.00380	0.0616	2.2.1	0.31 ± 0.11	0.0369	7	0.00054	0.0232
									2.2.2	0.21 ± 0.07	0.0250	11	0.00024	0.0154
									2.2.3	0.20 ± 0.10	0.0238	12	0.00029	0.0171
									2.2.4	0.25 ± 0.16	0.0298	10	0.00060	0.0245
									2.2.5	0.03 ± 0.03	0.0036	38	0.00002	0.0040
3.0	0.26 ± 0.17	3	3.1	0.27 ± 0.08	0.0702	7	0.00254	0.0504	3.1.1	0.21 ± 0.08	0.0147	21	0.00014	0.0120
									3.1.2	0.12 ± 0.10	0.0084	31	0.00015	0.0121
									3.1.3	0.26 ± 0.15	0.0183	18	0.00028	0.0168
									3.1.4	0.10 ± 0.05	0.0070	34	0.00004	0.0061
									3.1.5	0.18 ± 0.11	0.0126	25	0.00014	0.0119
									3.1.6	0.13 ± 0.08	0.0091	28	0.00007	0.0086
			3.2	0.43 ± 0.12	0.1118	4	0.00631	0.0795	3.2.1	0.15 ± 0.07	0.0168	20	0.00021	0.0145
									3.2.2	0.21 ± 0.13	0.0235	13	0.00049	0.0221
									3.2.3	0.27 ± 0.15	0.0302	9	0.00074	0.0272
									3.2.4	0.15 ± 0.11	0.0168	20	0.00029	0.0171
									3.2.5	0.12 ± 0.04	0.0134	24	0.00011	0.0105
									3.2.6	0.10 ± 0.10	0.0112	26	0.00019	0.0137
			3.3	0.30 ± 0.14	0.0780	6	0.00393	0.0627	3.3.1	0.71 ± 0.15	0.0554	5	0.00212	0.0460
									3.3.2	0.29 ± 0.15	0.0226	15	0.00047	0.0216
4.0	0.09 ± 0.06	4	4.1	0.22 ± 0.08	0.0198	8	0.00023	0.0150	4.1.1	1.00 ± 0.0	0.0198	17	0.00023	0.0150
			4.2	0.21 ± 0.09	0.0189	9	0.00022	0.0150	4.2.1	0.22 ± 0.11	0.0042	37	0.00002	0.0039
									4.2.2	0.46 ± 0.07	0.0087	30	0.00005	0.0070
									4.2.3	0.32 ± 0.11	0.0060	35	0.00003	0.0052
			4.3	0.20 ± 0.13	0.0180	10	0.00028	0.0168	4.3.1	0.41 ± 0.18	0.0074	33	0.00006	0.0076
									4.3.2	0.42 ± 0.23	0.0076	32	0.00007	0.0082
									4.3.3	0.17 ± 0.15	0.0031	39	0.00002	0.0039
			4.4	0.21 ± 0.08	0.0189	9	0.00021	0.0145	4.4.1	0.53 ± 0.24	0.0100	27	0.00008	0.0089
									4.4.2	0.47 ± 0.24	0.0089	29	0.00007	0.0082
			4.5	0.16 ± 0.09	0.0144	11	0.00016	0.0126	4.5.1	1.00 ± 0.0	0.0144	22	0.00016	0.0126
	Σ=1.00				Σ= 1.0000						Σ=1.0002			

NOTES:

(1) Average and standard deviation ($\bar{x} \pm 1\sigma$) are based on responses of eight individuals who were asked to estimate what % each objective of this level contributes to overall goal of safe, effective, environmentally sound radioactive waste disposal.

(2) Average and standard deviation ($\bar{x} \pm 1\sigma$) are based on responses of eight individuals who were asked to estimate what % each objective of this level contributes to the appropriate upper level objective; each set of subobjectives of this level was assumed to sum to 100% with respect to the appropriate objective of the next higher level.

(3) Relative weight is the proportion of the overall goal of safe, effective, environmentally sound waste disposal attributed to this objective; it is calculated by multiplying average value of this level by the average value of each appropriate higher level from columns 2, 5, and 12.

(4) Variance, σ^2, is calculated by $\sigma^2 = x_1^2\sigma_2^2 + x_2^2\sigma_1^2$, where x_1 and σ_1 are the appropriate values from column 2; x_2 and σ_2 are appropriate values from column 5.

(5) Variance, σ^2, is calculated by $\sigma^2 = (x_1x_2)^2\sigma_3^2 + (x_2x_3)^2\sigma_1^2 + (x_1x_3)^2\sigma_2^2$, where x_1 and σ_1 are the appropriate values from column 2; x_2 and σ_2, from column 5; x_3 and σ_3 from column 11.

Columns 3, 7, and 13 of Table 2 rank the objectives by their weight relative to all other objectives of the same level. By ordering the objectives from the highest to the lowest rank and plotting their weights, graphs are obtained that show the relative importance of each objective from each level of the tree (Figure 3).

This weighting scheme accommodates the necessary trade-offs about which objectives are more important to meet at the possible expense of others. Such trade-offs are required because the search for repository locations will never encounter a place on the earth's surface that is ideal with respect to all or perhaps any of the objectives.

This weighting scheme does not account for possible mutual dependency among weights for individual objectives. For example, if a site had virtually zero water movement for transporting radioactive waste (Objective 2.1.1), geochemical retardation (Objective 2.1.2) would be of less importance than if water movement were rapid. Thus, variable weights based on mutual dependency of processes or conditions are not explicitly addressed. Also the number of objectives within a given branch of the tree influences the weights assigned to those objectives. As a result, branches with fewer objectives tend to contain more heavily weighted objectives.

Attributes

Locations were evaluated by assessing how well each performance objective is achieved at each location. This was done, in turn, by independently evaluating how well pertinent physical conditions in alternative locations satisfy individual performance objectives. These pertinent physical conditions are called attributes. To be used in screening, such attributes had to meet three criteria:

- Address the objectives
- Discriminate among alternative locations of host rocks within the screening area
- Be able to be measured or inferred on a standard basis throughout the screening area.

A set of 31 attributes was defined for use in the NNWSI area-to-location screening (Table 3). Twenty-three of the 31 attributes vary geographically (attributes 1 through 23, Table 3). For each geographical attribute, a map was prepared that shows the distribution of attribute conditions throughout the screening area. Experts primarily from the US Geological Survey and others worked closely with the Technical Overview Contractor to define discriminating mapping units for the geographical attributes. The mapping units were divided into discrete zones that discriminate among alternative locations. The specific favorability of each mapping unit for satisfying the performance objectives was not a factor in selecting the units. The maps were thus compiled solely from judgments about how physical conditions vary within the screening area. This separated generally objective judgments about the physical data from more subjective judgments about their favorability for repositories.

Detailed discussion of the rationale for selecting the mapping units, descriptions of the maps themselves, and supporting references are contained in the companion report devoted solely to the attributes and their favorability.[12]

Although the purpose of screening was to identify favorable geographic locations, preliminary evaluations of candidate host rocks were performed separately from geographic evaluations to determine if at least one usable rock type occurs beneath locations rated most favorable. Accordingly, 8 of the 31 attributes vary as a function of rock type rather than geographical position (attributes 24 through 31, Table 3). Nine rock types known to occur in the screening area were selected for evaluation. For each of the eight host-rock attributes, a single attribute value was assigned to each of the nine rock types by experts primarily from Sandia and Los Alamos National Laboratories. Host-rock attributes that vary with depth (such as in situ stress and temperature) were not considered.

Relations Between Attributes and Objectives

To evaluate the relative merits of alternative locations, attributes were quantitatively related to performance objectives. Relationships that make this necessary link have two basic facets. The first establishes which attributes are useful for evaluating locations with respect to each lower-level objective. The second defines the relative favorability of each discrete attribute condition for satisfying the objectives.

A system matrix was established wherein attributes form the rows and objectives form the columns (Table 4). This matrix is referred to as the attribute-objective matrix and allows one to graphically consider the usefulness of every attribute with respect to each lower-level objective. If an attribute is useful for evaluating a particular objective, a weight was assigned at the intersection of the appropriate column and row. For an objective with only one pertinent attribute, a weight of 100% was assigned to that attribute; for an objective with more than one pertinent attribute, the total weight of 100% was divided among the attributes according to the percent contribution of each attribute in evaluating the objective. By considering every matrix intersection and making a judgment about each, weights were obtained for all the attributes with respect to all performance objectives. These weights define the relative importance of individual attributes for evaluating specific objectives.

Attribute weights were not determined by a poll. In lieu of a poll, the Technical Overview Contractor assigned the attribute weights shown in Table 4 based on subjective evaluation of the relative impacts of the attributes on performance with the appropriate objectives. Weights in each column sum to 100%. Consequently, the combined contributions of all attributes for a particular objective allow comprehensive numerical analysis of locations with respect to that objective. For some objectives (i.e., 3.1.4, 3.3.2, 4.3.1, and 4.3.2), no discriminating attributes were identified or no data were available. As a result, the weights associated with these objectives do not affect the screening analyses.

The second facet of quantitative relationships between objectives and attributes establishes the relative favorability for each discriminating condition for each attribute. These relationships are expressed as relative favorability graphs. Attribute conditions that discrimiate place from place or rock type from rock type are independent variables of the favorability graphs. The dependent variables are favorability numbers on a scale of 0 to 10. The independent and dependent variables for each attribute are plotted on an abscissa and ordinate, respectively (Figure 4). In effect, these graphs constitute quantitative criteria of the screening activity. They tie objectives to data as follows: performance objectives establish goals; attributes define discriminating physical conditions in the screening area; and favorability graphs provide a quantitative standard for assessing how well the physical conditions meet the objectives.

Table 3. NNWSI Screening Attributes

	No.	Title	Discriminating Conditions	Major Contributor*
Geographically Discriminating Attributes	1	Volcanic Potential	4 Zones of Relative Potential	USGS
	2	Fault Density	3 Zones of Relative Density	USGS
	3	Fault Trend	3 Zones of Compass Direction	USGS
	4	Age of Faulting	3 Zones of Fault Ages	USGS
	5	Natural Seismic Potential	Discrete Values of Expected Ground Acceleration (g's)	USGS
	6	Weapons Seismic Potential	5 Zones of Expected Ground Acceleration (g's)	SNL
	7	Bed Attitude	3 Zones of Amount of Rock Dip (degrees)	USGS
	8	Erosion Potential	5 Zones of Erosional Intensity	SNL
	9	Flood Potential	4 Zones of Flooding Hazards	SNL
	10	Terrain Ruggedness	4 Zones of Slope Steepness (%)	SNL
	11	Resource Potential	3 Zones of Potential for Finding Metal Ores	USGS
	12	Groundwater Resources Potential	5 Zones of Potential for Groundwater Use	USGS
	13	Groundwater Flux	6 Zones of Groundwater Flux (m^3/sec)	USGS
	14	Groundwater Flow Direction	5 Zones of Upgradient Distance from Production Areas	SNL
	15	Thickness of Unsaturated Zone	3 Zones of Depth to Water Table (meters)	USGS
	16	Sensitive Floral Species	14 Units of Potential for Finding Sensitive Species	EG&G
	17	Sensitive Faunal Species	5 Zones of Species Habitats	EG&G
	18	Revegetation Potential	5 Zones Vegetation Assemblages	EG&G
	19	Known Cultural Resources	3 Zones of Types of Cultural Resources	DRI
	20	Potential Cultural Resources	10 Units of Potential Density of Cultural Resources	DRI
	21	Air Pollution Potential	5 Zones of Air Quality	DRI
	22	Permitting Difficulties	4 Zones of Land Ownership and Control	SNL
	23	Private Land Use	Private and Non-Private Land	UNLV
Host-Rock Attributes	24	Thermal Conductivity	5 Ranges of Thermal Conductivity (W/m°K)	SEWG
	25	Compressive Strength (Containment)	3 Ranges of Unconfined Compressive Strength (psi)	SEWG
	26	Compressive Strength (Construction)	3 Ranges of Unconfined Compression Strength (psi)	SNL
	27	Expansion-Contraction	Expansion of Contraction Behavior upon Heating	SEWG
	28	Mineral Stability	9 Rank Orders of Mineral Stability upon Heating	LANL
	29	Stratigraphic Setting	14 Condition of Stratigraphically Weighted Sorption Capacity	LANL
	30	Hydraulic Retardation	7 Rank Orders Radionuclide Diffusion into Rock Matrix	LANL
	31	Hydraulic Transmissivity	4 Ranges of Hydraulic Transmissivity (m^2/sec)	USGS

*Major Contributors

USGS	= US Geological Survey	DRI	= Desert Research Institute
SNL	= Sandia National Laboratories	LANL	= Los Alamos National Laboratory
EG&G	= Edgarton, Germehausen, and Grier	SEWG	= Site Evaluation Working Group

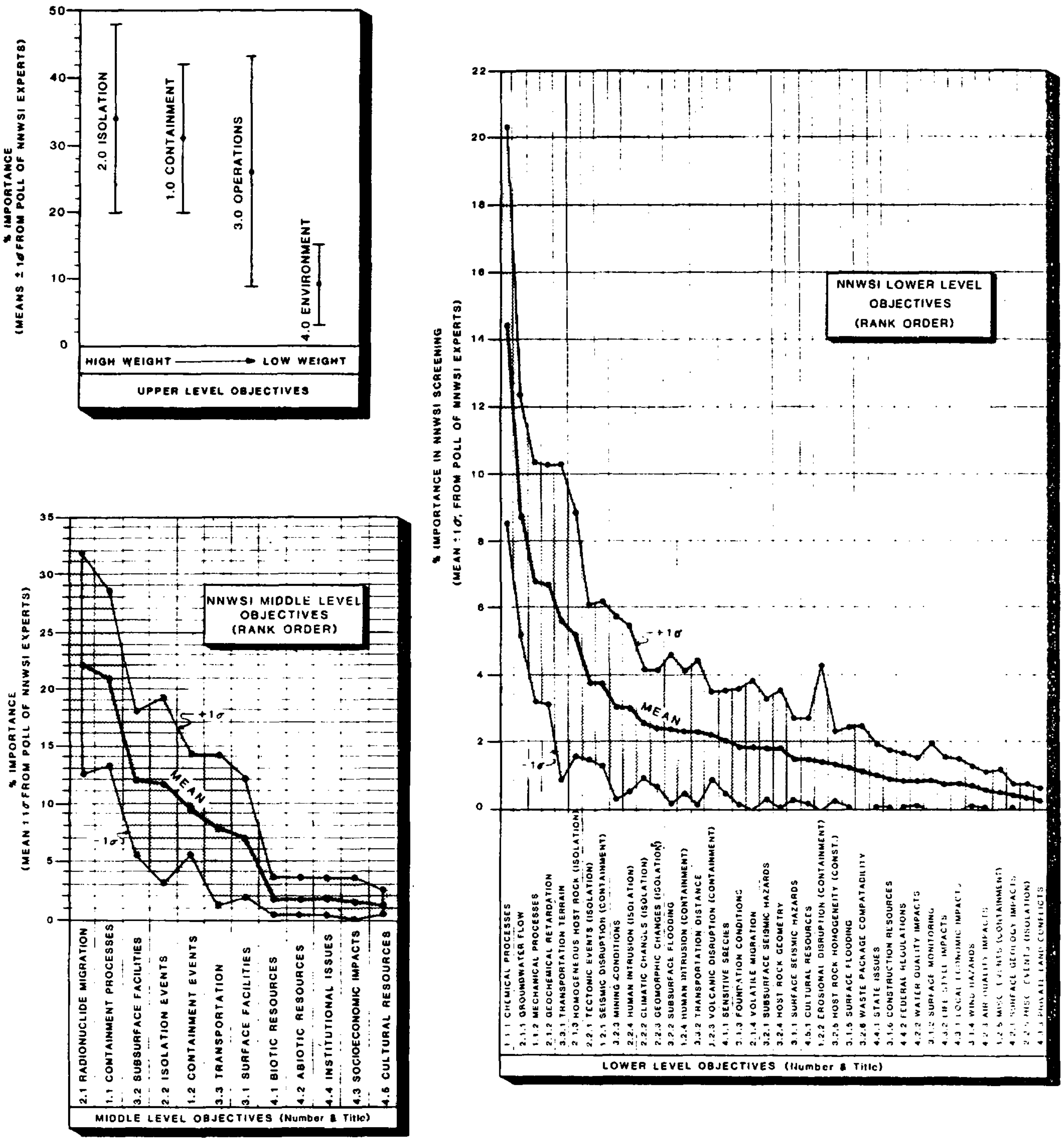


Figure 3. Performance Objectives Ordered by Average Weight (See Table 2 for plotted values.)

Table 4. Attribute-Objective Matrix With Weights Assigned to Attributes

OBJECTIVES (WEIGHTS IN PARENTHESES)

OVERALL GOAL: PROVIDE SAFE, EFFECTIVE & ENVIRONMENTALLY SOUND RADIOACTIVE WASTE DISPOSAL

LEVEL 1: 1.0 PROVIDE CONTAINMENT (31%); 2.0 PROVIDE ISOLATION (34%); 3.0 PROVIDE SAFE COST EFFECTIVE CONSTRUCTION & OPERATIONS (30%); 4.0 PROVIDE ACCEPTABLE ENVIRONMENTAL IMPACTS (5%)

LEVEL 2: 1.1 DISRUPTIVE PROCESSES; 1.2 DISRUPTIVE EVENTS; 2.1 RADIONUCLIDE MIGRATION; 2.2 DISRUPTIVE EVENTS; 3.1 SURFACE FACILITIES; 3.2 SUBSURFACE FACILITIES; 3.3 TRANSPORTATION SYSTEMS; 4.1 BIOTIC SYSTEMS; 4.2 ABIOTIC SYSTEMS; 4.3 SOCIOECONOMIC IMPACTS; 4.4 INSTITUTIONAL IMPACTS; 4.5 CULT. RES. (10%)

ATTRIBUTES (WEIGHTS AT MATRIX INTERSECTIONS)

Attribute	1.1.1 Chemical	1.1.2 Mechanical	1.2.1 Seismic	1.2.2 Erosional	1.2.3 Volcanic	1.2.4 Human intrusion	1.2.5 Miscellaneous	2.1.1 Groundwater flow	2.1.2 Nuclide retard.	2.1.3 Host rock thick.	2.1.4 Volatile migration	2.2.1 Tectonic	2.2.2 Climatic	2.2.3 Geomorphic	2.2.4 Human induced	2.2.5 Misc. & complexity
GEOGRAPHICAL – TECTONIC/SEISMIC: 1 Volcanic potential			5		100							40				
2 Fault density	5							5			10					80
3 Fault trend			5									10				
4 Age of faulting			20									10				
5 Natural seismic potential			50									20				
6 Weapons seismic potential							100								10	
GEOLOGIC/SURFACE: 7 Bed attitude (rock dip)																50
8 Erosion potential				100										60		
9 Flood potential														10		
10 Terrain ruggedness														10		50
11 Rare & precious metal resource pot.						50									40	
HYDROLOGICAL: 12 Groundwater resource potential						50									40	
13 Groundwater flux	5							10	10							
14 Groundwater flow direction								20								
15 Thickness of unsaturated zone								5					100			
ENVIRONMENTAL: 16 Sensitive floral species																
17 Sensitive faunal species																
18 Revegetation potential																
19 Known cultural resources																
20 Potential cultural resources																
21 Air pollution potential																
INSTITUTIONAL: 22 Permitting difficulties																
23 Private land use																
HOST ROCK – GEOMECHANICAL: 24 Thermal conductivity	20	20														
25 Compressive strength (containment)		40								30						
26 Compressive strength (construction)																
27 Expansion-contraction		20														
GEOCHEMICAL: 28 Mineral stability	10	10							10		5					
29 Stratigraphic setting									70	80	20					
30 Hydraulic retardation								10	10		10					
HYDROLOGICAL: 31 Hydraulic transmissivity	80							40			40					

Attribute	3.1.1 Seismicity	3.1.2 Monitoring reqm'ts	3.1.3 Foundation cond.	3.1.4 Wind loads	3.1.5 Flooding	3.1.6 Avail. nat. res.	3.2.1 Seismicity	3.2.2 Flooding	3.2.3 Mining cond.	3.2.4 Host rock geom.	3.2.5 Host rock hydrog.	3.2.6 Waste pkg. accept.	3.3.1 Terrain	3.3.2 Existing corridor	4.1.1 Sensitive sys.	4.2.1 Surface geology	4.2.2 Water quality	4.2.3 Air quality	4.3.1 Local economics	4.3.2 Life styles	4.3.3 Land use	4.4.1 State issues	4.4.2 Federal regs.	4.5.1 Archl. & hist. sites
GEOGRAPHICAL – TECTONIC/SEISMIC: 1 Volcanic potential																								
2 Fault density							10	10	20		50													
3 Fault trend																								
4 Age of faulting																								
5 Natural seismic potential	90						85																	
6 Weapons seismic potential	10						5																	
GEOLOGIC/SURFACE: 7 Bed attitude (rock dip)										100	40													
8 Erosion potential			10																					
9 Flood potential			20		100			5					30			[illegible]								
10 Terrain ruggedness		70	70										70			[illegible]								
11 Rare & precious metal resource pot.											10													
HYDROLOGICAL: 12 Groundwater resource potential																	100							
13 Groundwater flux								10																
14 Groundwater flow direction								10	10															
15 Thickness of unsaturated zone																								
ENVIRONMENTAL: 16 Sensitive floral species		5													40									
17 Sensitive faunal species		7													50									
18 Revegetation potential															10									
19 Known cultural resources		8																						30
20 Potential cultural resources		10																						70
21 Air pollution potential																		100						
INSTITUTIONAL: 22 Permitting difficulties																							100	
23 Private land use																					100			
HOST ROCK – GEOMECHANICAL: 24 Thermal conductivity									10			20												
25 Compressive strength (containment)																								
26 Compressive strength (construction)									40															
27 Expansion-contraction												40												
GEOCHEMICAL: 28 Mineral stability									10			40												
29 Stratigraphic setting																								
30 Hydraulic retardation																								
HYDROLOGICAL: 31 Hydraulic transmissivity								20	10															

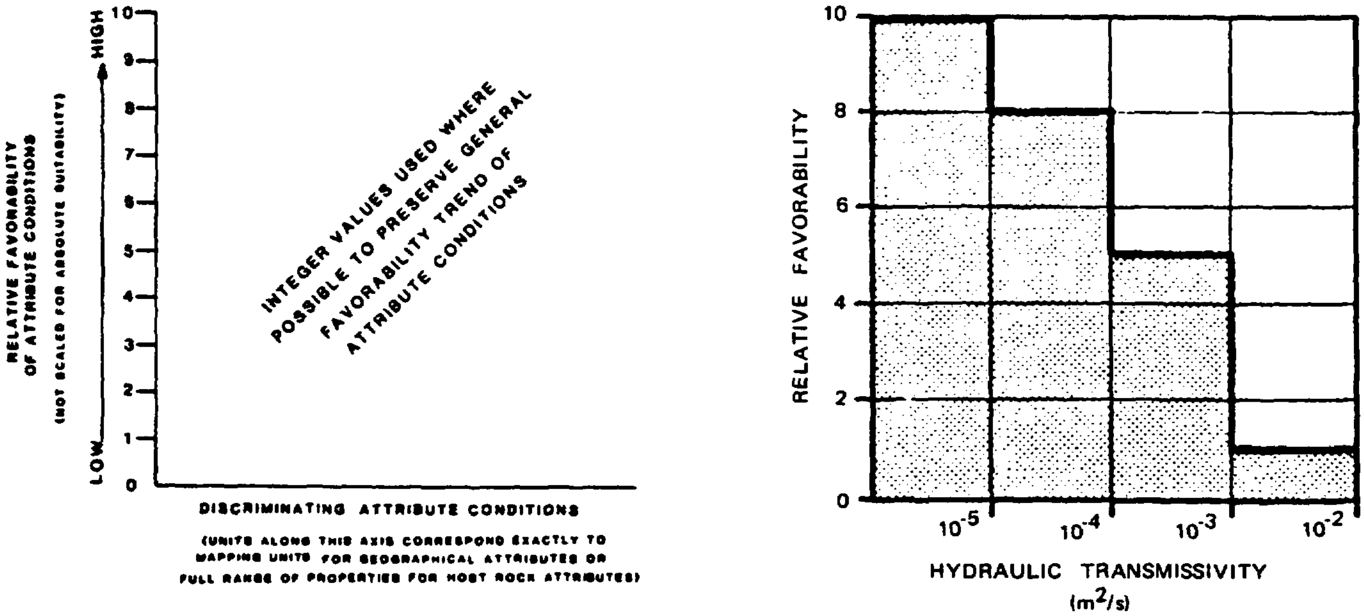


Figure 4. General Form of Favorability Graphs (left) and an Example for Hydraulic Transmissivity (right)

Favorability values of zero were generally reserved for possibly exclusionary conditions such as the presence of Quaternary faults, private land, or extensive mineral deposits. However, no reasons are known that establish these conditions as necessarily exclusionary. Nonetheless, their definition as "undesirable conditions or features" in draft NRC technical criteria for geological repositories[5] warranted drawing attention to such conditions by assigning them a favorability of zero. In this screening, the zero values were only used as nonexclusionary. The range of favorability numbers for each attribute generally encompasses the largest range from 0 to 10 compatible with simple graphs. This provides as much discriminating capability as possible for each attribute.

With one exception, the general trend of favorabilities for attributes used to assess more than one objective is the same for each of the different objectives. Therefore, only one favorability graph was required for most attributes. The exception, compressive strength of host rocks, requires two separate graphs: one for mining objectives and one for containment and isolation objectives.

Location and Host-Rock Rating Process

Ratings were calculated for each of 1514 half-mile-square grid cells* that make up the screening area and for each of the nine candidate host rocks. Each attribute map was digitized on an APPLICON Graphics System (AGS) by assigning Z values to the mapping units (Figure 5). Favorability numbers from the favorability graphs were also digitized. By replacing mapping unit numbers on the base map with corresponding favorability numbers, a favorability surface was generated for each attribute. Z values (or elevations) on these surfaces correspond to the favorability of the attribute at each grid cell (Figure 6).

*Alternative locations in the screening area are strictly defined as these one-half mile square grid cells. Each of these grid locations is separately evaluated by data digitized and processed on an APPLICON Graphics System. Repository locations were identified from the screening results where about 40 or more contiguous grid cells (~10 sq mi) were rated similarly.

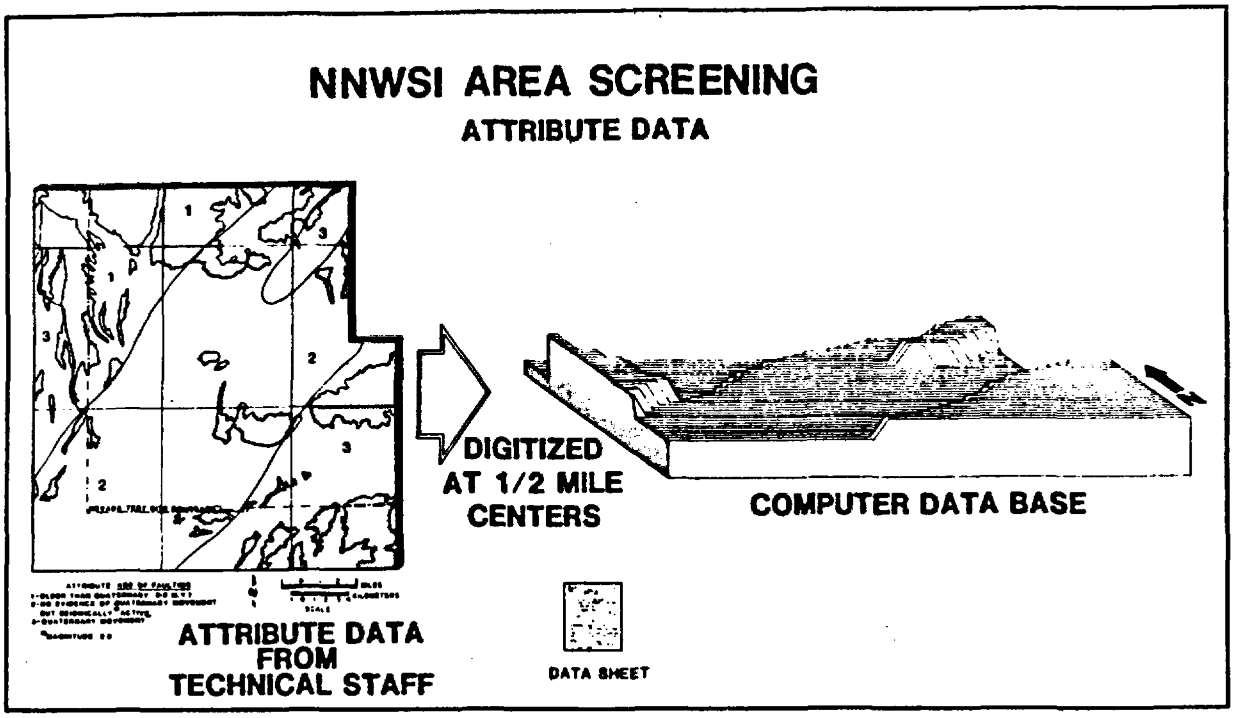


Figure 5. Example of Digitized Attribute Map

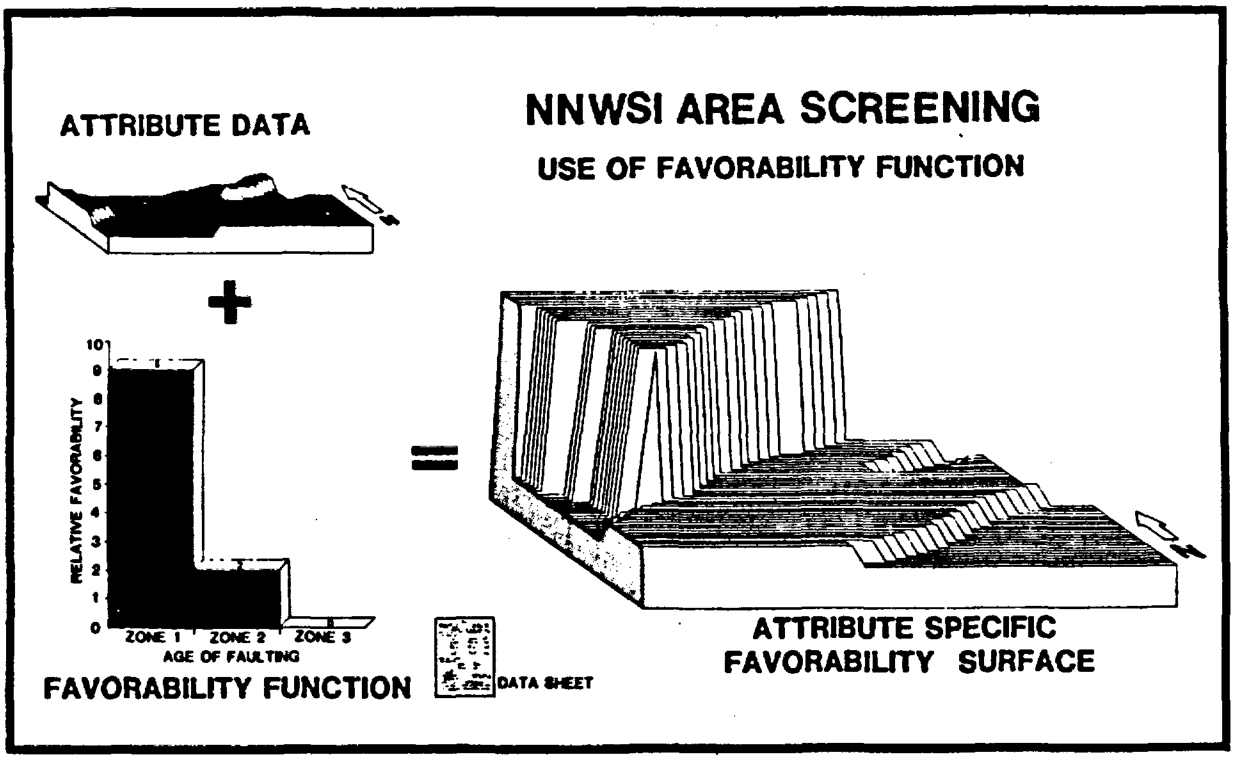


Figure 6. Example of Digitized Favorability Surface for One Attribute

Weights for the objectives and attributes were also digitized (Figure 7). These weights were organized in the computer as a matrix analogous to Table 4. The weights assigned to objectives and attributes can be changed easily at an interactive cathode ray tube (CRT) terminal of the APPLICON computer. Different results of rating calculations based on different weights were obtained in this manner.

Ratings were calculated for alternative locations using the weights and favorability values of attributes 1 through 23. Host-rock ratings were based only on attributes 24 through 31. The weight for each attribute-objective intersection of the matrix was multiplied by the appropriate favorability values of the corresponding attributes. The weighted favorability values from all attribute-objective matrix intersections were summed for each grid cell of the base map. This produced a map of 1514 individual favorability scores for the screening area. In this manner, each of the 1514 grid cells is (in effect) an alternative location with its own rating.

Ranges of rating values were displayed on the base map providing a graphical image of locations with greater or lesser favorability. Though each grid cell is strictly an alternative location, distinct locations for repositories were interpreted to occur where ~40 contiguous grid cells (~10 sq mi) were rated similarly. Because of uncertainties inherent in the many assumptions used in screening, confident discrimination among various locations is probably limited to about three meaningful categories: favorable, neutral, and unfavorable.

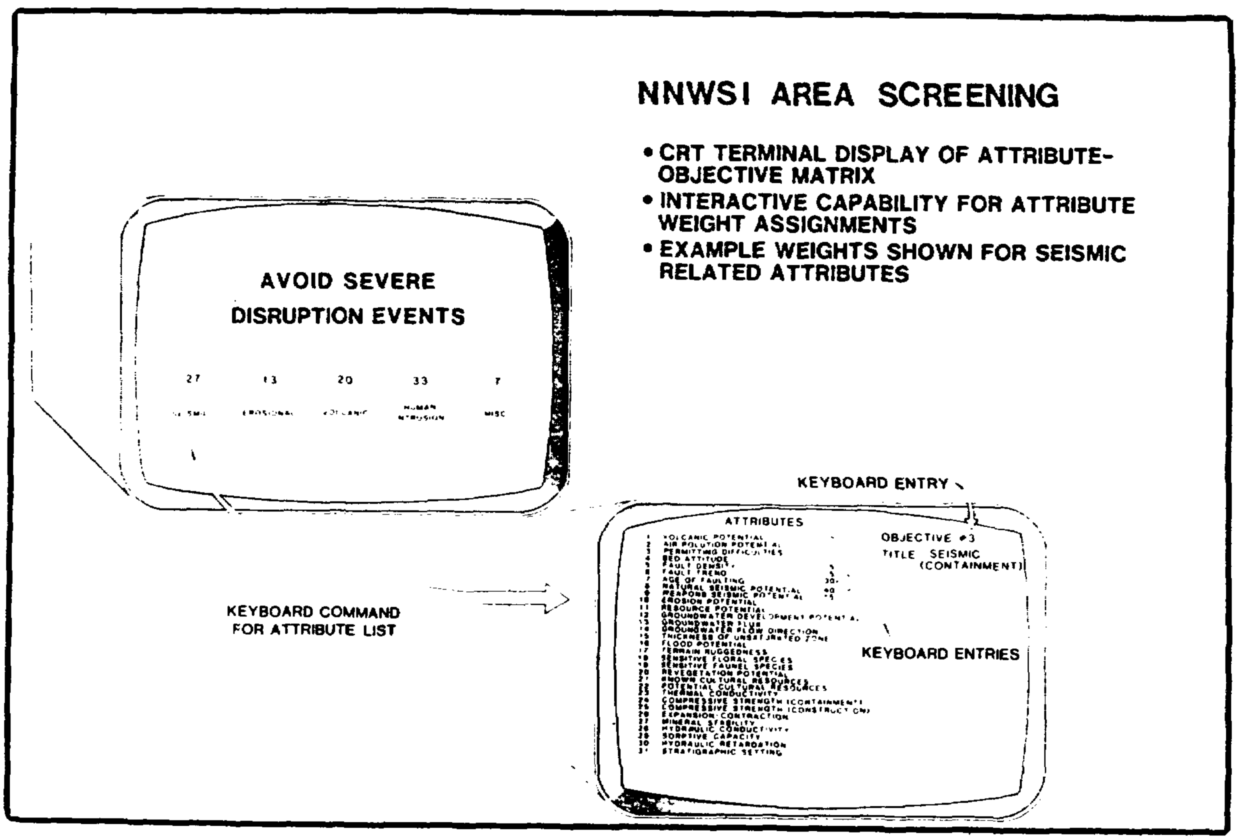


Figure 7. Example of How Weights for Objectives and Attributes Can Be Changed at CRT Terminal

Host-rock ratings were obtained by the same process. Because the host-rock attributes do not vary geographically for a single rock type, but do vary from rock type to rock type, host-rock calculations were repeated only for each of the nine rock types rather than for each geographic grid cell. Outputs of host-rock evaluations were lists of rating numbers for each of the nine potential host rocks. These values can be assigned to the geographical grid cells corresponding to the subsurface distribution of appropriate rocks yielding a geographical rating that includes the contribution of host-rock attributes.

The process for calculating ratings (R) for each half-mile square cell of the base map or each host rock can be summarized as follows:

$$R = \sum_{i=1}^{m} \sum_{j=1}^{n} F_j W_{ij} \qquad (2)$$

where

m = the total number of lower-level objectives
n = the total number of attributes
i = the lower-level objective number
j = the attribute number
F_j = the favorability value for the j^{th} attribute at the grid cell or host rock in question
W_{ij} = the weight of the j^{th} attribute applied to the i^{th} objective and is obtained by multiplying the weight of the i^{th} objective from Table 2, column 12, by the weight of the appropriate j^{th} attribute from Table 4.

Interactive capabilities of the AGS terminals permitted the sensitivity of screening results to various assumptions about the weights to be easily investigated. The method by which various weighting assumptions were investigated was to assign all the weight to selected subsets of objectives or attributes. This allowed assessments of which combinations of objectives or attributes are responsible for high and low ratings of different locations and host rocks in the screening area.

1.0 Identify Locations Capable of Adequate Radionuclide Containment

Description

Containment implies maintaining radioactive wastes within prescribed boundaries for a given length of time and for controlling release rates after that time (e.g., within the waste package and backfill envelope). In lieu of acceptable release rates yet to be specified by regulatory agencies, this objective pursues little or no release of radionuclides from the waste package for long periods of time.

This objective corresponds to Objective 1 of the US Department of Energy's Waste Confidence Rulemaking,[10] which states

> "Waste containment within the immediate vicinity of initial placement should be virtually complete during the period when radiation and thermal output are dominated by fission product decay. Any loss of containment should be a gradual process which results in very small fractional waste inventory release rates extending over very long release times; i.e., catastrophic losses of containment should not occur."

Containment is an essential element in the overall scheme of preventing radionuclide release from a repository to the human environment (hereafter called the accessible environment). The parallel concept is isolation (i.e., the prevention of radionuclide migration from the emplacement rock to the accessible environment after or if containment is lost (see Objective 2.0)). Containment and isolation are two separate elements of the multiple barrier concept; i.e., successive "barriers" or factors that independently inhibit waste release and/or transport to the accessible environment. Knowledge about both barriers is critically important for assessing long-term safety of repository sites; i.e., ensure that no radioactive releases from a repository result in unacceptable doses to future generations. Containment and isolation together comprise the design elements of the repository concept that ensures long-term safety for humans with respect to radioactive wastes from the nuclear fission energy cycle. Figure 21 in Reference 2 shows location and host-rock ratings based solely on the upper-level containment objective.

The upper-level objective for containment is divided into two middle-level objectives that address distinct components: i.e., expected processes and unexpected but possible disruptive events. Each of these middle-level objectives, in turn,is subdivided into a set of lower-level objectives that make up distinct components of the respective middle-level objective.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- "The mined geologic disposal system shall provide the capability to adequately *contain* and isolate radionuclides to ensure that no releases resulting in unacceptable doses to the public occur." (Emphasis Added) [Requirement 3.1.2]
- "The site shall provide natural barriers that will effectively *contain* and isolate radionuclides. Thus, the site must provide capabilities to (1) *contain the waste*, (2) isolate the waste from man, and (3) assist in keeping man away from the waste." (Emphasis Added) [Requirement 3.2.2, para 1]
- "The mined geologic disposal system shall meet all applicable standards and shall *contain* and isolate radioactive wastes to the extent necessary to ensure that releases of radionuclides to the biosphere do not result in an unacceptable increase in doses to individuals and to the general population." (Emphasis Added) [Criterion 4.2]

NWTS-33(2)[4]

- "The geohydrologic regime in which the site is located shall have characteristics compatible with waste *containment*, isolation, and retrieval." (Emphasis Added) [Criterion 3.2, para 1]
- "The site shall have geochemical characteristics compatible with waste *containment*, isolation, and retrieval." (Emphasis Added) [Criterion 3.3, para 1]

- "The site shall have geologic characteristics compatible with waste *containment*, isolation, and retrieval." (Emphasis Added) [Criterion 3.4, para 1]

10 CFR 60 (Proposed)[5]

- "The engineered system shall be designed so that even if full or partial saturation of the underground facility were to occur, and assuming anticipated processes and events, the waste package will contain all radionuclides for at least the first 1,000 years after permanent closure." [§60.111(b) (2) (i)]
- "For HLW, the engineered system shall be designed so that, after the first 1,000 years following permanent closure, the annual release rate of any radionuclide from the engineered system into the geologic setting, assuming anticipated processes and events, is at most one part in 100,000 of the maximum amount of that radionuclide calculated to be present in the underground facility (assuming no release from the underground facility) at any time after 1,000 years following permanent closure." [§60.111(b) (2) (ii) (A)]
- "During the containment period, the geologic setting shall mitigate the impacts of premature failure of the engineered system." [§60.111(b) (3) (i)]

Relative Importance

Containment of wastes at the site of emplacement is one of the most important objectives for repository performance. Both DOE and NRC[3-5] explicitly require significant containment (confinement in NRC terminology) as an essential part of the total repository system. Together with isolation, containment constitutes an element of the overriding objective to provide safety from radiogenic hazards for present and future generations. Considered together, containment and isolation account for about two-thirds of the total importance in location screening. Approximately one-half of the importance for long-term safety or one-third of the total importance for location screening is placed on finding locations that have characteristics that will enhance containment of emplaced wastes.

This weighting is based on the weighting poll that resulted in an average assignment of 31% to the importance of the containment branch of the objectives tree. This makes containment second among the four upper-level objectives in importance, though the difference between weights for containment and isolation may not be statistically significant (Figure 3). However, it is apparent that the poll expressed agreement with a general national consensus that long-term safety is of primary importance and that both containment and isolation capabilities should be considered carefully when siting a repository.

Applicable Attributes

Volcanic Potential
Fault Density
Fault Trend
Age of Faulting
Natural Seismic Potential
Weapons Seismic Potential
Erosion Potential
Metal Resource Potential
Groundwater Resource Potential
Groundwater Flux
Thermal Conductivity
Compressive Rock Strength
Expansion-Contraction Behavior
Mineral Stability
Hydraulic Transmissivity

Fifteen attributes are used to rate expected performance of alternative locations with respect to containment. This is achieved by using a distinctive set of host-rock and geographical attributes for evaluating performance for each of the seven subobjectives comprising the lower-level of this branch of the objectives tree (sections for Objectives 1.1.1, 1.1.2, and 1.2.1 through 1.2.5). Thus, containment potential of alternative locations is evaluated by summing the contributions to containment provided by attributes addressing component lower-level objectives. The importance of the attributes is about equally divided between host-rock and geographical attributes. The host-rock attributes primarily address expected near-field concerns (Objective 1.2) whereas the geographical attributes primarily address the potential for unexpected, far-field disturbances to containment.

1.1 Screen for Natural Systems With Potential to Resist Processes That Might Degrade Waste Packages

Description

This objective calls for locations where normally expected, natural processes will maintain wastes in their emplacement positions for very long periods of time. Interactions between a waste package and surrounding natural systems can be either chemical or mechanical. These two types of interactions may lead to containment failure; together they comprise a comprehensive set of processes that may result in the escape of radionuclides from their emplacement positions. Processes refer to changes toward equilibrium conditions, including those changes induced by emplacement of the wastes. Whether chemical or mechanical processes will occur in and around waste packages is not in question; they will. Therefore, this screening seeks settings for waste emplacement with natural conditions that minimize the effects of these changes, both on the initiation of release of radioactive components from waste packages and on subsequent release rates. Avoidance or reduction of waste-package disruption processes depends, at least in part, on conditions of the natural environment that may vary from location to location. Therefore, this objective pursues locations where natural conditions retard these disruptive processes. This middle-level objective is divided into two component lower-level objectives that address chemical and mechanical processes which might disrupt containment.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall provide a geologic system which can be shown to accommodate anticipated geomechanical, chemical, thermal, and radiological stresses caused by waste/rock interactions." [Criterion 3.4(2)]

10 CFR 60 (Proposed)[5]

- No specific correlative requirements.

Relative Importance

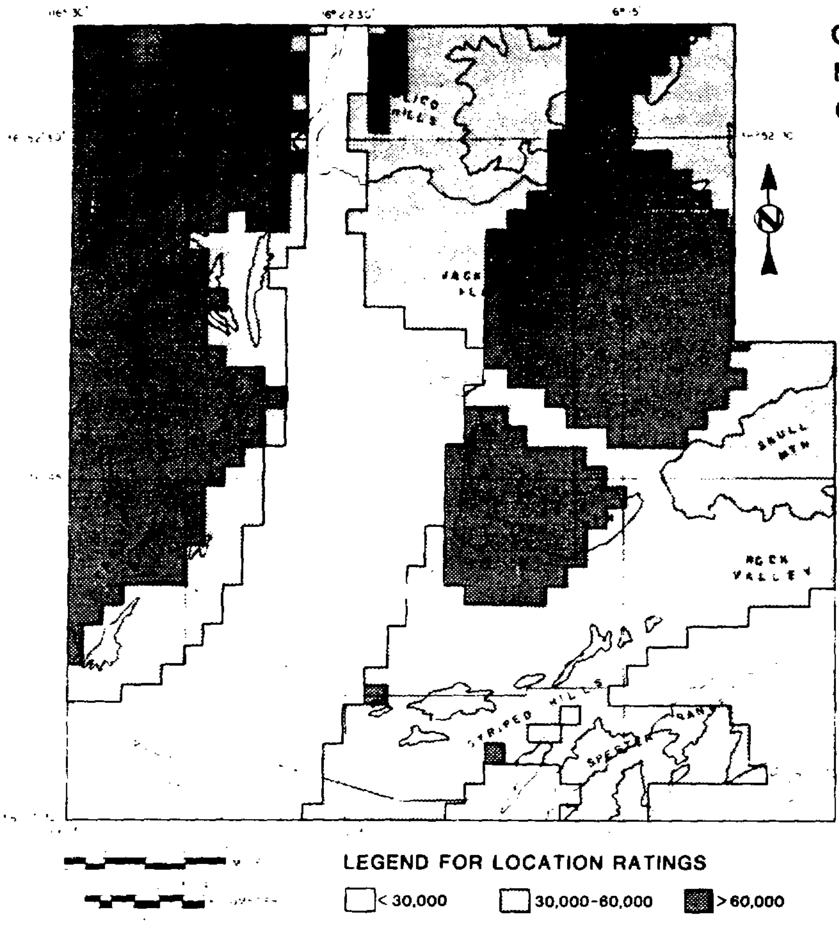
With rare exceptions, containment will be lost only when some process acts slowly upon the emplaced waste containers. Expected processes that may degrade containment are considered more important than low-probability events that may or may not disrupt containment. Processes that might disrupt containment have been identified in laboratory experiments and theoretical studies. Though disruption rates and/or consequences may be very low, the occurrence of some disruption is almost certain. Bounding and, if possible, mitigating the effects of these processes is paramount in assuring a predictable degree of containment. About two-thirds of the total importance of the containment branch of the objectives tree is assigned to finding locations where these processes are expected to be relatively benign. This is based on the weighting poll that resulted in an average assignment of 68% to the process branch of containment objectives. Because the containment branch as a whole was assigned 31%, about 21% of the overall importance for location screening was assigned to reducing deleterious aspects of natural processes that will interact with waste packages making this objective second in importance among the 12 middle-level objectives (Figure 3).

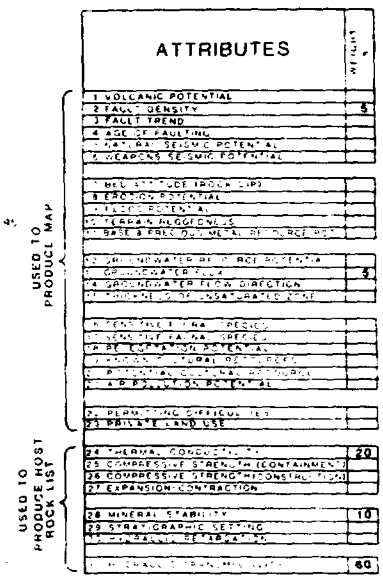
Applicable Attributes

Fault Density
Groundwater Flux
Thermal Conductivity
Compressive Rock Strength
Expansion-Contraction Behavior
Mineral Stability
Hydraulic Conductivity

These seven attributes are used to rate expected performance of alternative locations with respect to this objective. This is achieved by using a distinctive set of attributes for evaluating performance for each of the two subobjectives that comprise the lower-level of this branch of containment (Sections 1.1.1 and 1.1.2). These attributes predominantly address host-rock characteristics, because chemical and mechanical interactions that will affect containment are overwhelmingly controlled by near-field conditions.

OBJECTIVE 1.1.1
MINIMIZE DISRUPTION CHEMICAL PROCESSES





HOST ROCK RATINGS

AGE	ROCK TYPE	RATING*
YOUNGER	Alluvium	43,000
	Basalt	58,000
	Non-welded Paintbrush Tuff	63,000
	Topopah Spring Tuff	34,000
	Calico Hills Tuff	73,000
	Crater Flat Tuff	77,000
	Granite	100,000
	Argillite	86,000
OLDER	Carbonate	40,000

* Based on Attributes 24,28&31 only

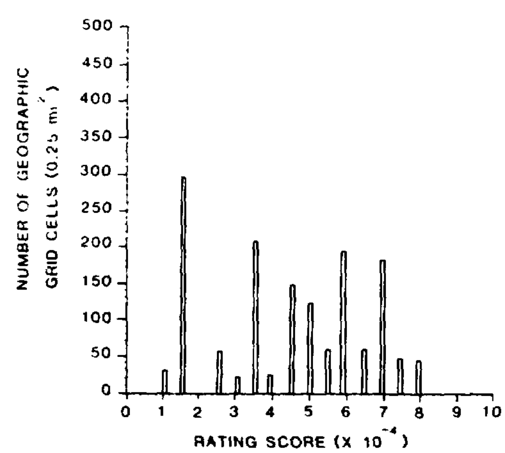


Figure 8. Objective 1.1.1—Minimize Disruption Chemical Processes. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting the potential for chemical release, weighted according to the attribute list (upper right). Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map; table (lower right) shows the rating values of nine potential host-rock types based on rock attributes affecting potential chemical releases; also weighted according to the attribute list (upper right). The sum of attribute weights is 100%; the maximum possible rating value for locations or host rocks is 100 000.

1.1.1 Minimize Potential for Chemically Induced Release

Description

Locations will be sought where chemical processes acting on emplaced wastes are expected to be relatively benign. Chemical release of radioactive wastes from the waste package will probably be caused by solution of waste package components (including radionuclides) in groundwater circulating past the package. Other possible (but less likely) chemical release mechanisms include migration of radioactive gases (predominently krypton) out of the waste package through fissures and cracks and solid-state diffusion of radioactive elements into the surrounding rock. The release of gases is of concern primarily for spent fuel (assuming krypton would be separated from solid wastes during reprocessing) and only for the first hundred years or so out of the reactor; after that krypton will have decayed to innocuous levels.[14] Chemical solution of wastes in groundwater can be discouraged by selecting locations that have reducing groundwater (low Eh, that in most cases lowers reactivity) and pH levels (generally 6 through 8) that would reduce the reactivity of most radionuclides. Slow-moving groundwater and restricted-flow regimes will limit the maximum rate at which radionuclides can be dissolved by setting an upper limit on the amount of waste required to obtain saturation conditions per unit time. If wastes are emplaced in an unsaturated environment, the flux of water past the waste packages is likely to be lower, *cet par.*, than if wastes are emplaced in a saturated zone. If radionuclides are not chemically released to circulating groundwater, the potential for transport of waste contaminants to the accessible environment is essentially nil. This screening does not address the relative capabilities of alternative, engineered waste-package systems to retard radionuclide release. Therefore, the objective is to select locations with natural, existing conditions that will inhibit or prevent chemical processes, including those induced by waste emplacement. With rare exceptions, no loss of containment and, by extension, no loss of isolation can occur unless wastes are somehow dissolved in some transporting medium that can move wastes to the accessible environment. By far the most likely transporting medium is groundwater. Thus, this objective means, in essence, avoiding conditions that facilitate solution of wastes in groundwater. Figure 8 shows location and host-rock ratings based solely on this objective.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located so that the present and probable future geohydrological regime will *minimize contact between groundwater and wastes* and will prevent radionuclide migration or transport from the repository to the accessible environment in unacceptable amounts." (Emphasis Added) [Criterion 3.2(1)]
- "The site shall be located so that subsurface rock dissolution that may be occurring, or is likely to occur, can be shown to have no unacceptable impact on system performance." [Criterion 3.2(4)]
- "The site shall be located so that the chemical interactions between radionuclides, rock, groundwater, or engineered components will not unacceptably affect system performance." [Criterion 3.3(1)]
- "The site shall provide a geologic system which can be shown to accommodate anticipated geomechanical, *chemical*, thermal, and radiological stresses caused by waste/rock interactions." (Emphasis Added) [Criterion 3.4(2)]

10 CFR 60 (Proposed)[6]

[Potentially Adverse Conditions]

- "Evidence of dissolutioning of soluble rocks." [§60.123(b) (5)]
- "Conditions in the host rock that are not reducing conditions." [§60.123(b) (13)]
- "Groundwater conditions in the host rock, including but not limited to high ionic strength or ranges of Eh-pH, that could affect the solubility and chemical reactivity of the engineered systems." [§60.123(b) (14)]

Relative Importance

Avoiding expected chemical processes that may rapidly degrade containment is considered the single most important of the 40 lower-level objectives. If solution of emplaced wastes in groundwater can be avoided, the chances are exceedingly low that wastes will be transported to the accessible environment. Thus, high importance is given to seeking natural geochemical conditions that are expected to act very slowly (if at all) on emplaced wastes. About two-thirds of the importance of the "process" branch of the containment objectives was assigned to chemical disruption processes. This is based on the weighting poll that resulted in an average assignment of 68% to the chemical side of the process branch of containment objectives. Because the process branch itself was assigned an average weight of 21%, this objective accounts for about 14% of the total importance for location screening; thus, this objective is the most important of the 40 lower-level objectives in the NNWSI area-to-location screening (Figure 3).

However, parametric studies indicate that waste-package performance is relatively unimportant in providing long-term isolation of wastes.[15,16] These conclusions are based on assumptions that geologic systems provide more than 1000 yr of far-field isolation and that draft NRC release limits[5] are the standards for judging performance. Near-field containment is crucial to meeting release standards if geologic isolation systems fail within the first few hundred years after emplacement. Thus, avoidance of near-field disruptive chemical processes is important only as an independent barrier in a multiple-barrier system that includes, but does not entirely rely on, far-field geologic isolation. If the geologic isolation system performs as expected, the importance of near-field containment (i.e., chemical processes that facilitate waste stability) becomes less important to assuring isolation of wastes from man.

Applicable Attributes

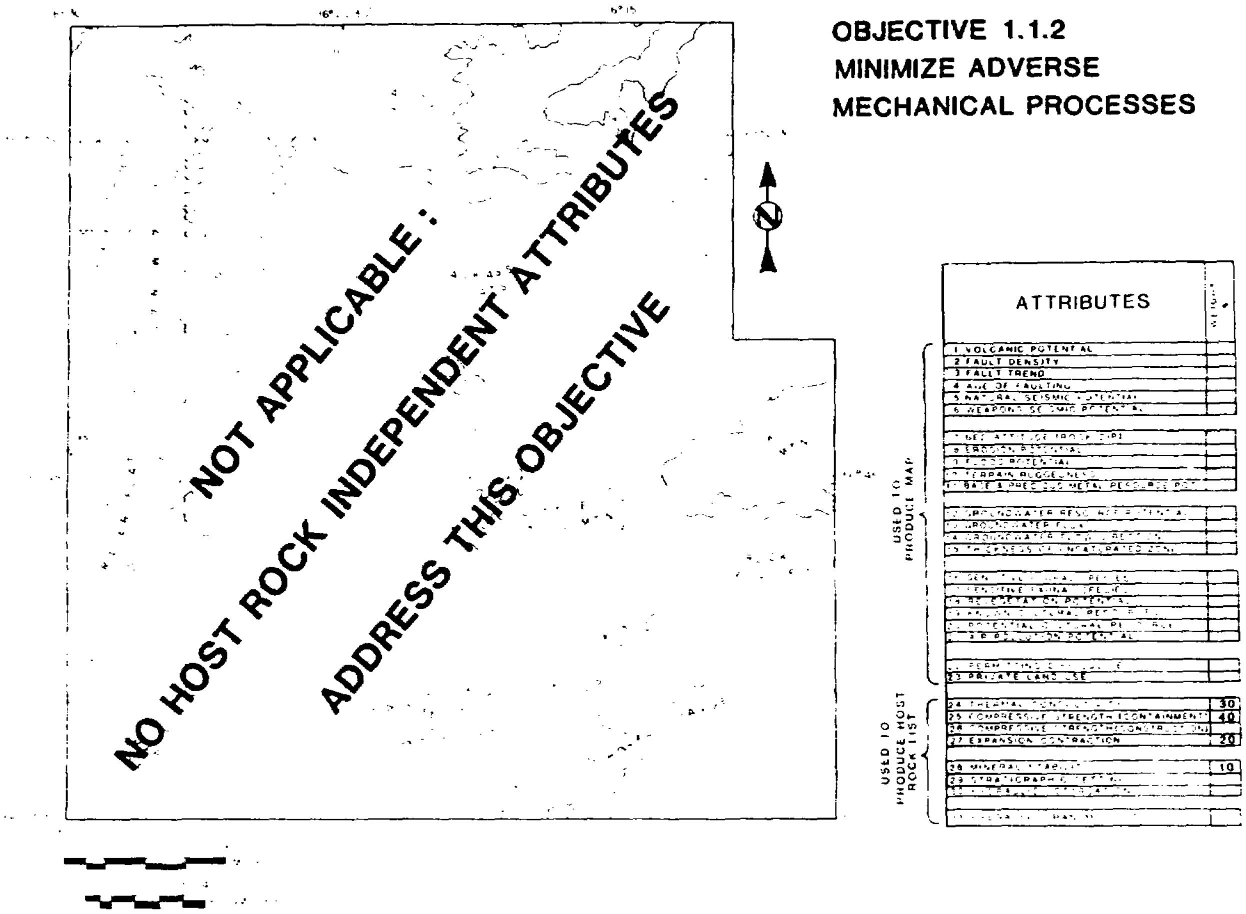
Hydraulic Transmissivity
Groundwater Flux
Thermal Conductivity
Mineral Stability
Fault Density

Attributes selected to rate alternative locations with respect to the potential for chemically induced releases are those that affect the ability of groundwater to reach and react with waste packages. The amount and chemical characteristics of groundwater that ultimately will contact the waste canister will determine the leaching rate of waste package components. Two elements of the hydrologic environment that influence chemical release are groundwater chemistry and hydraulics of the structural-stratigraphic setting that will determine the amount of groundwater access to the waste package.

Fault density provides indirect information about hydraulics of the structural setting. An area with a greater density of faults may possess more fractures that transmit water and a resulting greater potential for groundwater to reach and dissolve waste packages. Also, faults may be barriers to groundwater flow, thus aiding waste package stability. Fault density data are available only for the mountain ranges and restricted portions of the alluvial valleys.

Groundwater flux and hydraulic transmissivity are attributes that give more direct and reliable indications of the amount of water potentially reaching waste packages. In the vicinity of waste packages, additional mechanical stresses induced by thermal expansion of the surrounding rock mass caused by waste-decay heat may fracture the nearby rocks and introduce new water pathways to the waste. In addition, the induced heat may accelerate chemical reactions between ambient water and the waste. Thermal conductivity of the rocks will affect the amount of near-field temperature increase and therefore is relevant for assessing waste package performance. Another attribute used to measure the rock mass and mineral response around waste packages is mineral stability, which may affect both the amount of water available for reaction because of mineral dehydration and the ease of water movement caused by mineral contraction or expansion.

Relative weighting of these five attributes for evaluating this objective is based on the presumption that near-field (i.e., host-rock) properties that affect the quantity of groundwater reaching the waste package are most important in assessing chemical release. Hydraulic transmissivity is the most important measure of the ability of a rock mass where waste is emplaced to transport groundwater. Thermal conductivity (a measure of the rock's ability to absorb heat-induced stresses and subsequent fracturing) is ranked second since heat-induced disturbance of the near-field environment may permit easier entrance of additional groundwater. While the remaining three attributes are important measures of the potential for chemically induced releases, they are given lower importance primarily because of their imprecise mapping accuracy and their inability, as geographically mapped, to discriminate among near-field conditions of alternative host rocks. Groundwater flux, in particular, is a measure of paramount importance, but the attribute map does not indicate whether the total flux occurs in one or more restricted-depth intervals or if it is diffused throughout the entire saturated depth.



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	56,500
	Basalt	60,000
	Nonwelded Paintbrush Tuff	56,500
	Topopah Spring Tuff	72,500
	Calico Hills Tuff	54,000
	Crater Flat Tuff	69,000
	Granite	70,000
	Argillite	70,000
OLDER	Carbonates	80,000

Based on Attributes 24,25,27&28 only.

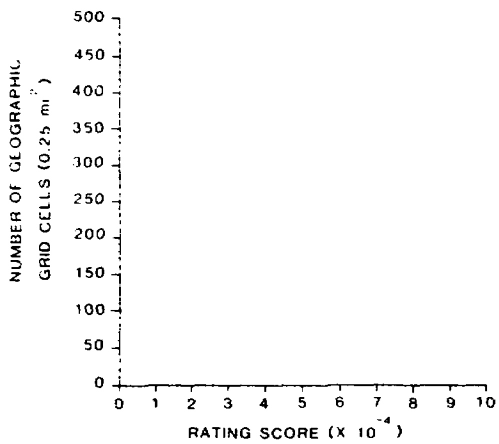


Figure 9. Objective 1.1.2—Minimize Adverse Mechanical Processes. Rating values (table, lower right) of nine potential host-rock types are based on attributes affecting mechanical responses of rocks, weighted according to the attribute list (upper right). The sum of attribute weights is 100%; the maximum possible rating value is 100 000. Since none of the geographical attributes used in screening (1 through 23, upper right) addresses mechanical behavior of specific rocks, no geographical ratings are available for mechanical processes (upper left); therefore, neither are histogram values for the ratings of geographical grid cells (lower left). This objective was used only to help rate rock types and could not be used to help discriminate among alternative locations.

1.1.2 Minimize Potential for Mechanically Induced Release

Description

Locations will be sought where mechanical processes acting on wastes and surrounding rocks are expected to have little effect on containment capabilities. Mechanical processes might directly cause radionuclide releases from emplacement locations or accelerate chemical releases. Such processes include thermophysical processes as excessive thermal expansion of the waste or surrounding rock, rock creep, and subsidence of overburden into the excavated chambers. These processes could induce volumetric change, spalling, or fracturing of the holes in which the waste is emplaced, which, in turn, could cause cracking, buckling, or stretching of waste containers, thereby accelerating access to the waste by groundwater.

Assuming that the waste packages will include some type of backfill material between waste containers and the rock walls of emplacement holes, it is very unlikely that mechanical processes by themselves will cause radionuclides to be released from the waste packages (i.e., to lose containment). Rather, the effects of mechanical processes on the rates of chemical release are of primary concern for this objective. For example, if thermal expansion were to shear a waste package and physically transport part of the solidified waste to a position outside the initial emplacement position (i.e., technically a strict breach of containment), the wastes would still have to be dissolved before they would pose a real containment problem. However, cracking, rupturing, or bending a waste package may provide zones of weakness that are more readily attacked by chemical processes. Mechanical breaking of waste forms may also increase the surface area exposed to chemical attack, thereby accelerating chemical release. Either is sufficient to reduce containment capabilities. In addition, if thermal expansion cracks the rock around a waste package, access to the waste by water may increase, especially during dilation when the rocks around a repository will begin to cool.

Therefore, locations will be sought where natural properties reduce the likelihood of severe mechanical disruption of waste packages and of the nearby rocks under conditions induced by emplacement of heat-generating waste packages. Favorable properties include rocks with low volumetric changes upon heating and high resistance to cracking under stresses induced by heating or excavation. With respect to rock deformation, rocks that behave by ductile rather than brittle deformation are preferred, since ductile rocks are more likely to seal potential conduits for groundwater circulation in the vicinity of waste packages. Figure 9 shows host-rock ratings based solely on this objective; location ratings are unavailable because of lack of relevant attributes.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall provide a geologic system which can be shown to accommodate anticipated *geomechanical*, chemical, thermal, and radiological stresses caused by waste/rock interactions." (Emphasis Added) [Criterion 3.4(2)]

10 CFR 60 (Proposed)[6]

- "The underground facility shall be designed so that the predicted thermomechanical response of the rock will not degrade significantly the performance of the repository or the ability of the natural or engineered barriers to retard radionuclide migration." [§60.132(k) (1)]

[Potential Adverse Conditions]

- "Processes that would reduce sorption, *result in degradation of the rock strength*, or adversely affect the performance of the engineered system." (Emphasis Added) [§60.123(b) (15)]

Relative Importance

Avoiding mechanical processes that may rapidly degrade containment is one of the most important of the lower-level objectives. The relatively high importance is derived from a concern that mechanical deformation of repository host rocks caused by excavation of tunnels and emplacement of heat-producing wastes may permit more circulating groundwater to contact the emplaced wastes or may cause waste containers to break, thereby exposing more waste surface area to corrosion than would occur without the deformation. This could accelerate loss of containment by chemical processes. Thus, the importance of mechanical processes on containment is related to their effects on near-field chemical processes. Therefore, mechanical processes are less important than chemical processes, because chemical processes are the active mechanism by which containment is most likely to be lost. About one-third of the importance of the "process" branch of the containment objective is assigned to avoiding disruptive mechanical processes; the other two-thirds is assigned to chemical processes. This is based on the weighting poll that resulted in an average assignment of 32% to the mechanical side of the process branch of containment objectives. Because the process branch itself was assigned an average weight of 21%, this objective accounts for about 7% of the total importance for location screening, making this objective the third most important of the 40 lower-level objectives (Figure 3).

The relatively high importance of this objective is shown by DOE's extensive research program to characterize the thermal-mechanical properties of candidate host media. However, recent parametric studies indicate that the role of near-field containment is minimal in assessing isolation of buried wastes from man.[15 16] These studies suggest, contrary to common belief, that mechanical processes that affect rocks immediately surrounding a repository may have very little effect on either containment or isolation. It is reasonable to argue that mechanical effects such as cracking of nearby rocks may even enhance isolating qualitities of some near-field geologic systems.[9] Particularly in fracture-flow systems, this may increase the surface area over which geochemically retarding reactions between dissolved waste and rock could occur. It may also increase the cross-sectional area of groundwater flow, thereby reducing flow velocities, other things being equal.

Applicable Attributes

Compressive Strength (containment)
Thermal Conductivity
Expansion/Contraction
Mineral Stability

Attributes for rating alternative locations with respect to the potential for mechanically induced release are those that influence the ease with which groundwater may contact the waste under thermally stressed environments. Mechanical distortions of waste packages could be caused by mechanical behavior in the surrounding rock mass, which in turn is strongly dependent on the mechanical strength of the rock. Thus, compressive sheer strength is an applicable attribute. Stresses and strains caused by expansion of the rock mass could result in the backfill oozing out of the hole or indirect fracturing of the waste package, thereby decreasing the effectiveness of containment. Volumetric contractions caused by mineralogical changes (particularly dehydration of expandable clays, hydrated natural glasses, or certain zeolites) could facilitate creep, resulting in unequal stress distribution and bending or cracking along the length of the waste canister. Such volume changes may also produce wider fractures along which water could more easily migrate toward the waste. Thus, attributes that address rock volume changes (i.e., expansion-contraction behavior and mineral stability) are also relevant for evaluating this objective. These three attributes are dependent on temperature changes, so thermal conductivity is a fourth relevant attribute. Compressive strength directly indicates the resistance of the rock mass to brittle deformation from increased thermal loads and is considered a most important attribute for evaluating this objective. Thermal conductivity is also of high importance because it measures the ability of the rock mass to dissipate heat and thereby reduce thermally induced mechanical stresses or volume changes. Expansion/contraction and mineral stability are very closely related, and their combined importance is about the same as that of each of the other attributes. In situ temperature and in situ stress are also needed to assess the impact of thermal loads on mechanical behavior around waste packages. However, a lack of site-specific information on either of these factors precluded their consideration in screening.

1.2 Screen for Natural Systems With Minimum Potential for Unexpected Events That Might Disrupt Waste Packages

Description

This objective calls for locations where unexpected events that are reasonably likely to occur would not severely disrupt the capabilities of a waste package to contain the wastes, or, alternatively, to avoid locations where such events with potentially severe consequences are reasonably likely. "Events" in this context refer to limited duration changes that result in relatively sudden and complete readjustments of natural thermal, mechanical, or chemical conditions toward equilibrium. This screening therefore considers as events only those occurrences caused by relatively rapid release of accumulated stresses in the natural system. Such events may or may not occur, as opposed to normally expected processes (Objective 1.1). The potential for future disruptive events occurring, as well as the potential consequences of such events, will be considered when evaluating this objective. Areas that have experienced volcanism or faulting during the recent geologic past (Pleistocene and Holocene), that are in or near active earthquake belts, or that have complex tectonic and structural characteristics are inferred to have greater potential than more stable geologic environments for recurrent activity and concomitant disruption of the containment system. Other disruptive events that could result in loss of containment include deep erosion, human intrusion, and miscellaneous occurrences such as meteorite impacts or sabotage. Identification of areas with lower likelihood for these disruptive occurrences will aid the selection of locations that offer more favorable qualities for containment of wastes within the emplaced waste packages. This middle-level objective is divided into five component lower-level objectives that address separate types of potentially disruptive events.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located such that credible tectonic phenomena will not degrade system performance below acceptable limits." [Criterion 3.5]
- "The site shall be located so that its tectonic environment can be evaluated with a high degree of confidence to identify tectonic elements and their impact on system performance." [Criterion 3.5(1)]

10 CFR 60 (Proposed)[5]

[Potentially Adverse Conditions]

- "Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such a magnitude that large-scale surface water impoundments could be created that could affect the performance of the geologic repository through changes in the regional groundwater flow." [60.123(a) (7)]
- "The existence of a fault that has been active during the Quaternary Period." [60.123(b) (6)]
- "Potential for creating new pathways for radionuclide migration due to presence of a fault or fracture zone irrespective of the age of last movement." [60.123(b) (7)]
- "Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or magnitude of earthquakes may increase." [60.123(b) (10)]

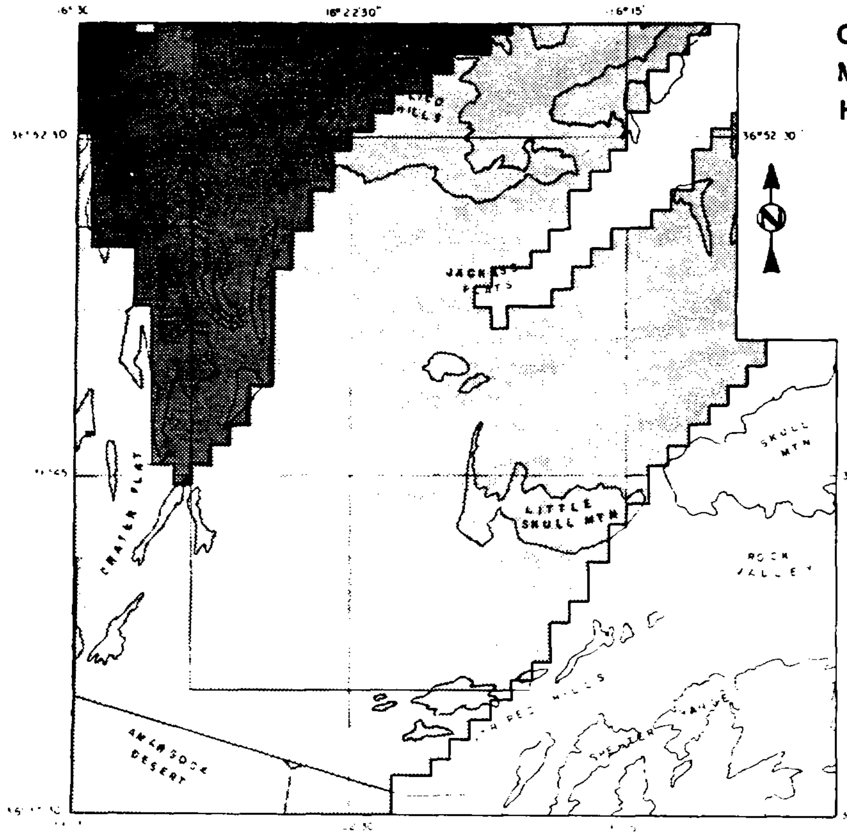
Relative Importance

In the containment branch of the objectives tree, more importance is assigned to finding locations where known, currently active processes are expected to be benign (Objective 1.1) than to this objective for avoiding hypothetical, disruptive events. This assessment of screening priorities reflects judgments about the relative risks associated with expected processes and hypothetical events. Expected processes are based on extrapolations of existing conditions and are judged to dominate the risks from a repository, with some small incremental risk attributable to hypothetical disruptive events. This inference is supported by estimated low probabilities and/or slight consequences associated with many disruptive event scenarios.[17,18] About one-third of the total importance of the containment objective is assigned to finding locations with little likelihood for disruptive events. This is based on the weighting poll that resulted in an average assignment of 32% to the event branch of the containment objectives. Because the containment branch as a whole is assigned 31%, about 10% of the overall importance for location screening at the NTS is assigned to finding locations with relatively low likelihood for containment disrupting events. This makes this objective fourth in importance among the 12 middle-level objectives of the objectives tree.

Applicable Attributes

Volcanic Potential
Fault Trend
Age of Faulting
Natural Seismic Potential
Weapons Seismic Potential
Erosion Potential
Metal Resource Potential
Groundwater Resource Potential

Eight attributes are used to rate expected performance of alternative locations with respect to this objective. This is achieved by using a distinctive set of attributes in evaluating performance for each of the five subobjectives that comprise the lower level of this branch of the tree. These eight attributes all address host-rock independent conditions because the potential for catastrophic disruptions of containment depends on regionally (not stratigraphically) distributed processes. Thus, this middle-level objective is evaluated by summing the contribution to the potential for containment-disrupting events provided by regional characteristics of the screening area.



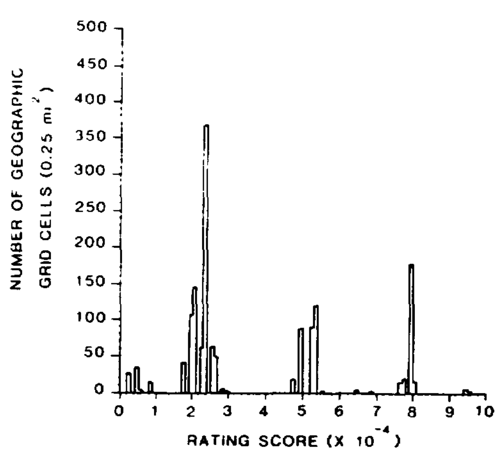
OBJECTIVE 1.2.1 MINIMIZE SEISMIC HAZARDS TO CONTAINMENT

	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	5
	2 FAULT DENSITY	
	3 FAULT TREND	5
	4 AGE OF FAULTING	30
	5 NATURAL SEISMIC POTENTIAL	60
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	

LEGEND FOR LOCATION RATINGS

<20,000 | 20,000–75,000 | >75,000

Based on Attributes 1,3,4&5 only.



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
OLDER	Granite	
	Argillite	
	Carbonate	

Figure 10. Objective 1.2.1—Minimize Seismic Hazards to Containment. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting seismicity, weighted according to the attribute list (upper right). The sum of attribute weights is 100%; histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since none of the attributes addresses the seismic responses of specific rock types, no host-rock ratings are available (lower right); therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

1.2.1 Minimize Potential for Seismic Hazards to Containment in a Sealed Repository

Description

Locations will be sought where seismic activity from natural sources is expected to be low relative to regional seismic patterns (both in historical and recent geological time). Natural seismic hazards can arise from fault movements, earthquakes, or volcanic seisms. Seismic events may produce sufficient ground motion to directly damage a containment system by breaking waste canisters, thereby leading to penetration of groundwater to and eventual solution of radionuclides from waste packages. Vibratory ground motion could also produce new fractures in rock materials around the waste packages, thereby allowing water easier access to wastes. Related hazards that may result from seismic events include landslides and rockfalls that may impound surface waters and temporarily modify the hydrologic environment. Figure 10 shows location ratings based solely on this objective; host-rock ratings are unavailable because of lack of relevant attributes.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located so that Quaternary faults can be identified and shown to have no unacceptable impact on system performance." [Criterion 3.5(2)]
- "The site shall be located so that ground motion associated with the maximum credible earthquake will not have unacceptable impact on system performance." [Criterion 3.5(5)]

10 CFR 60 (Proposed)[5]

- "The geologic setting shall have exhibited structural and tectonic stability since the start of the Quaternary Period." [§60.112(a)]

[Potentially Adverse Conditions]

- "A fault in the geologic setting that has been active since the start of the Quaternary Period and which is within a distance of the disturbed zone that is less than the smallest dimension of the fault rupture surface." [60.123(a) (5)]
- "More frequent occurrence of earthquakes or earthquakes of higher magnitude than is typical of the area in which the geologic setting is located." [60.123(b) (9)]

Relative Importance

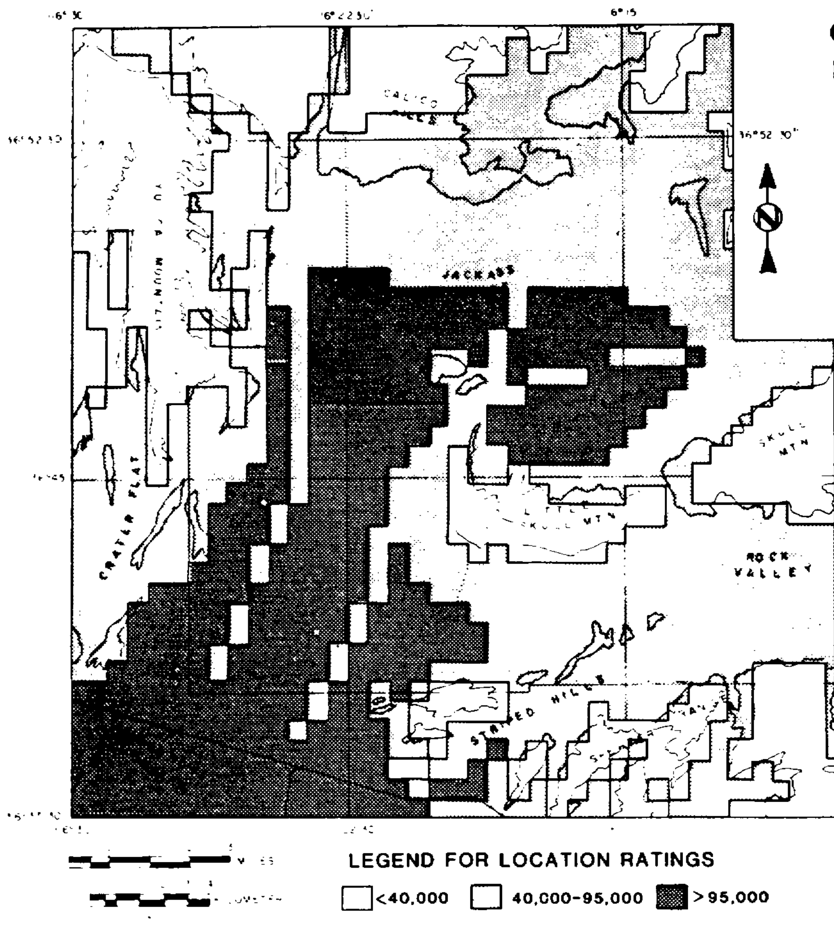
Finding locations with relatively low seismic activity is considered most important for enhancing confidence in preserving expected containment qualities for the required time. The threats that earthquakes and fault movements pose to containment are unclear, but they seem to be related to disturbances of rock, waste-container strength, fracture patterns, and modification of hydrologic flow conditions.[19] However, a general consensus (as reflected in the weighting poll) assumes seismic hazards are the greatest threat to containment of all possible hypothetical events. Perhaps this reflects concerns about the high probability of repeated, low-magnitude seismic activity in the screening area, despite the unformulated mechanisms for serious consequences. The weighting poll resulted in an assignment of about 37% to the relative importance of seismic activity with respect to all containment disrupting events. Because the events branch of containment objectives was assigned a weight of 10% of the overall importance for location screening, this objective accounts for ~3% to 4% of the total importance for screening. Therefore, this objective is the eighth most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

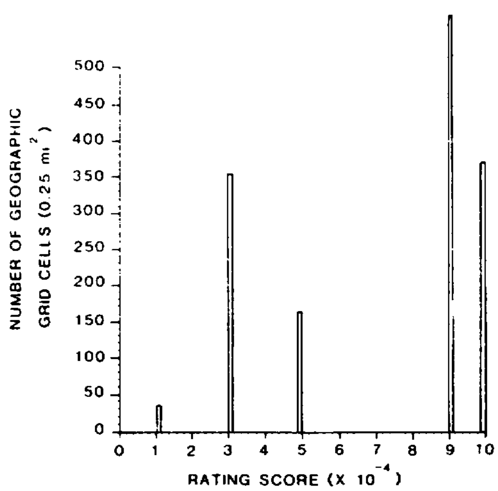
Natural Seismic Potential
Age of Faulting
Fault Trend
Volcanic Potential

Attributes selected to rate alternative locations with respect to seismic hazards to containment are those that correlate with faulting or earthquake potential. Faulting and ground-shaking are the two seismic mechanisms of concern for disrupting containment. No attribute used in this screening directly assesses the potential for faulting through the repository. Natural seismic potential directly addresses the issue of ground motion and is considered the most important attribute for defining seismic-induced hazards because it involves a systematic approach to defining seismic risk. However, this attribute is based primarily on historical seismic activity, whereas the objective addresses long-term containment. The other faulting attributes are indirectly included in the seismic potential map, but address longer term risks. Age

OBJECTIVE 1.2.2
MINIMIZE EROSIONAL HAZARDS



	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	100
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

(Rating column marked: NOT APPLICABLE)

Figure 11. Objective 1.2.2—Minimize Erosional Hazards to Containment. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting erosion, weighted according to the attribute list (upper right). The sum of attribute weights is 100%; histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since none of the attributes addresses susceptibility of specific rock types to erosion, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

of faulting is the second most important attribute for assessing seismic risk, because it directly concerns the long-term geologic record for faulting. Potential for volcanic seisms is not incorporated in the natural seismicity attribute. Therefore, the attribute for volcanic potential is included for indirectly evaluating seismic risk. Fault trend is another indirect measure of the age of faulting. Because of their indirectness, these latter two attributes are of less importance for evaluating seismic risk.

1.2.2 Minimize Potential for Erosional Disruption of Waste Packages

Description

Locations will be sought where the potential is negligible for deep erosion during the next few tens of thousands of years. Erosion of deep chasms or lateral cliff erosion could directly exhume buried waste packages before the radioactivity decays to innocuous levels. Locations can be selected to minimize the likelihood that deep incision or rapid lateral erosion will disrupt the waste deep enough to prevent any conceivable erosion-breaching scenario and by avoiding areas likely to serve as a focus for rapid stream incision such as faults or other linear weaknesses. Avoidance of high, surface-water discharge environments will also reduce the likelihood of deep stream incision. Avoidance of locations near steep, high cliffs will reduce the chance of exhumation of a repository by lateral cliff erosion. Figure 11 shows location ratings based solely on this objective; host-rock ratings are unavailable due to lack of relevant attributes.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located so that long-term, continuing uplift or subsidence rates can be shown to have no unacceptable impact on system performance." [Criterion 3.5(4)]

10 CFR 60 (Proposed)[5]

- "The geologic setting shall have exhibited hydrogeologic, geochemical, and *geomorphic* stability since the start of the Quaternary Period." (Emphasis Added) [§60.112(b)]

[Favorable Conditions]

- "Conditions that permit the emplacement of waste at a minimum depth of 300 meters from the ground surface." [§60.122(i)]

[Potentially Adverse Conditions]

- "Evidence of extreme erosion during the Quaternary Period." [§60.123(b) (4)]

Relative Importance

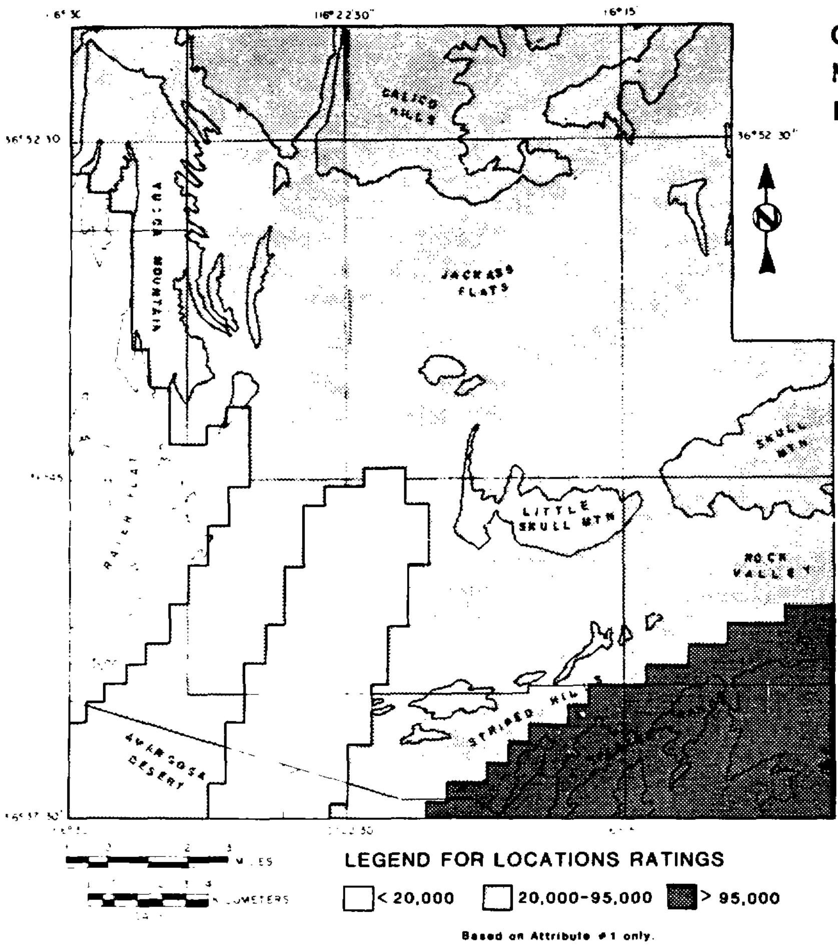
Finding locations with relatively low hazards to containment from erosional activity is, with the exception of miscellaneous events, the least important objective for types of events. This reflects a general consensus that the physical possibility of erosion breaching a deep repository at the NTS is essentially nil in the time period of tens of thousands of years. The arid climate of southern Nevada assures continuation of very slow erosion rates in the mountains and deposition in the basins of the screening area, even under pluvial conditions.[20] In this arid setting, direct erosional hazards to containment are nil, resulting in low importance for erosional concerns in location screening. The weighting poll resulted in an assignment of about 14% to the concerns for containment-threatening erosional events. Since the events branch of containment objectives was assigned a weight of 10%, this objective accounts for about 1.5% of the total importance for screening. Therefore,this objective is the twenty-third most important of the 40 lower-level objectives (Figure 3).

Applicable Attribute

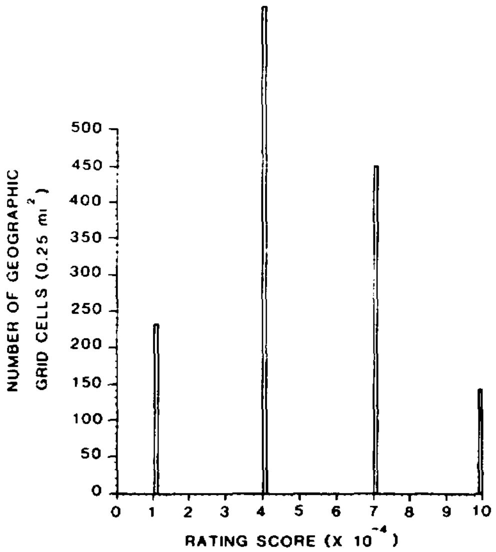
Erosion Potential

This objective is addressed only by a single attribute (erosion potential) that was compiled specifically to rate locations with respect to this objective. It accounts for the effects of bed attitude, flood potential, topographic slope, and elevation. Thus, this attribute is assigned 100% of the importance for evaluating this objective.

OBJECTIVE 1.2.3
MINIMIZE VOLCANIC HAZARDS



	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	100
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	NOT APPLICABLE
	Non-welded Paintbrush Tuff	NOT APPLICABLE
	Topopah Spring Tuff	NOT APPLICABLE
	Calico Hills Tuff	NOT APPLICABLE
	Crater Flat Tuff	NOT APPLICABLE
OLDER	Granite	NOT APPLICABLE
	Argillite	NOT APPLICABLE
	Carbonate	NOT APPLICABLE

Figure 12. Objective 1.2.3—Minimize Volcanic Hazards to Containment. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting the potential for volcanism, weighted according to the attribute list (upper right). The sum of attribute weights is 100%; histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since none of the attributes addresses the susceptibility of specific rock types to volcanic effects, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

1.2.3 Minimize Potential for Volcanic Disruption of Waste Packages

Description

Locations will be sought where the potential for volcanic eruptions during the next few tens of thousands of years is low relative to regional recurrence rates. Proximity to zones of active volcanism threatens a repository by increasing the likelihood that future volcanic eruptions might occur within or near the repository location. Such eruptions could disrupt containment by ingesting all or parts of waste canisters in rising lavas, carrying the waste to the surface, and exposing them directly to the human environment.[21] Increased local temperatures associated with volcanism could accelerate chemical reactions involving waste packages. Intrusion of magma into a repository could occur along feeder conduits, dikes, or fault passageways. Avoidance of environments with such structural features will reduce the likelihood that volcanic disruption of a repository will occur. Figure 12 shows location ratings based solely on this objective; host-rock ratings are not aplicable due to lack of relevant attributes.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located so that the centers of Quaternary igneous activity can be identified and shown to have no unacceptable impact on system performance." [Criterion 3.5(3)]

10 CFR 60 (Proposed)[5]

- "The geologic setting shall have exhibited structural and tectonic stability since the start of the Quaternary Period." [§60.112(a)]

[Potentially Adverse Conditions]

- "Evidence of igneous activity since the start of the Quaternary Period." [60.123(b) (11)]

Relative Importance

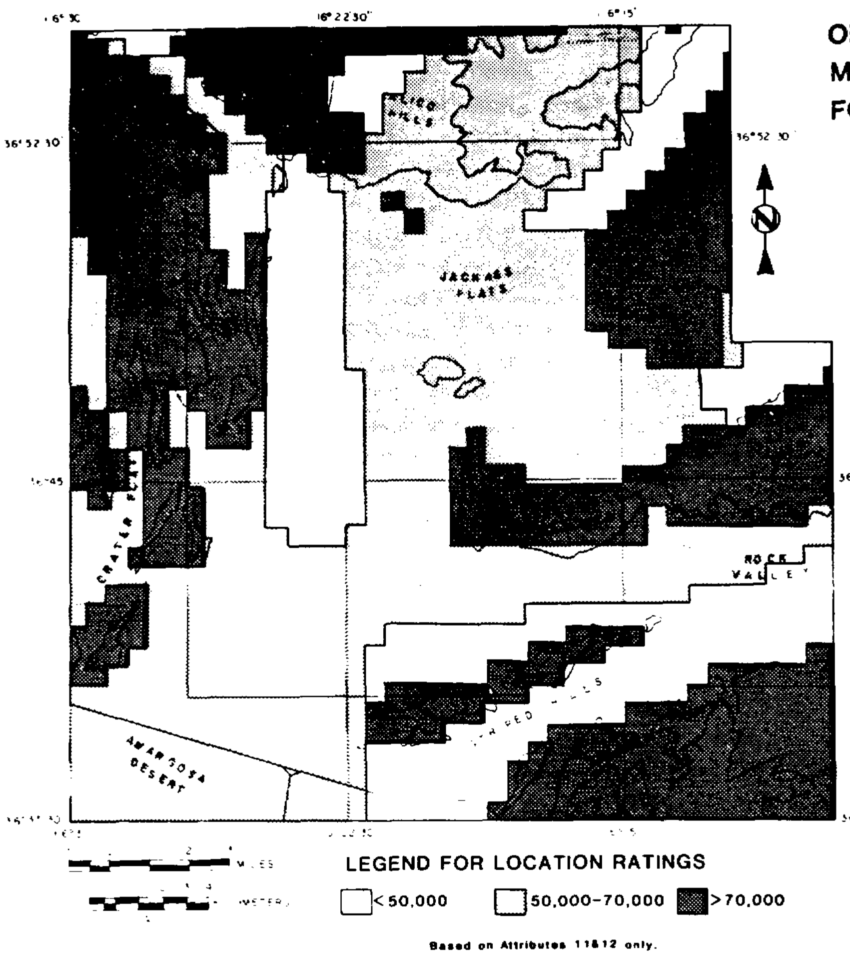
Finding locations with relatively low hazards to containment from volcanic eruptions is the third most important objective concerning types of events potentially affecting containment. Both the probability of basaltic eruption in the SW NTS area[22] and the likely consequences of such eruption[18] are low relative to regulatory standards.[23] Silicic eruptions are even less likely than basaltic eruptions, but radiological consequences would probably be much higher. Considered together, the hazards to containment from all types of volcanism are almost nil over the next few tens of thousands of years. Although consequences of volcanism would probably be greater than those from earthquakes, the much lower likelihood of volcanic eruptions was reflected in the weighting poll that resulted in lower importance assigned to volcanic events than seismic events. The weighting of volcanism in the poll was also slightly lower than concerns about human intrusion. About 21% of the weight for the event branch of containment objectives was assigned to avoidance of locations where volcanic events are relatively more likely. Because the events branch was assigned 10%, this objective accounts for about 2% of the overall importance in screening, making this objective the sixteenth most important of the 40 lower-level objectives (Figure 3).

Applicable Attribute

Volcanic Potential

Only one attribute (volcanic potential) is used to rate expected performance of locations with respect to this objective. All mapping units on the attribute map represent probabilities of volcanic disruptions of about 10^{-8} to 10^{-9} per 10 sq km.[22] Fault density and fault trend attributes may correlate with volcanic recurrence potential because caldera rims and other major tectonic trends where eruptions are more likely are indicated by surface faulting. However, these features are incorporated in the volcanic potential map. Thus, this attribute is assigned 100% of the importance for evaluating this objective.

OBJECTIVE 1.2.4
MINIMIZE POTENTIAL FOR HUMAN INTRUSION



Group	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT	50
	12 GROUNDWATER RESOURCE POTENTIAL	50
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	

HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
OLDER	Granite	
	Argillite	
	Carbonate	

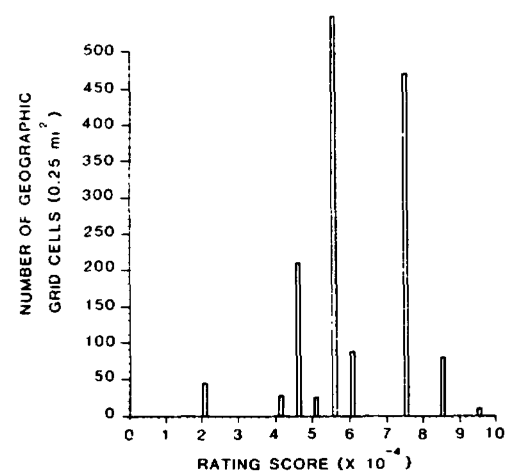


Figure 13. Objective 1.2.4—Minimize Potential for Human Intrusion of a Sealed Repository. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting the likelihood of human penetrative activities, weighted according to the attribute list (upper right). The sum of attribute weights is 100%; histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since none of the attributes addresses susceptibility of specific rock types to human intrusion, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

1.2.4 Minimize Potential for Inadvertent Human Intrusion of a Sealed Repository

Description

Locations will be sought where the potential is low for inadvertant human exhumation or penetration of emplaced waste canisters. Human intrusion could occur either accidentally (such as during the search for resources) or deliberately (such as recovery of the radioactive waste or by sabotage). Reducing the likelihood of human intrusion can be achieved by avoiding areas that are attractive with respect to both resource value and scientific interest.[24] Locating a repository deep beneath the surface also reduces the likelihood of human intrusion by increasing the costs of drilling or mining to the buried wastes. Deliberate exposure of buried wastes by future generations is not to be avoided as part of this objective. If future generations knowingly violate containment, they assume all responsibility for the consequences of their informed actions. Figure 13 shows location ratings based solely on this objective; host-rock ratings are unavailable due to lack of relevant attributes.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- "The site shall provide natural barriers that will effectively contain and isolate radionuclides. Thus, the site must provide capabilities to (1) contain the waste, (2) isolate the waste from man, and (3) *assist in keeping man away from the waste*." (Emphasis Added) [Requirement 3.2.2]
- "The repository shall contribute to the containment and isolation capabilities of the mined disposal system by (1) limiting adverse impacts of repository development and operation on waste package and site performance, (2) using engineered barriers that maintain the natural capabilities of the disposal system, (3) monitoring the system performance, and (4) *providing measures to protect against human intrusion*." (Emphasis Added) [Requirement 3.3.2]

NWTS-33(2)[4]

- "The site shall be located to reduce the likelihood that past or future human activities would cause unacceptable impacts on system performance." [Criterion 3.6]
- "The site shall be located on land for which the federal government can obtain ownership, control access, and obtain all surface and subsurface rights necessary to ensure that surface and subsurface activities at the site will not cause unacceptable impact on system performance." [Criterion 3.6(2)]

10 CFR 60[6]

[Potentially Adverse Conditions]

- "Evidence of subsurface mining for resources." [60.123(b) (1)]
- "Evidence of drilling for any purpose." [60.123(b) (2)]
- "Resources that have either greater gross value, net value, or commercial potential than the average for other representative areas of similar size that are representative of and located in the geologic setting." [60.123(b) (3)]

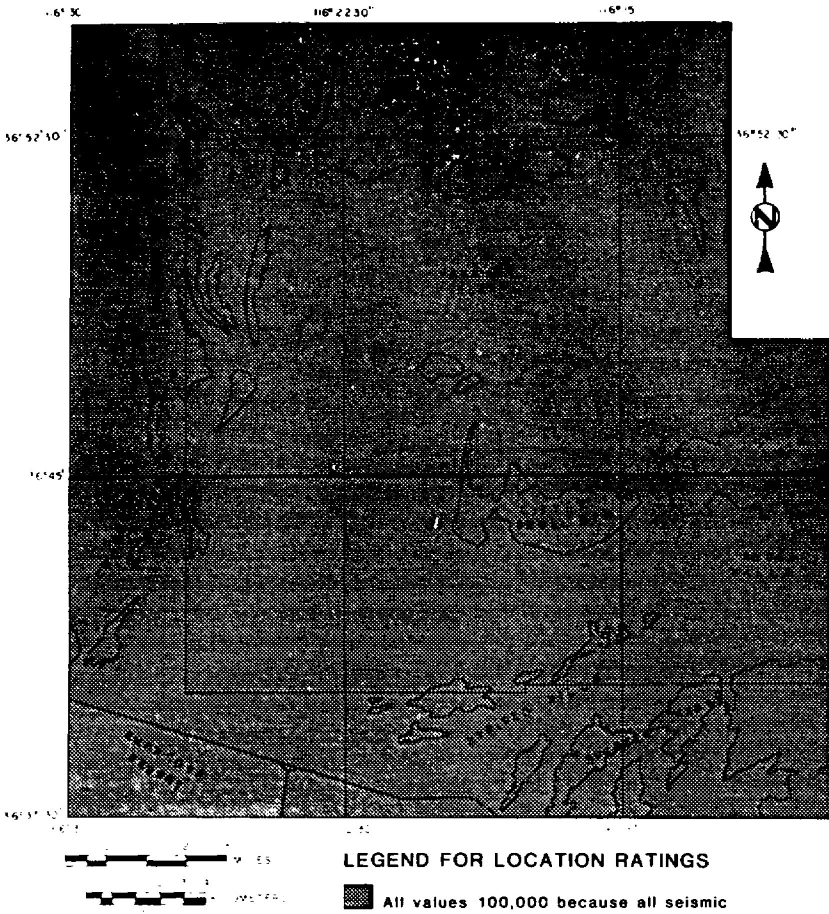
Relative Importance

Finding locations with relatively low hazards to containment because of inadvertent human intrusion of a sealed repository is the second most important objective concerning types of events potentially affecting containment. Current strategy[11, 24] assumes that appropriate safeguards against inadvertent human exhumation of buried wastes can be engineered by using permanent markers at the repository site and by extensive dissemination of repository documents to records centers and libraries. In addition, the radiological health consequences of such intrusions are likely to be limited to a few individuals unless nearly absurd scenarios for dispersive mechanisms are invoked.[25] This rationale is reflected by the weighting poll that assigned about 23% to the importance of avoiding human intrusion as an element of the event branch of the containment objectives. Since the events branch is assigned a weight of 10%, somewhat more than 2% of the overall screening activity is assigned to this objective. Therefore this objective is the fourteenth most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

Base and Precious Metal Resource Potential
Groundwater Resource Potential

Two attributes were used to rate alternative locations with respect to the potential for inadvertant human disruption of containment. These attributes delineate zones previously mined for metals or inferred to have a high potential for future development,



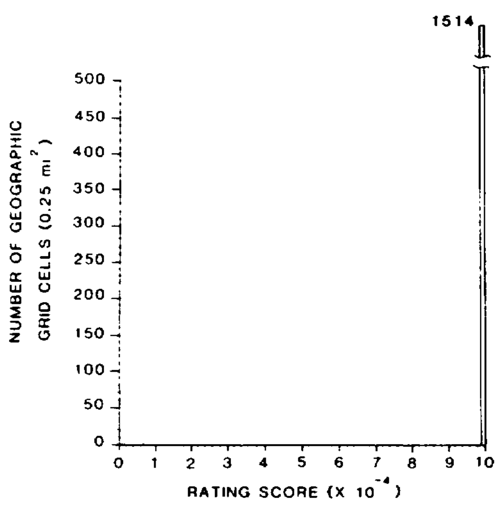
OBJECTIVE 1.2.5 MINIMIZE MISCELLANEOUS HAZARDS

ATTRIBUTES		WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	100
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	

LEGEND FOR LOCATION RATINGS

All values 100,000 because all seismic accelerations are predicted to be<0.3g; thus this objective is non-discriminating.

Based on Attribute #6 only.



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
OLDER	Granite	
	Argillite	
	Carbonate	

Figure 14. Objective 1.2.5—Minimize Miscellaneous Hazards. Map (upper left) and histogram (lower left) show a nondiscriminating, highest possible rating of 100 000 for all of the 1514 grid cells of the screening area. Weapons seismic potential, which was assigned 100% of the weight for evaluating this objective (list, upper right), is so low throughout the entire screening area that its favorability is high and does not vary within discriminating levels for seismic hazards. Since no attributes used in screening (upper right) address miscellaneous hazards associated with specific rock types, no host-rock ratings were obtained for this objective (lower right).

and zones where usable groundwater resources are known or inferred to occur. The applicability of these two attributes presumes that future societies will be more likely to concentrate subsurface penetrations in areas that have a higher chance of containing mineral or groundwater resources.

1.2.5 Minimize Potential for Miscellaneous Events That Might Disrupt Containment

Description

Miscellaneous events refer to extremely unlikely or mitigatable events. It is placed here as a catchall. Miscellaneous events such as meteorite impacts and nuclear explosions have potential for inducing substantive cratering or fracturing to considerable depth, however unlikely the occurrence. Such events could expose the waste directly or damage the repository by producing sufficient seismic motion. Locations will be selected with due consideration to such miscellaneous events that might affect waste package performance. Figure 14 shows location ratings based solely on this objective; host-rock ratings are unavailable because of a lack of relevant attributes.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- "Technical conservatism shall be applied throughout the NWTS program. The methods used to design, develop, and demonstrate the disposal system shall be sufficiently conservative to account for residual uncertainties of potential importance to system effectiveness and shall provide reasonable assurance that regulatory standards will be met." [Objective 2.3]

NWTS-33(2)[4]

- No specific correlative requirements.

10 CFR 60 (Proposed)[5]

[Favorable Conditions]

- "Any local condition of the disturbed zone that contributes to isolation." [60.122(j)]

Relative Importance

The relative importance of undefined miscellaneous events that might disrupt containment is hard to assess without specifying the events. The other four lower-level objectives of this branch of the objectives tree are assumed to exploit all credible, containment-threatening event types. Therefore, very low importance is assigned to this objective. In the weighting poll, only about 5% of the event branch of the containment objectives was assigned to this objective. Since this branch was assigned a weight of 10%, this objective accounts for only about 0.5% of the overall importance in screening. Therefore, this objective is the thirty-seventh most important of the 40 lower-level objectives (Figure 3).

Applicable Attribute

Weapons Seismic Potential

Only one attribute addresses this objective, weapons seismic potential. Ground motion caused from weapons testing, however, is not expected to affect containment because current assumptions about land use and yield limits do not indicate ground motions that would compromise containment. In addition, weapons tests are scheduled events and proper mitigating measures can be taken at a repository site during the tests. The occurrences of other miscellaneous events such as meteorite impact, sabotage, sea-level incursion, and glaciation are so unlikely that they are considered incredible and nondiscriminating.

2.0 Identify Locations That Permit Adequate Radionuclide Isolation

Description

Isolation implies separation of waste contaminants from the accessible environment in both a spatial and temporal sense (the two are somewhat interchangeable). Only after (or if) containment fails does transport of radionuclides to the accessible environment become possible. The isolation objective is designed to ensure that radionuclides will not reach the accessible environment for a very long time, or, if they reach the accessible environment, they will do so at acceptable rates or in acceptable concentrations to be established by the Environmental Protection Agency.[23] This objective corresponds to Objective 2 of the Department of Energy's Waste Confidence Rulemaking,[11] which states

> "Disposal systems should provide reasonable assurance that wastes will be isolated from the accessible environment for a period of at least 10 000 years with no prediction of significant decreases in isolation beyond that time."

The isolation component of the multiple barrier concept is itself composed of quasi-independent multiple barriers. Long (both spatial and temporal) groundwater flow paths and radionuclide sorption will impede the migration of radionuclides toward humans in the event of containment failure. Secondly, geological and hydrological stability will ensure long-term, relatively predictable isolation qualities. These distinct barriers that enhance isolation are addressed, respectively, by two component middle-level objectives. The two middle-level objectives, in turn, are each addressed by a distinctive set of lower-level objectives. Figure 25 in Reference 2 shows location and host-rock ratings based solely on this upper-level isolation objective.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- "The mined geologic disposal system shall provide reasonable assurance that waste will be adequately isolated from the accessible environment for a period of at least 10 000 years with no prediction of significant decreases in isolation beyond that time. The potential risk to future generations shall be limited to the extent reasonably achievable." [Objective 2.1]
- "The mined geologic disposal system shall provide the capability to adequately contain and *isolate* radionuclides to ensure that no releases resulting in unacceptable doses to the public occur." (Emphasis Added) [Requirement 3.1.2]
- "The site shall provide natural barriers that will effectively contain and *isolate* radionuclides. Thus, the site must provide capabilities to (1) contain the waste, (2) *isolate the waste from man*, and (3) assist in keeping man away from the waste." (Emphasis Added) [Requirement 3.2.2]
- "The mined geologic disposal system shall meet all applicable standards and shall contain and *isolate* radioactive wastes to the extent necessary to ensure that releases of radionuclides to the biosphere do not result in an unacceptable increase in doses to individuals and to the general population." (Emphasis Added) [Criterion 4.2]

NWTS-33(2)[4]

- "The geohydrologic regime in which the site is located shall have characteristics compatible with waste containment, *isolation*, and retrieval." (Emphasis Added) [Criterial 3.2]
- "The site shall have geochemical characteristics compatible with waste containment, *isolation*, and retrieval." (Emphasis Added) [Criterion 3.3]
- "The site shall have geologic characteristics compatible with waste containment, *isolation*, and retrieval." (Emphasis Added) [Criterion 3.4]
- "The site shall be located in a geologic environment that physically separates the radioactive wastes from the biosphere and that has geometry adequate for repository placement." [Criterion 3.1]

10 CFR 60 (Proposed)[6]

- "The geologic setting shall be selected and the subsurface facility designed so as to assure that releases of radioactive materials from the geologic repository following permanent closure conform to such generally applicable environmental radiation protection standards as may have been established by the Environmental Protection Agency." [§60.111(b) (1)]
- "Following the containment period, the geologic setting, in conjunction with the engineered system as long as that system is expected to function, and alone thereafter, shall be capable of isolating radioactive waste so that transport of radionuclides to the accessible environment shall be in amounts and concentrations that conform to such generally applicable environmental standards as may have been established by the Environmental Protection Agency." [§60.111(b) (3) (ii)]

Relative Importance

Isolation of wastes from the accessible environment is one, if not the most, important objectives for repository performance. Both DOE and NRC explicitly require substantially complete isolation of wastes for long periods of time.[3-5 11] Together with containment, isolation constitutes an element of the overriding objective to provide safety from radiogenic hazards for present and future generations. Approximately one-half of the objective for safety or one-third of the total importance for screening is placed on finding locations that have characteristics that will enhance isolation of wastes from humans. This is based on the weighting poll that resulted in an average assignment of 34% to the isolation branch of the objectives tree. This makes isolation first in importance among the four upper-level objectives (Figure 3), though the difference between the importance assigned to isolation and containment may not be statistically significant. It is apparent that those polled expressed agreement with a general national consensus that isolation capabilities should be considered carefully when siting a repository.

Applicable Attributes

Volcanic Potential
Fault Density
Fault Trend
Age of Faulting
Natural Seismic Potential
Weapons Seismic Potential
Bed Attitude (rock dip)
Erosion Potential
Flood Potential
Terrain Ruggedness
Metal Resource Potential
Groundwater Resource Potential
Groundwater Flux
Groundwater Flow Direction
Thickness of Unsaturated Zone
Rock Compressive Strength
Mineral Stability
Stratigraphic Retardation
Hydraulic Retardation
Hydraulic Transmissivity

Twenty attributes were used to rate expected performance of alternative locations with respect to isolation. This was achieved by using a distinctive set of geographical and host-rock attributes in evaluating performance for each of the nine subobjectives comprising the lower level of this branch of the objectives tree (Objectives 2.1.1 through 2.1.4 and 2.2.1 through 2.2.5). Thus, isolation potential of alternative locations was evaluated by summing the contributions to isolation provided by attributes addressing component lower-level objectives. The importance of the attributes was divided between host-rock attributes that address near-field, expected conditions, processes that contribute to isolation (Objective 2.1), and geographical attributes that predominately address the potential for far-field, unexpected disturbances of isolation systems (Cbjective 2.2).

2.1 Screen for Natural Systems That Will Retard Migration of Radionuclides

Description

This objective calls for locations with existing geologic, hydrologic, and geochemical processes and conditions that will inhibit migration of radionuclides through the subsurface toward the accessible environment. Such inhibiting factors include long groundwater flow times, sorptive mineral species along the flow paths, flow behavior that allows the groundwater to contact a large volume of sorbing rock materials, and rock properties that allow diffusion of radionuclides from flow channels into the rock matrix. These factors are sought to provide the last of the "multiple barriers" in the event that the containment element of the repository system fails. This objective is analogous to Objective 1.1 of the containment branch of the objective tree in that it addresses transport processes that will be likely to occur under normally expected conditions. This middle-level objective is divided into four component lower-level objectives that address distinct aspects of expected, isolating processes.

Corresponding DOE and NRC Criteria

- Not specifically addressed in NWTS-33(1), NWTS-33(2), or proposed 10 CFR 60.[3-5]

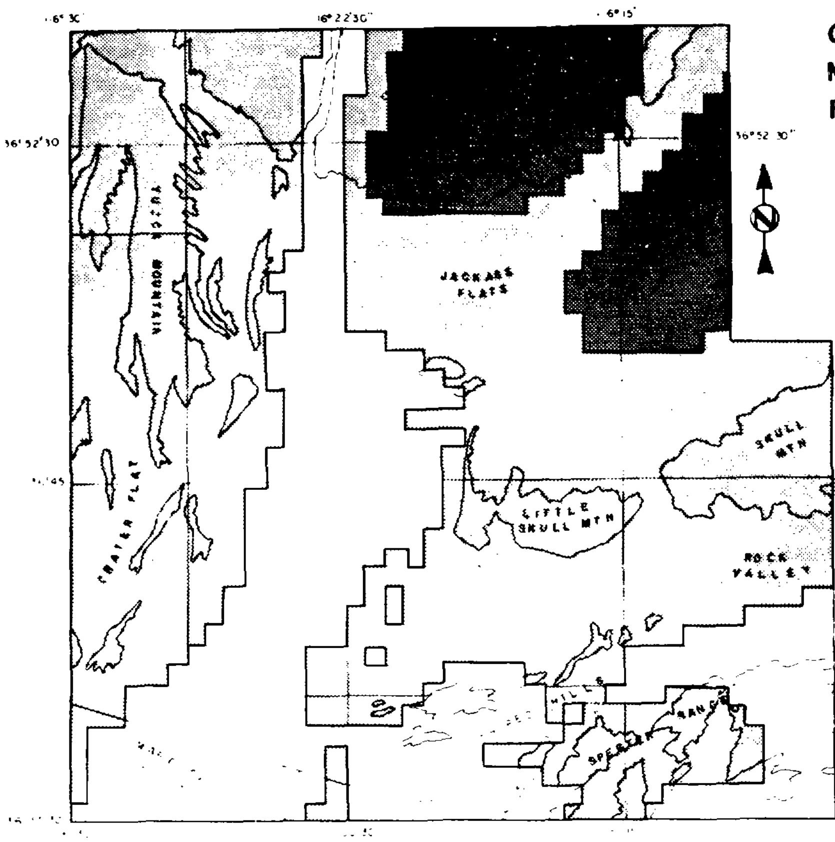
Relative Importance

Finding locations with existing geologic, hydrologic, and geochemical processes and conditions that enhance far-field isolation of emplaced wastes is considered the single most important of the 12 middle-level objectives (Figure 3). Under normal conditions, flowing groundwater is the only medium avail able for transporting waste constituents from a repository to the accessible environment. Geochemical reactions among the water, waste constituents, and rocks through which the water flows will tend to retard movement of waste radionuclides relative to groundwater flow rates. Hydrologic flow and geochemical retardation are known to occur in rocks at the NTS. From extrapolation of laboratory and field tests, these processes can be predicted with certainty to occur in and around a repository. Only their rates (not their occurrence) are in question. If containment is lost, these extant geochemical and hydrologic phenomena will determine the amounts, concentrations, and time of release of radionuclides to the accessible environment. Because of the certainty of groundwater transport and geochemical retardation, this isolation objective is rated more important than the other middle-level isolation objective (i.e., to avoid locations where hypothetical events may affect normally expected transport mechanisms). About two-thirds of the total importance of the isolation branch of the objectives tree is assigned to finding locations where radionuclide transport processes are benign. This is based on the weighting poll where an average of about 65% of the importance of isolation was assigned to this objective. Because the isolation branch of the objectives tree was assigned 34%, this objective accounts for about 22% of the overall importance in screening. This makes isolation-enhancing conditions and processes the most important of the 12 middle-level objectives (Figure 3).

Applicable Attributes

Fault Density
Groundwater Flux
Groundwater Flow Direction
Thickness of Unsaturated Zone
Compressive Strength
Mineral Stability
Stratigraphic Setting
Hydraulic Retardation
Hydraulic Transmissivity

Nine objectives are used to rate expected performance of alternative locations with respect to this objective. This is achieved by using a distinctive set of attributes in evaluating performance for each of the four lower-level objectives that comprise this branch of isolation objectives (Objectives 2.1.1 through 2.1.4). These attributes mainly address host-rock characteristics that influence the flow of groundwater and geological delay of radionuclide migration. Significant weight is also given to far-field attributes that influence the flow of groundwater through a repository and toward the accessible environment. Thus, this middle-level objective is evaluated by summing the contributions of expected near- and far-field hydrologic and geochemical conditions addressed by component lower-level objectives.



LEGEND FOR LOCATION RATINGS

<20,000 | 20,000-70,000 | >70,000

Based on Attributes 2,13,14&15 only.

OBJECTIVE 2.1.1
MAXIMIZE GROUNDWATER FLOW TIME

	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	5
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT.	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	10
	14 GROUNDWATER FLOW DIRECTION	30
	15 THICKNESS OF UNSATURATED ZONE	5
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	10
	31 HYDRAULIC TRANSMISSIVITY	40

HOST ROCK RATINGS

AGE	ROCK TYPE	RATING*
YOUNGER	Alluvium	60,000
	Basalt	45,000
	Non-welded Paintbrush Tuff	83,000
	Topopah Spring Tuff	18,000
	Calico Hills Tuff	100,000
	Crater Flat Tuff	80,000
	Granite	85,000
	Argillite	85,000
OLDER	Carbonate	8,000

*Based on Attributes 30& 31 only.

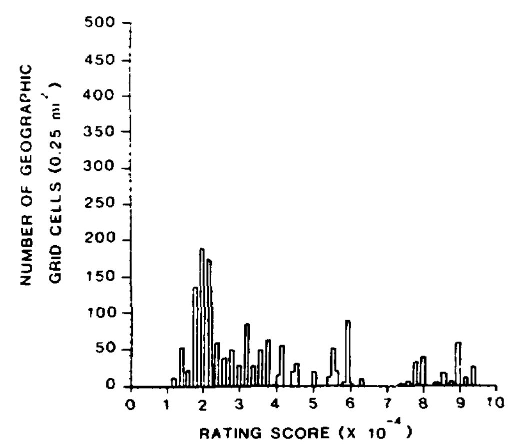


Figure 15. Objective 2.1.1—Maximize Groundwater Flow Time. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting the potential for groundwater flow time, weighted according to the attribute list (upper right). Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map; table (lower right) shows the rating values of nine potential host-rock types based on rock attributes affecting potential groundwater flow rates, also weighted according to the attribute list (upper right). The sum of attribute weights is 100%; the maximum possible rating value for locations or host rocks is 100 000.

2.1.1 Maximize Groundwater Flow Time to the Accessible Environment

Description

Locations will be sought where long times are required for groundwater to flow from a repository to the accessible environment. Groundwater transport is the most likely mechanism by which buried wastes may migrate to the accessible environment. This assumes that the most likely mechanism by which containment will fail is by dissolution of the waste in groundwater[26] whereby the dissolved radionuclides are free to migrate with the circulating groundwater in the vicinity of a repository. Locations will be favored from which the flow of groundwater through the host rock and other units to the accessible environment possess travel times exceeding, as a minimum, 1000 years. The minimum time in which radionuclides dissolved in groundwater can reach the accessible environment is determined by the groundwater flow rate and the dispersion rates of radionuclides in the direction of the flowing water.[15] Thus, by selecting locations where groundwater flow time is long, the minimum time in which radionuclides could reach the accessible environment is also long. Very-low flow rates are obtained where low-hydraulic conductivities occur along flow paths and where other features such as tightly sealed faults and fractures may retard groundwater circulation. Both vertical and horizontal components of groundwater flow need to be considered. If flow is essentially horizontal, vertical flow from a repository to an aquifer may, in individual cases, provide sufficient isolation. The effects of the thermal load on groundwater flow induced by decay heat from the waste (e.g., formation of convective, density-driven flow cells) may affect flow times to an aquifer and will be considered. Figure 15 shows location and host-rock ratings based solely on this objective.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located so that the present and probable future geohydrological regime will minimize contact between groundwater and wastes and will prevent radionuclide migration or transport from the repository to the accessible environment in unacceptable amounts." [Criterion 3.2(1)]
- "The site shall be located so that the hydrological regime can be sufficiently characterized to permit modeling to show that present and probable future conditions have no unacceptable impact on repository performance." [Criterion 3.2(2)]

10 CFR 60 (Proposed)[5]

- "The geologic repository shall be located so that prewaste emplacement groundwater travel times through the far field to the accessible environment are at least 1000 years." [§60.112(c)]
- "The nature and rates of hydrogeological processes that have occurred since the start of the Quaternary Period are such that when projected, they would not affect or would favorably affect the ability of the geologic repository to isolate the waste." [§60.122(c)]

[Favorable Conditions]

- "A host rock that provides the following groundwater characteristics: (1) low groundwater content; (2) inhibition of groundwater circulation in the host rock; (3) inhibition of groundwater flow between hydrogeologic units or along shafts, drifts, and boreholes; and (4) groundwater travel times, under prewaste emplacement conditions, between the underground facility and the accessible environment that substantially exceed 1000 years." [§60.122(f)]

Relative Importance

Finding locations with long groundwater flow time from a repository to the accessible environment was highly important in the screening activity. If groundwater flow times are sufficiently long (e.g., >1000 years), releases of radionuclides to the accessible environment will be very low, even if containment should immediately and completely fail, because fission products in the original wastes will have decayed to innocuous levels of radiotoxicity.[14]

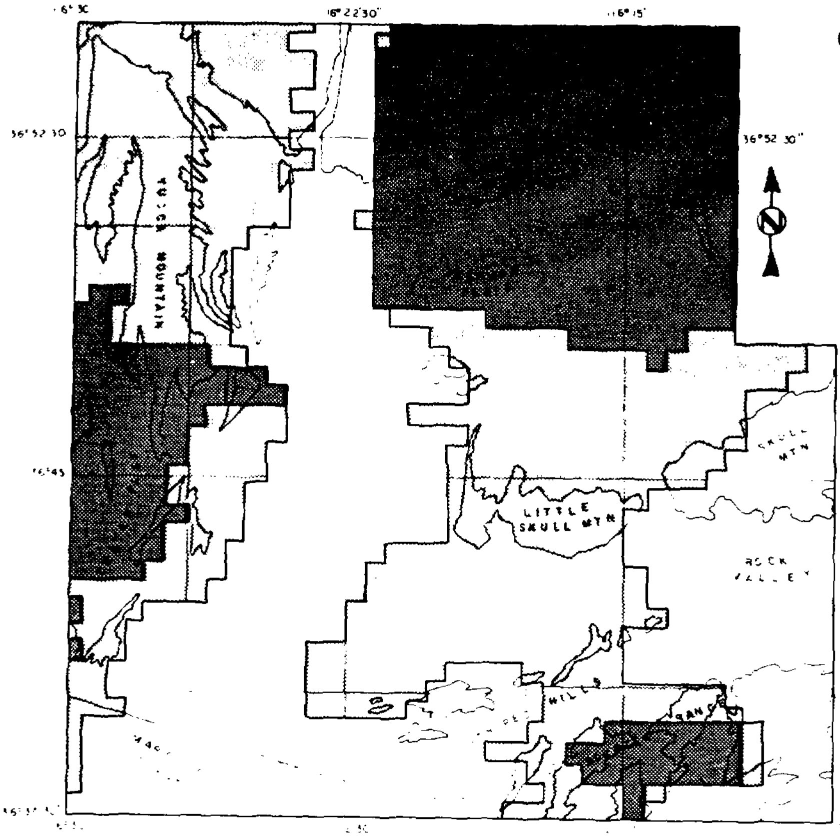
Current studies[15-16] suggest that groundwater flow time by itself may be sufficient to assure compliance with draft EPA release limits.[23] As an independent barrier to release of unacceptably harmful radiogenic toxicity from a repository, groundwater flow time is an essential element of the multiple barrier, defense-in-depth strategy for human protection. Thus, groundwater flow time provides an independent, effective barrier between man and buried wastes. Because of this independent, isolating potential, major importance is given to seeking locations with long groundwater flow time. About 40% of the radionuclide migration branch of the isolation objectives is assigned by the weighting poll to this objective. Because the migration branch was assigned an average weight of 22%, long groundwater flow time accounts for about 8% to 9% of the total importance for location screening. Therefore, this objective is second in importance only to reducing containment-threatening chemical processes, the other major, independent barrier to radionuclide release under normally expected conditions (Figure 3).

Applicable Attributes

Hydraulic Transmissivity
Groundwater Flow Direction
Hydraulic Retardation
Groundwater Flux
Thickness of the Unsaturated Zone
Fault Density

Six attributes were used to rate alternative locations with respect to this objective. All six address factors that may influence groundwater movement in the saturated or unsaturated zone. Factors that influence flow in the saturated zone are both structural and hydrologic in nature. Fault density is inferred to address the potential for flow provided by structural conduits. Hydraulic transmissivity, hydraulic retardation, groundwater flux, and groundwater flow direction are characteristics of the hydrologic environment that directly measure saturated flow factors. An attribute used to assess unsaturated flow time is the thickness of the unsaturated zone. The thicker this zone, ideally, the longer will be the groundwater transport time to an underlying aquifer or overlying surface. The most important of these attributes are groundwater flow direction and hydraulic transmissivity because these provide the most applicable information about potential transport time to the accessible environment. Groundwater flux is considered less important because it provides estimates of total flux distributed throughout the entire saturated thickness and, therefore, does not necessarily represent local, applicable flow from a repository at a given depth. Hydraulic retardation is also less important because its relation to flow velocity via dispersion and diffusion mechanisms is poorly understood. Thickness of the unsaturated zone and fault density are considered least important because they are very indirect indicators of flow conditions.

OBJECTIVE 2.1.2 MAXIMIZE RADIONUCLIDE RETARDATION

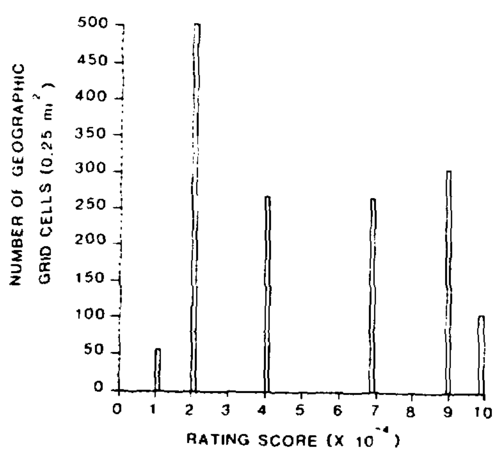


LEGEND FOR LOCATION RATINGS

☐ < 30,000 ☐ 30,000–80,000 ▩ > 80,000

Based on Attribute #13 only.

	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	10
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	10
	29 STRATIGRAPHIC SETTING	70
	30 HYDRAULIC RETARDATION	10
	31 HYDRAULIC TRANSMISSIVITY	



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING*
YOUNGER	Alluvium	33,000
	Basalt	29,000
	Non-welded Paintbrush Tuff	33,000
	Topopah Spring Tuff	34,000
	Calico Hills Tuff	81,000
	Crater Flat Tuff	46,000
	Granite	45,000
	Argillite	82,000
OLDER	Carbonate	19,000

* Based on Attributes 28–30 only.

Figure 16. Objective 2.1.2—Maximize Radionuclide Retardation. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting the potential for radionuclide retardation, weighted according to the attribute list (upper right). Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map; table (lower right) shows the rating values of nine potential host-rock types based on rock attributes affecting potential radionuclide retardation, also weighted according to the attribute list (upper right). The sum of attribute weights is 100%; the maximum possible rating value for locations or host rocks is 100 000.

2.1.2 Maximize Retardation of Radionuclides Along Flow Paths

Description

Locations will be sought where geochemical processes along groundwater flow paths between a repository and the accessible environment will retard movement of radionuclides relative to groundwater flow rates. The maximum radionuclide migration rates are directly related to groundwater flow rates (Objective 2.1.2), but these maximum rates are unlikely to occur. Various chemical interactions between the water, dissolved chemical species, and the rocks through which the water flows will tend to delay or stop the migration of some of those species, including radionuclides.[27 28] Such interactions include sorption or adhesion of radionuclides to charged particles on the rock surface; ionic exchange of radionuclides with similarly charged and sized elements on the rock surface and within mineral lattice structures; diffusion of radionuclides from fractures into the rock matrix; precipitation of radionuclides either alone or in combination with other elements to form solid minerals in voids along the flow path; and molecular filtering of large radionuclides along flow paths where the interconnected voids are extremely small.[28] For screening, these processes are collectively referred to as sorption to simplify descriptions, though it is recognized that this term is strictly a misnomer for many of the geochemical processes that might retard radionuclide migration. Locations will be favored where appropriate sorptive materials and geochemical conditions along the flow path will reduce the total, cumulative population of radionuclides released to the accessible environment, the rate of release, and the time of initial and peak release concentrations. These retardation effects will allow the total ionizing radioactivity accessible by humans to decay to much lower levels than if no retardation were to occur. Figure 16 shows location and host-rock ratings based solely on this objective.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located so that the chemical interactions between radionuclides, rock, groundwater, or engineered components will not unacceptably affect system performance." [Criterion 3.3(1)]

10 CFR 60 (Proposed)[5]

- "The nature and rates of geochemical processes that have occurred since the start of the Quaternary Period are such that when projected, they would not affect or would favorably affect the ability of the geologic repository to isolate the waste." [§60.122(d)]

[Favorable Conditions]

- "Geochemical conditions that (1) promote precipitation or sorption or radionuclides; (2) inhibit the formation of particulates, colloids, and inorganic and organic complexes that increase the mobility of radionuclides; and (3) inhibit the transport of radionuclides by particulates, colloids, and complexes." [60.123(g)]
- "Mineral assemblages that, when subjected to anticipated thermal loading, will remain unaltered or alter to mineral assemblages having increased capacity to inhibit radionuclide migration." [§60.122(h)]

[Potential Adverse Conditions]

- "Conditions in the host rock that are not reducing conditions." [60.123(b) (13)]
- "Groundwater conditions in the host rock, including but not limited to high ionic strength or ranges of Eh-pH, that could affect the solubility and chemical reactivity of the engineered systems." [60.123(b) (18)]
- "Processes that would reduce sorption, result in degradation of the rock strength, or adversely affect the performance of the engineered system." [§60.123(b) (15)]

Relative Importance

Finding locations with relatively high geochemical capacity for retarding the migration of radionuclides from a repository to the accessible environment was one of the most important objectives in screening. Geochemical retardation can significantly delay releases of toxic waste elements to the accessible environment.[15] Even if containment were immediately and completely lost, and if groundwater flow times to the accessible environment were very short (e.g., tens of years), geochemical processes in certain settings would delay release of waste components until the fission products had decayed to innocuous levels. As an independent barrier to release of unacceptably harmful radiogenic toxicity from a repository, geochemical retardation of radionuclide migration is an essential element of the multiple barrier, defense-in-depth strategy for human protection. Thus, geochemical reactions along migration pathways provide an independent barrier between man and buried wastes. Because of this independent, isolating potential, major importance is given to seeking locations with high geochemical capacity for retarding radionuclide migration in the subsurface. About one-third of the importance for normally expected isolation is assigned to geochemical retardation mechanisms. This is based on the weighting poll that resulted in an average assignment of about 30% of the importance for expected isolation processes to this objective. Since ex pected isolating processes are assigned 22%, geochemical retardation accounts for about 6% to 7% of the total importance for location screening. Therefore, this objective is the fourth most important of the 40 lower-level objectives (Figure 3).

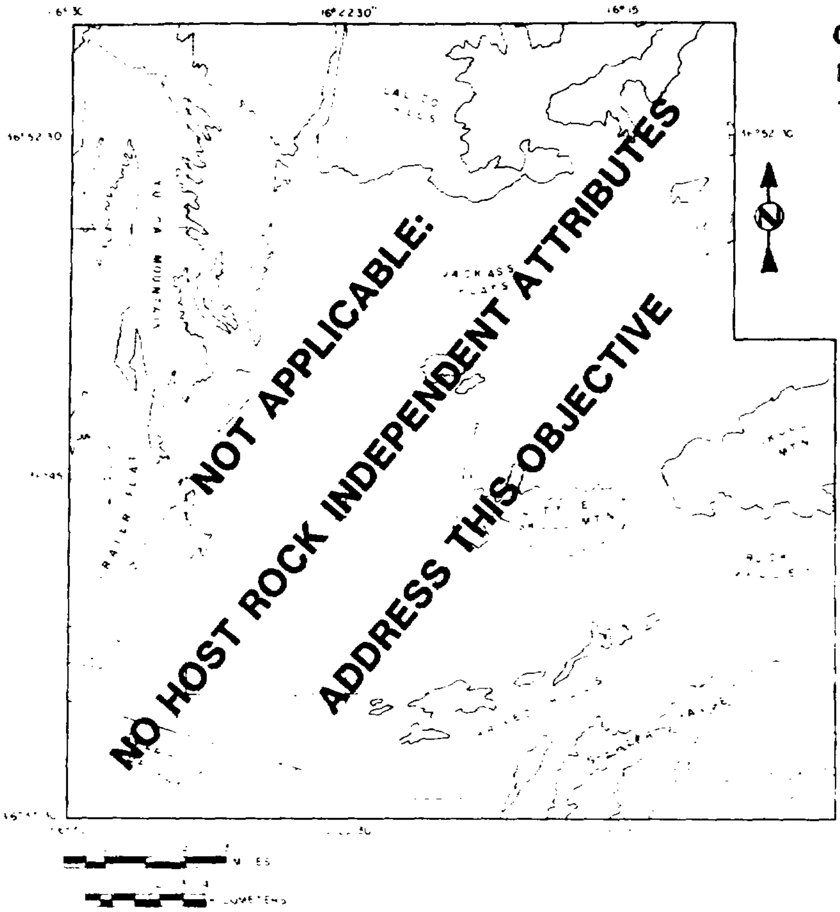
Applicable Attributes

Stratigraphic Setting
Hydraulic Retardation
Mineral Stability
Groundwater Flux

Four attributes were used to rate alternative locations with respect to this objective. They each address one or more of the factors that influence nuclide retardation:

- Sorption chemistry of the rock
- Chemistry of the groundwater
- Volume and velocity of water movement
- Surface area of the rock contacted by the moving water.

The first factor is measured by mineral stability and the sorption potential caused by stratigraphic setting. Sufficient information on groundwater chemistry is not yet available; therefore no applicable attribute was developed for screening. Groundwater flux is a direct measure of the volume of the water passing through the rock, though stratigraphic differences are not accounted for by this attribute. Surface area for chemical interactions is addressed by hydraulic retardation that provides a qualitative estimate of the ease with which radionuclides are expected to diffuse from flow conduits into the rock matrix. Because the far-field provides the greatest contribution to retarding nuclide migration, stratigraphic setting (which addresses the largest volume of rock) is assigned the most importance of the four attributes. The other three attributes are less direct measures of retardation capacity and are assigned equal importance, but lower than stratigraphic sorption potential.



OBJECTIVE 2.1.3
MAXIMIZE HOST ROCK THICKNESS

	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	20
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	80
	30 HYDRAULIC SEPARATION	
	[illegible]	

HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	40,000
	Basalt	25,000
	Non-welded Paintbrush Tuff	40,000
	Topopah Spring Tuff	30,000
	Calico Hills Tuff	92,000
	Crater Flat Tuff	42,000
	Granite	37,000
	Argillite	100,000
OLDER	Carbonate	18,000

Based on Attribute 25&29 only.

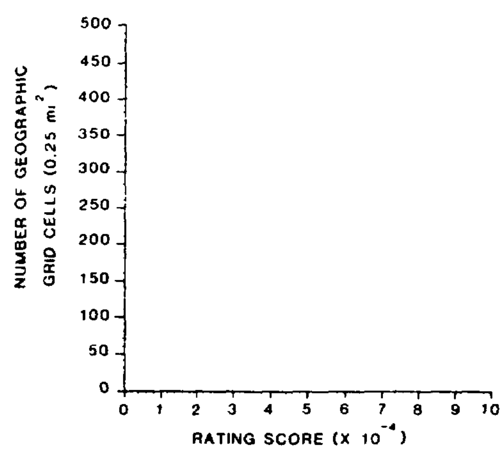


Figure 17. Objective 2.1.3—Maximize Host Rock Thickness. Rating values (table, lower right) of nine potential host-rock types are based on attributes affecting the potential thickness and extent of mechanically and chemically similar rock layers, weighted according to the attribute list (upper right). The sum of attribute weights is 100%; the maximum possible rating value is 100 000. Since none of the geographical attributes used in screening (1 through 23, upper right) addresses the thickness nor extent of host rocks, no geographical ratings are available for the potential thickness and extent of mechanically and chemically similar rock layers (upper left); therefore there are no histogram values for the ratings of geographical grid cells (lower left). This objective was used only to help rate rock types and could not be used to help discriminate among alternative locations.

2.1.3 Maximize Extent of Host Rock With Relatively Effective Isolating Qualities

Description

Locations will be sought where a host rock for waste emplacement is sufficiently thick and occurs over a large enough area to provide desirable isolation qualities for a relatively large distance along any potential flow path from the emplaced waste (such isolation qualities are assumed to be inherent properties of a host rock). Previous distinctions between a host rock and surrounding or stratigraphically adjacent units is often based on stratigraphic nomenclature. The definition herein of a "host rock" addresses the isolation qualities (Objectives 2.1.2 and 2.1.3) of all rock materials surrounding emplaced wastes and is perhaps independent of formal or functional stratigraphic units. Assuming the hydrologic properties of the host rock would be such that it would not be considered as the accessible environment, an extensive host-rock mass surrounding the waste provides a lengthy barrier between the waste and nearby aquifers, which may be considered as "accessible environments." The objective is to provide a large distance of desirable isolating properties along any line outward from a repository, with emphasis on lines along potential waste migration pathways. In this sense, the rock mass sought for emplacement is a stratigraphic setting that provides relatively effective isolation qualities for some distance away from a repository. "Homogeneous host rock" in this context refers primarily to radionuclide retarding properties, both hydrological and geochemical. For example, even though hydraulic conductivities of two layers of rock above a repository may vary by several orders of magnitude, if both layers are geochemical barriers to groundwater flow (i.e., sorption capacity is above a certain value), then both layers may be considered as parts of a single, homogeneous, isolating "host rock." Figure 17 shows host-rock ratings based solely on this objective; location ratings are unavailable due to lack of relevant attributes.

Corresponding DOE and NRC Criteria

- Not specifically addressed by NWTS-33(1), NWTS-33(2), or proposed 10 CFR 60.[3-5]

Relative Importance

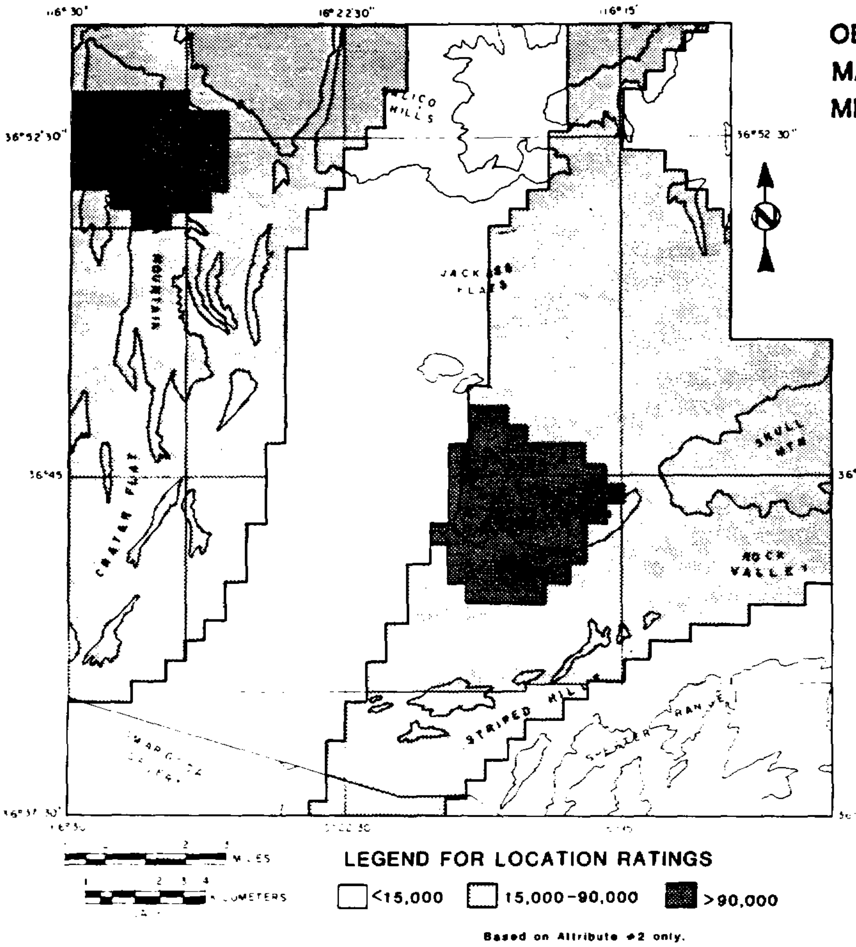
Finding a location with an extensive, relatively homogeneous, isolating host rock at waste emplacement depths was one of the more important objectives in the screening. A thick, laterally extensive repository host rock will assure similar, presumably favorable, isolation qualities for some distance away from the emplacement position of the buried waste. Extent of the host rock is the key feature primarily because greater extent implies greater retardation capability (assuming a highly sorptive, poorly transmissive host rock is chosen). Great extent also implies relative simplicity and resulting easier modelability within the range of expected changes induced by a repository. About one-fourth of the importance for existing isolating qualities is assigned to this objective. This is based on the weighting poll that resulted in an average assignment of about 23% of the isolation processes branch of the objectives tree to this objective. Since the isolation processes are assigned a weight of 22%, this objective accounts for about 5% of the total importance for location screening. Therefore, this objective is the sixth most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

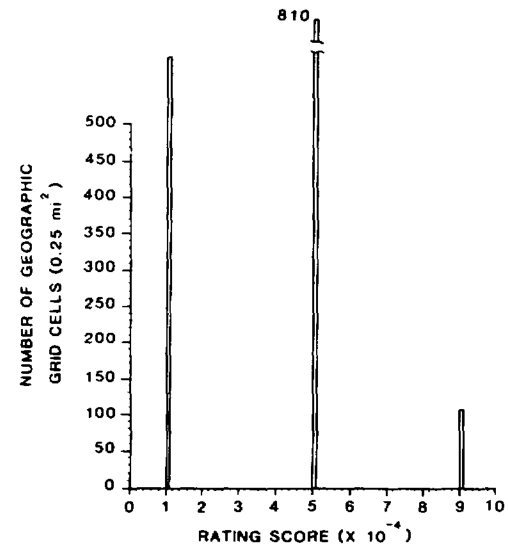
Stratigraphic Setting
Compressive Strength (containment)

Two attributes were used to rate alternative locations with respect to this objective. An ideal attribute to measure this objective would be thickness of the potential repository units. This information is available for point sources and outcrops but has not been compiled throughout the screening area for this activity. The attribute for stratigraphic setting is applicable, however, because it reflects geochemical capability for retarding migration in a vertical dimension, thereby producing an estimate of the thickness of effective radionuclide-retarding conditions. Compressive strength is the other but much less important attribute, because it addresses a rock's susceptibility to sustaining open fractures for long distances.

OBJECTIVE 2.1.4
MAXIMIZE VOLATILE MIGRATION TIME



USED TO	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	10
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	5
	29 STRATIGRAPHIC SETTING	30
	30 HYDRAULIC RETARDATION	15
	31 HYDRAULIC TRANSMISSIVITY	40



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING*
YOUNGER	Alluvium	49,000
	Basalt	38,000
	Non-welded Paintbrush Tuff	61,000
	Topopah Spring Tuff	26,000
	Calico Hills Tuff	91,000
	Crater Flat Tuff	65,000
	Granite	68,000
	Argillite	83,000
OLDER	Carbonate	23,000

*Based on Attributes 28–31 only.

Figure 18. Objective 2.1.4—Maximize Volatile Migration Time. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting the potential for migration of volatile radionuclides, weighted according to the attribute list (upper right). Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map; table (lower right) shows the rating values of nine potential host-rock types based on rock attributes affecting potential volatile migration, also weighted according to the attribute list (upper right). The sum of attribute weights is 100%; the maximum possible rating value for locations or host rocks is 100 000.

2.1.4 Maximize Migration Time for Volatile Radionuclides

Description

Locations will be sought where the potential is low for transport of gaseous radioactive waste components to the accessible environment in the event they escape from waste packages. Fractures, fault planes, and other potential structural conduits and interconnected voids in a rock's matrix may allow gases to buoyantly or diffusively rise to the accessible environment, thereby short-circuiting groundwater flow paths and times. Thus, locations with lower likelihood for possessing numerous structural conduits and with lower rock-matrix transmissivity for gases will be favored. It is assumed that sorption of radioactive gases correlates with sorption of elements dissolved in water; therefore, locations will also be favored that have good sorptive properties between a repository and the surface. Figure 18 shows location and host-rock ratings based solely on this objective.

Corresponding DOE and NRC Criteria

- Not specifically addressed by NWTS-33(1), NWTS-33(2), or proposed 10 CFR 60.[3-5]

Relative Importance

Finding locations with properties that inhibit migration of volatile waste components away from a repository is moderately important in the screening activity. Since volatile components will either be removed from the waste before emplacement or will account for a minor proportion of the overall waste toxicity,[14] this objective is considered less important than objectives for finding locations with favorable water-migration characteristics. About one-tenth of the importance for existing isolating processes was assigned to this objective. This was based on the weighting poll that resulted in an average assignment of about 8% of the importance for the isolation processes branch of the objectives tree to concerns for volatile migration. Since this branch of the tree was assigned a weight of 22%, volatile migration accounts for somewhat less than 2% of the total importance for location screening. Therefore, this objective is the nineteenth most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

Hydraulic Transmissivity
Hydraulic Retardation
Stratigraphic Setting
Fault Density
Mineral Stability

Five attributes were used to rate alternative locations with respect to this objective. Hydraulic transmissivity was considered the most important attribute. It provides a surrogate measure of the potential for gas migration, assuming a direct correlation between fluid and gaseous flow rate as a function of permeability. Stratigraphic setting presumably represents sorption potential for volatile migration and is considered almost as important as hydraulic transmissivity. Hydraulic retardation is inferred to address the capability of migrating fluids (presumably including gases) to diffuse into the rock mass, thereby providing a greater volume of rock for geochemical reactions that retard gas migration. This attribute is considered much less important than hydraulic transmissivity. Mineral stability, a near-field phenomena that may affect gas migration, was given low importance because the area affected will be only a small portion of the total rock mass through which volatile radionuclides must migrate. Structural conduits in a rock mass are inferred to increase the potential for gaseous migration to the surface environment. Accordingly, fault density as an indicator of potential, interconnected geologic conduits is an applicable, but low importance attribute.

2.2 Screen for Natural Systems With Minimum Potential for Adverse Changes to Existing Radionuclide Migration and Retardation Processes

Description

This objective calls for locations with low potential for natural or man-made changes during the next few ten thousand years that might adversely and significantly affect the natural system's capability for retarding radionuclide migration from a repository to the accessible environment. A potential exists that existing groundwater flow systems and geochemical retardation conditions will change during rapid natural events, slow acting processes, or human-induced causes. These possible changes may enhance or degrade the isolation qualities of a repository's natural setting.[26 29] Since a location will be chosen that presumably possesses adequate isolation qualities based on current natural conditions, only those possible events that may significantly degrade isolation capabilities were considered in this screening. This objective is analogous to Objective 1.2 of the containment branch of the objectives tree in that it addresses the desire to avoid or minimize the potential for future events or processes that might adversely affect normally expected and currently operating processes. Assessments of the likelihood of future events must be based on probabilistic projections of spatial and temporal distributions of past events and/or on deterministic models that predict expected events by deduction from first principals.[11] This middle-level objective is divided into five component lower-level objectives that address distinct types of potentially disruptive events.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located such that credible tectonic phenomena will not degrade system performance below acceptable limits." [Criterion 3.5]
- "The site shall be located so that its tectonic environment can be evaluated with a high degree of confidence to identify tectonic elements and their impact on system performance." [Criterion 3.5(1)]

10 CFR 60 (Proposed)[5]

[Potentially Adverse Conditions]

- "Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such a magnitude that large-scale surface water impoundments could be created that could affect the performance of the geologic repository through changes in the regional groundwater flow." [60.123(a) (7)]
- "Potential for creating new pathways for radionuclide migration due to presence of a fault or fracture zone irrespective of the age of last movement." [60.123(b) (7)]
- "Potential for changes in hydrologic conditions that would significantly affect the migration of radionuclides to the accessible environment including but not limited to changes in hydraulic gradient, average interstitial velocity, storage coefficient, hydraulic conductivity, natural recharge, potentiometric levels, and discharge points." [§60.123(b) (12)]

Relative Importance

Possible events that may or may not occur during the next few thousand years and that may or may not degrade existing isolation qualities are less important than currently existing conditions that enhance isolation. Accordingly, more importance was assigned to finding locations where existing isolating qualities are benign than to finding locations where hypothetical threats to current conditions are less likely than other locations. This general assessment of priorities was based on a judgment of relative risks associated with failure to properly ascertain current isolation qualities as opposed to failure caused by the disruptive effects of hypothetical events. Current conditions will dominate the risks of loss of isolation, with some small, incremental risk attributable to hypothetical events. This conclusion is based on an inference that low probabilities and slight consequences are generally associated with disruptive event scenarios.[17 18 30] About one-third of the total importance of the isolation branch of the objectives tree was assigned to this objective, based on the weighting poll that resulted in an average assignment of 35% to the event branch of the isolation objectives. Since the isolation branch as a whole was assigned 34%, about 12% of the overall importance for location screening was assigned to this objective. Therefore, this objective is third in importance among the 12 second-level objectives (Figure 3).

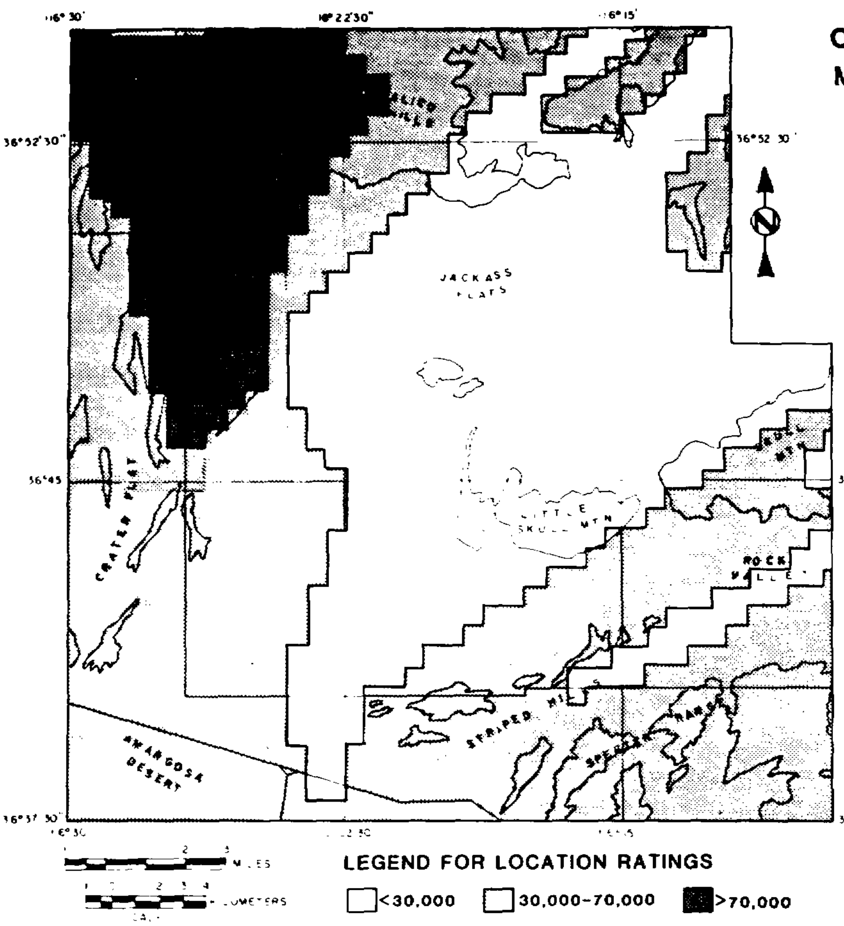
Applicable Attributes

Volcanic Potential
Fault Density
Fault Trend
Age of Faulting
Natural Seismic Potential
Weapons Seismic Potential
Bed Attitude (rock dip)
Erosion Potential
Flood Potential
Terrain Ruggedness
Metal Resource Potential
Groundwater Resource Potential
Thickness of Unsaturated Zone

Thirteen attributes were used to rate expected performance of alternative locations with respect to this objective. This was achieved by using a distinctive set of attributes in evaluating performance for each of the five subobjectives that comprise the lower-level of this branch of isolation objectives (Sections 2.2.1 through 2.2.5). These attributes address only host-rock independent conditions, because relevant, potential disturbances to the isolation system are all controlled far-field phenomena. Thus, this middle-level objective is evaluated by summing the contribution to potential isolation-disrupting events provided by regional characteristics of the screening area.

Thirteen attributes were used to rate expected performance of alternative locations with respect to this objective. This was achieved by using a distinctive set of attributes in evaluating performance for each of the five subobjectives that comprise the lower-level of this branch of isolation objectives (Sections 2.2.1 through 2.2.5). These attributes address only host-rock independent conditions, because relevant, potential disturbances to the isolation system are all controlled far-field phenomena. Thus, this middle-level objective is evaluated by summing the contribution to potential isolation-disrupting events provided by regional characteristics of the screening area.

OBJECTIVE 2.2.1
MINIMIZE TECTONIC IMPACTS



	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	40
	2 FAULT DENSITY	
	3 FAULT TREND	10
	4 AGE OF FAULTING	10
	5 NATURAL SEISMIC POTENTIAL	40
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	

LEGEND FOR LOCATION RATINGS

☐ <30,000 ☐ 30,000–70,000 ■ >70,000

Based on Attributes 1,3,4&5 only.

HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

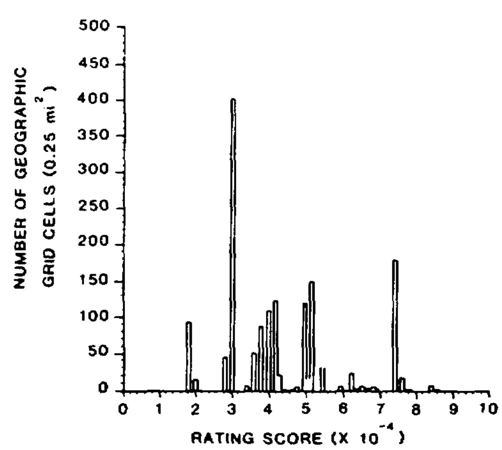


Figure 19. Objective 2.2.1—Minimize Tectonic Impacts. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting potential tectonic activity, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since none of the attributes addresses effects of tectonic activity on specific rock types, no host-rock ratings are available (lower right). This objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

2.2.1 Minimize Potential for Adverse Impacts on Isolation Caused by Tectonic Changes

Description

Locations will be sought that exhibit evidence of tectonic stability over the past few million years (Quaternary) and for which the current tectonic regime is expected to persist for the next few tens of thousands of years. The tectonic regime encompasses all changes in the structure and form of the earth's crust, including volcanic, orogenic, epirogenic, and seismic events. Earthquakes, fault movements, volcanic eruptions, and folding may alter existing hydrologic systems and perhaps even geochemical systems to a point where isolation qualities are measurably affected. Such events could change the structural fabric of the rocks, allowing water to flow more easily or rapidly from a repository to the accessible environment. Tectonic changes could also increase groundwater flux or shorten flow paths from a repository or down-gradient aquifer to the earth's surface. However, tectonic changes might also be beneficial to isolation, but it is considered prudent to seek areas where the likelihood for tectonic events is low, thus reducing the risks associated with possible deleterious events. Because the current tectonic regime of the screening area (as inferred from events and processes of the past few million years) includes minor tectonic changes, the objective is not to completely avoid such changes, but to avoid those locations where future concentrations of tectonic events are most likely to occur and locations into which concentrated activity might migrate. Stability in this screening therefore refers to relatively uninterrupted continuation of the past temporal and geographic pattern of tectonic activity. Such activity has been relatively benign during the immediate geologic past. Figure 19 shows location ratings based solely on this objective; host-rock ratings are unavailable due to lack of relevant attributes.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located so that Quaternary faults can be identified and shown to have no unacceptable impact on system performance." [Criterion 3.5(2)]
- "The site shall be located so that the centers of Quaternary igneous activity can be identified and shown to have no unacceptable impact on system performance." [Criterion 3.5(3)]
- "The site shall be located so that long-term, continuing uplift or subsidence rates can be shown to have no unacceptable impact on system performance." [Criterion 3.5(4)]
- "The site shall be located so that ground motion associated with the maximum credible earthquake will not have unacceptable impact on system performance." [Criterion 3.5(5)]

10 CFR 60 (Proposed)[5]

- "The geologic setting shall have exhibited structural and tectonic stability since the start of the Quaternary Period." [§60.112(a)]
- "The nature and rates of tectonic processes that have occurred since the start of the Quaternary Period are such that, when projected, they would not affect or would favorably affect the ability of the geologic repository to isolate the waste." [§60.122(a)]
- "The nature and rates of structural processes that have occurred since the start of the Quaternary Period are such that, when projected, they would not affect or would favorably affect the ability of the geologic repository to isolate the waste." [§60.122(b)]

[Potentially Adverse Conditions]

- "A fault in the geologic setting that has been active since the start of the Quaternary Period and which is within a distance of the disturbed zone that is less than the smallest dimension of the fault rupture surface." [60.123(a) (5)]
- "The existence of a fault that has been active during the Quaternary Period." [60.123(b) (6)]
- "Structural deformation such as uplift, subsidence, folding, and fracturing during the Quaternary Period." [60.123(b) (8)]
- "Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or magnitude of earthquakes may increase." [60.123(b) (10)]
- "Evidence of igneous activity since the start of the Quaternary Period." [§60.123(b) (11)]

Relative Importance

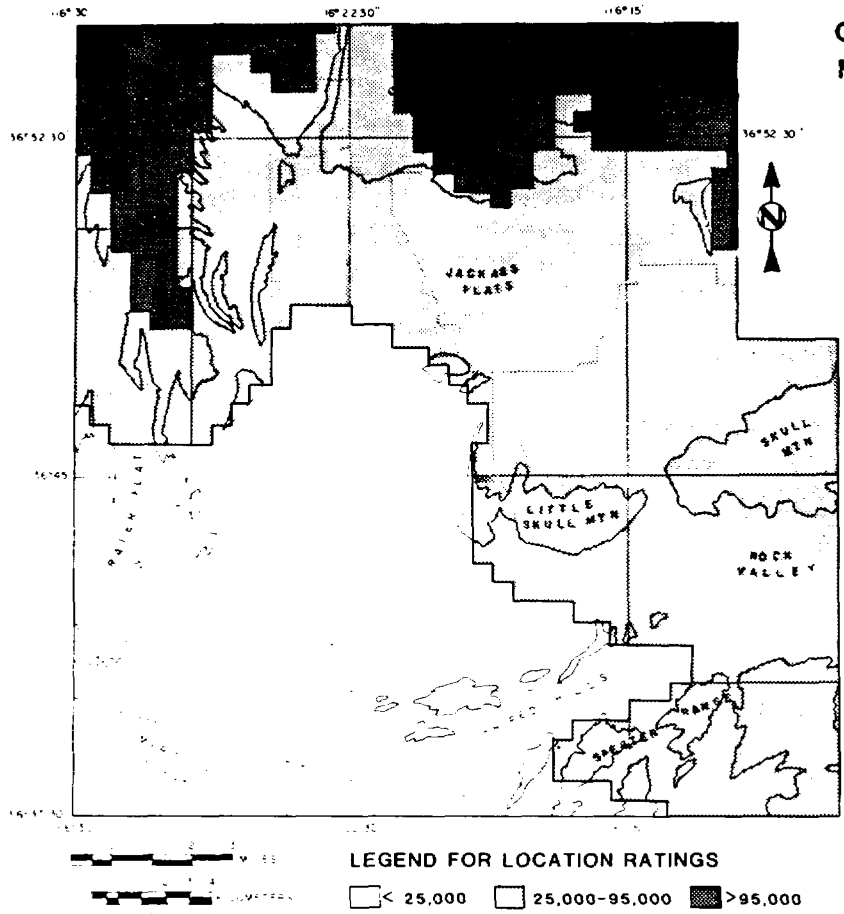
Finding locations with relatively low tectonic activity is one of the more important objectives in the screening activity. It addresses the most important event type to consider for ensuring isolation qualities of a site. Earthquakes, fault movements, volcanic eruptions, and folding may alter existing hydrologic systems and perhaps even geochemical systems to a point where isolation qualities are measurably affected. Because the likelihood of a tectonic event is quasi-proportional to the area considered, the larger size of the area over which isolation qualities will operate (as opposed to containment qualities) makes isolation-threatening events more likely than containment-threatening events. Based on the weighting poll, an average of about 30% of the importance for the events branch of the isolation objectives was assigned to this objective. Because the event branch itself was assigned a weight of 12%, this objective accounts for about 3% to 4% of the overall importance for screening. This makes this objective the seventh most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

Volcanic Potential
Natural Seismic Potential
Fault Trend
Age of Faulting

Four attributes were used to rate alternative locations with respect to this objective. Attributes that directly estimate natural seismic potential and volcanic potential are available. Fault trend and age of faulting are attributes that indirectly address the potential for tectonic deformation (i.e., uplift or subsidence by faulting and folding). In southern Nevada faulting is the primary mode of deformation. Fault trend is an attribute inferred to correlate with belts of greater and lesser tectonic activity. Areas that have experienced the most recent faulting are addressed by the attribute for the age of faulting. Therefore, these two attributes indirectly represent susceptibility to recurrence of tectonic deformation in the next few tens of thousands of years. The two attributes that directly estimate potential for tectonic activity are weighted equally and more heavily than the two indirect attributes.

OBJECTIVE 2.2.2
MINIMIZE CLIMATIC IMPACTS

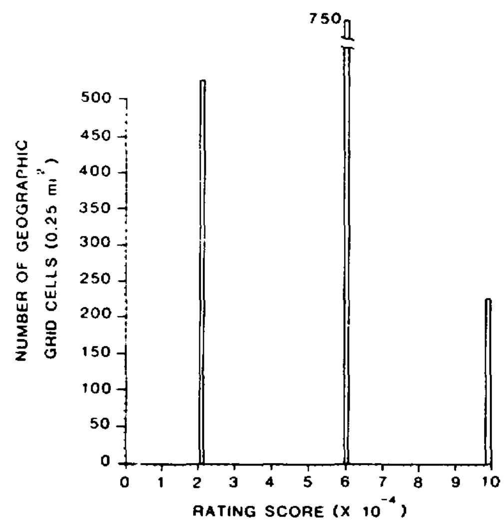


ATTRIBUTES		WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	100
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	

LEGEND FOR LOCATION RATINGS

□ < 25,000 □ 25,000-95,000 ■ >95,000

Based on Attribute #15 only.



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

Figure 20. Objective 2.2.2—Minimize Climatic Impacts. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting the impact of climatic change on a repository, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since none of the attributes addresses the responses of specific rock types to climatic conditions, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

2.2.2 Minimize Potential for Adverse Impacts on Isolation Caused by Climatic Changes

Descriptions

Locations will be sought that exhibit evidence of past stability of hydrologic systems during general climatic changes and for which the effects of future climatic changes are expected to also be relatively benign for repository performance. Changes in climate (e.g., pluvial cycles) can affect the amount and spatial distribution of both precipitation and evapotranspiration, thereby affecting the amount and location of groundwater recharge.[31] In turn, this might change local or regional hydraulic gradients and water table levels that could affect the elevation and/or location of groundwater flow paths and discharge area. Further, these changes could affect groundwater travel times from a location to the accessible environment because of changes in hydraulic gradient, discharge locations, or productivity of local aquifers (e.g., if the water tables rise into previously unsaturated but highly permeable zones). Therefore, locations that might experience increased recharge, water table levels, or hydraulic gradients in permeable zones are to be avoided. It is not reasonable to search for locations where climatic changes are predicted to be less than others, because if the climate changes, it will do so throughout the screening area. Changes in climate (if they occur) are likely to affect all portions of the screening area, though higher elevations may experience somewhat more change than lower elevations. However, climatic change per se is not the relevant concern; its effect on hydrologic systems is. Changes in the hydrologic regime are unlikely to vary as a function of local climatic changes except perhaps for some groundwater mounding under topographically high areas during pluvial climates. Thus, locations will be favored where the effects of potential climatic change on groundwater flow to the accessible environment are predicted to be inconsequential. Figure 20 shows location ratings based solely on this objective; host-rock ratings are unavailable due to lack of relevant attributes.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located so that the present and *probable future geohydrological regime* will minimize contact between groundwater and wastes and will prevent radionuclide migration or transport from the repository to the accessible environment in unacceptable amounts." (Emphasis Added). [Criterion 3.2(1)

10 CFR 60 (Proposed)[5]

- "The geologic setting shall have exhibited hydrogeologic, geochemical, and geomorphic stability since the start of the Quaternary Period." [§60.112(b)]

[Potentially Adverse Conditions]

- "Expected climatic changes that would have an adverse effect on the geologic, geochemical, or hydrologic characteristics." [§60.123(a) (8)]

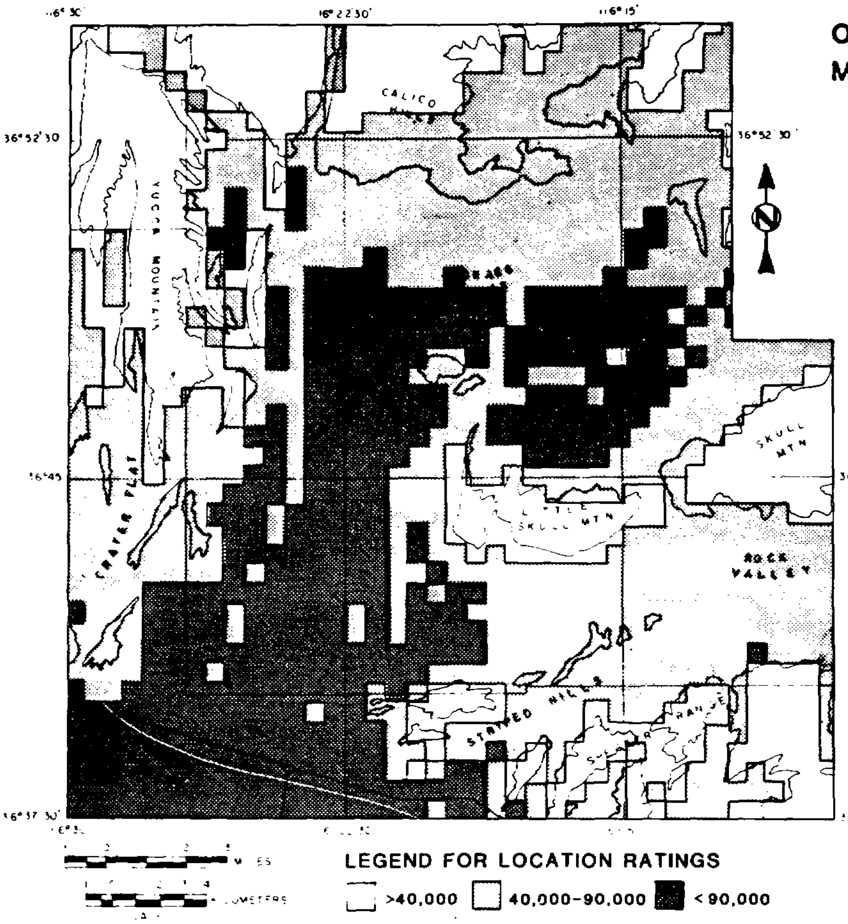
Relative Importance

Finding locations with relatively low potential for adverse effects of climatic change is a moderately important objective in the screening activity. This objective is the third most important subobjective of the events branch of isolation objectives. In general, changes in the elevation of the water table during the last pluvial climate were slight.[31] This fact combined with the low likelihood for local variations in climate makes the impacts of potential climatic changes on screening quite low. However, about 20% of the importance of the isolation events branch of the objectives tree was assigned to this objective by the weighting poll. Since the events branch of isolation objectives was assigned a weight of 12%, this objective accounts for about 2% to 3% of the overall importance for screening. Therefore, this objective is the eleventh most important of the 40 lower-level objectives (Figure 3).

Applicable Attribute

Thickness of the Unsaturated Zone

Only one attribute, thickness of the unsaturated zone, was used to rate alternative locations with respect to the impact of climatic change on a repository. It is presumed that the thickness of rocks above the water table offers greater potential for locating a repository in rocks that are currently unsaturated and that are likely to remain so should the water table rise because of pluvial conditions. Thick, unsaturated rocks also offer the opportunity to place a repository at a depth where a large amount of rock in which water cannot move upward toward the biosphere is above the repository, independent of climatic conditions.



OBJECTIVE 2.2.3
MINIMIZE GEOMORPHIC IMPACTS

	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	10
	9 FLOOD POTENTIAL	10
	10 TERRAIN RUGGEDNESS	10
	11 BASE & PRECIOUS METAL RESOURCE POT.	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	

LEGEND FOR LOCATION RATINGS

>40,000 | 40,000-90,000 | < 90,000

Based on Attributes 8,9 & 10 only.

HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

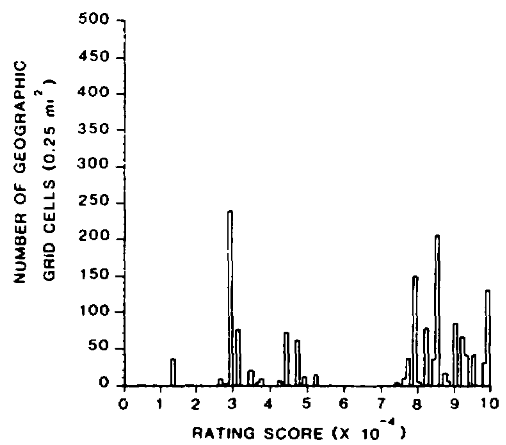


Figure 21. Objective 2.2.3—Minimize Geomorphic Impacts. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting geomorphic processes, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since none of the attributes addresses responses of specific rock types to geomorphic conditions or processes, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

2.2.3 Minimize Potential for Adverse Impacts on Isolation Caused by Geomorphic Changes

Description

Locations will be sought that exhibit evidence of past geomorphic stability, and for which future geomorphic processes are projected to retain or enhance current isolation qualities. Primary concerns about potential geomorphic changes involve erosional or depositional processes that might alter the hydrologic regime around a repository. Canyon incision by streams could cut into aquifers down-gradient from a repository, thereby shortening flow paths and times to natural discharge points. Conversely, deposition of sediment above the flow paths and in discharge areas could lengthen flow paths or add buffer materials between flow paths and the accessible environment. Erosion along steep high cliffs results in migration of the cliffs toward upstream areas.[32] [33] Such cliff migration could also intersect flow paths and short-circuit hydrologic isolation. Therefore, locations with high potential for either rapid deep stream incision or rapid cliff migration along flow paths between a repository and the accessible environment should be avoided. Other minor geomorphic situations should be avoided, such as potential landslide areas that might produce surface water impoundments that temporarily increase local groundwater recharge. However, in arid southern Nevada geomorphic change is not a significant concern. The general topography of the screening area has not significantly changed in the past ten million years or so[20] and is unlikely to change much in the next few hundred thousand to million years. Base level is established regionally by the Amargosa River and locally by Forty-Mile Wash, Topopah Wash, and other drainage lines graded to the Amargosa Desert. These conditions, in combination with an intense water deficit caused by low percipitation and high evaporation, are incapable of providing sufficient erosional energy to significantly alter current geomorphic controls on hydrologic systems in the screening area over the next few hundred of thousands of years. Figure 21 shows location ratings based solely on this objective; host-rock ratings are unavailable due to lack of relevant attributes.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The minimum depth of the repository waste emplacement area shall be such that credible human activities and *natural processes acting at the surface* will not unacceptably affect system performance." (Emphasis Added) [Criterion 3.1(1)]
- "The site shall be located so that long-term, continuing uplift or subsidence rates can be shown to have no unacceptable impact on system performance." [Criterion 3.5(4)]

10 CFR 60 (Proposed)[5]

- "The geologic setting shall have exhibited hydrogeologic, geochemical, and *geomorphic* stability since the start of the Quaternary Period." (Emphasis Added) [§60.112(b)]

[Favorable Conditions]

- "The nature and rates of geomorphic processes that have occurred since the start of the Quaternary Period are such that, when projected they would not affect or would favorably affect the ability of the geologic repository to isolate the waste." [60.122(e)]
- "Conditions that permit the emplacement of waste at a minimum depth of 300 meters from the ground surface." [§60.122(i)]

[Potentially Adverse Conditions]

- "Evidence of extreme erosion during the Quaternary Period." [§60.123(b) (4)]

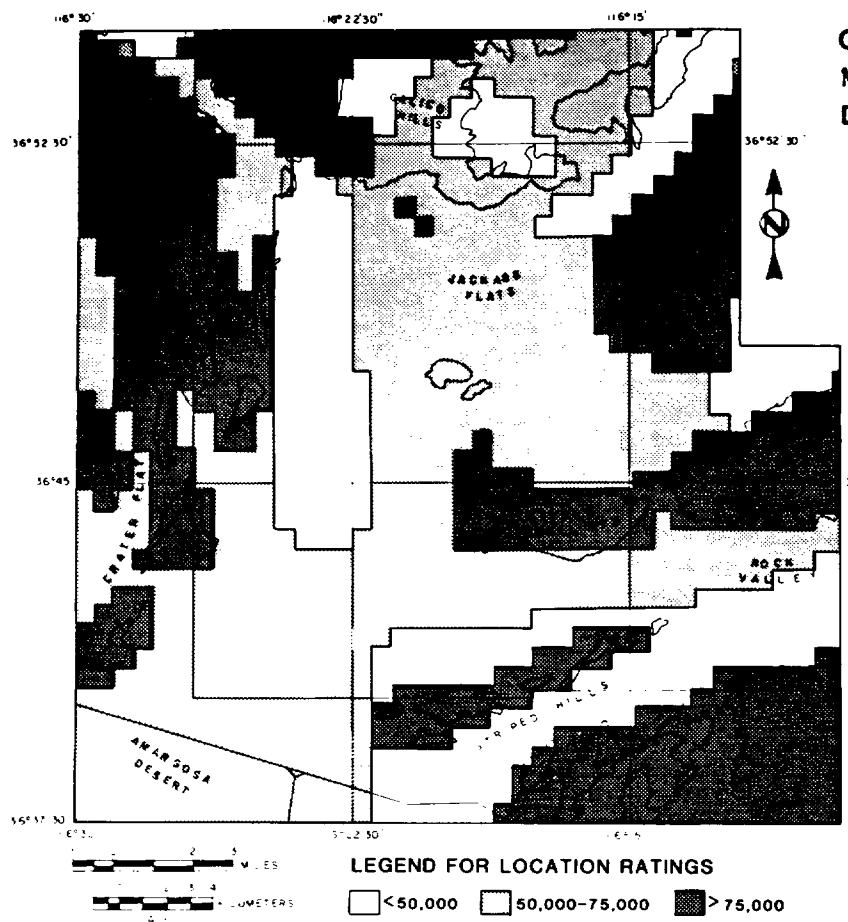
Relative Importance

Finding locations with relatively low potential for adverse geomorphic impacts on isolation qualities is moderately important in the screening activity. This objective is the fourth most important subobjective of the events branch of isolation objectives. Because geomorphic disturbances of isolation qualities are extremely unlikely in the screening area, the importance of geomorphic processes to waste isolation is accordingly low. An average of about 20% of the importance for events branch of isolation objectives was assigned to this objective by the weighting poll. Since about 12% was assigned to the events branch, this objective accounts for about 2% to 3% of the overall importance for screening. Therefore, this objective is the twelfth most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

Erosion Potential
Flood Potential
Terrain Ruggedness

Three attributes are used to rate alternative locations with respect to this objective. One (erosion potential) was specifically compiled to provide a direct indication of the hazards to isolation from geomorphic processes. Terrain ruggedness is used to indirectly indicate landslide potential, though many other factors contribute to landsliding. Terrain ruggedness does not provide a direct measurement of hydrologic hazards associated with landslides. The attribute for flood potential also indirectly addresses the potential for impoundments significant enough to alter recharge. Much higher weighting is given to the directly applicable erosion potential attribute, with the remaining weight equally split between the two indirect attributes.



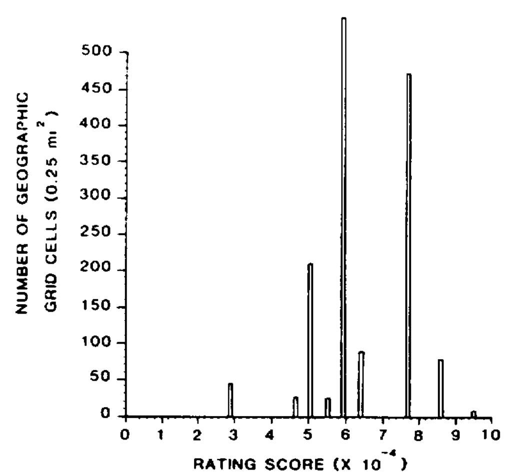
LEGEND FOR LOCATION RATINGS

<50,000 50,000–75,000 >75,000

Based on Attributes 6, 11 & 12 only.

OBJECTIVE 2.2.4 MINIMIZE HUMAN DISRUPTION

	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	10
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT.	45
	12 GROUNDWATER RESOURCE POTENTIAL	45
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
OLDER	Granite	
	Argillite	
	Carbonate	

Figure 22. Objective 2.2.4—Minimize Human Disruption. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting the potential for human interference with isolation systems, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since none of the attributes addresses reponses of specific rock types to human disturbances, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

2.2.4 Minimize Potential for Adverse Impacts on Isolation Caused by Human Activities

Description

Locations will be sought that are not attractive for any future human activities that might reduce a repository's isolation qualities. Drilling for mineral, energy, or water resources, or development of such resources, could provide direct connections between flow paths from a repository and the surface, thereby short-circuiting natural flow paths and times. These disturbances could also cause local withdrawals of groundwater and attendant modification of head distributions. In the arid climate of the screening area, future demands for groundwater will likely be great. The institutional will or ability of the DOE or its successors to restrict groundwater withdrawal from the NTS for domestic, industrial, or agricultural uses is uncertain for periods of time greater than tens to hundreds of years. If high grade metal ores were found in the screening area, demands for their development would be high, even if the DOE retains control of NTS land use, especially when high grade ores in the rest of the world are further depleted during the next few hundred years.[34] Other possible, human-induced impacts on a repository include construction of reservoirs that might alter the location's hydrologic system. Such alterations could increase hydraulic gradients or groundwater flux, thereby hastening transport of radionuclides to the accessible environment. Reservoirs are not possible in the arid portion of southern Nevada occupied by the screening area. With respect to possible resource exploration, it is not prudent to assume hypothetical, future resource values as a basis for assessing the attractiveness of an area for subsurface exploration because of the difficulty in projecting human behavior for the long time periods required for isolation.[24] Therefore, this objective is restricted to avoiding locations (including downgradient areas) where currently attractive resources occur. Additionally, only inadvertant effects on isolation qualities are considered. If future generations knowingly alter isolation qualities of a repository's setting, they then assume total responsibility for the consequences of their informed actions. It is not incumbent upon the current generation to presume a responsibility for protecting future generations from the consequences of their own informed decisions. Thus, the concern for human intervention in repository isolation systems only applies if records and memory of the repository are lost from history. Figure 22 shows location ratings based solely on this objective; host-rock ratings are unavailable due to lack of relevant attributes.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- "The repository shall contribute to the containment and isolation capabilities of the mined disposal system by (1) limiting adverse impacts of repository development and operation on waste package and site performance, (2) using engineered barriers that maintain the natural capabilities of the disposal system, (3) monitoring the system performance, and (4) *providing measures to protect against human intrusion.*" (Emphasis Added) [Requirement 3.3.2]

NWTS-33(2)[4]

- "The site shall be located to reduce the likelihood that past or future human activities would cause unacceptable impacts on system performance." [Criterion 3.6]
- "The site shall be located on land for which the federal government can obtain ownership, control access, and obtain all surface and subsurface rights necessary to ensure that surface and subsurface activities at the site will not cause unacceptable impact on system performance." [Criterion 3.6(2)]

10 CFR 60 (Proposed)[5]

- "Shafts shall be designed so as not to create a perferential pathway for migration of groundwater and so as not to increase the potential for migration through existing pathways." [§60.133(a)]

[Potentially Adverse Conditions]

- "Potential for human activity to affect significantly the geologic repository through changes in the hydrogeology." [60.123(a) (3)]
- "Evidence of subsurface mining for resources." [60.123(b) (1)]
- "Evidence of drilling for any purpose." [60.123(b) (2)]
- "Resources that have either greater gross value, net value, or commercial potential than the average for other representative areas of similar size that are representative of and located in the geologic setting." [§60.123(b) (3)]

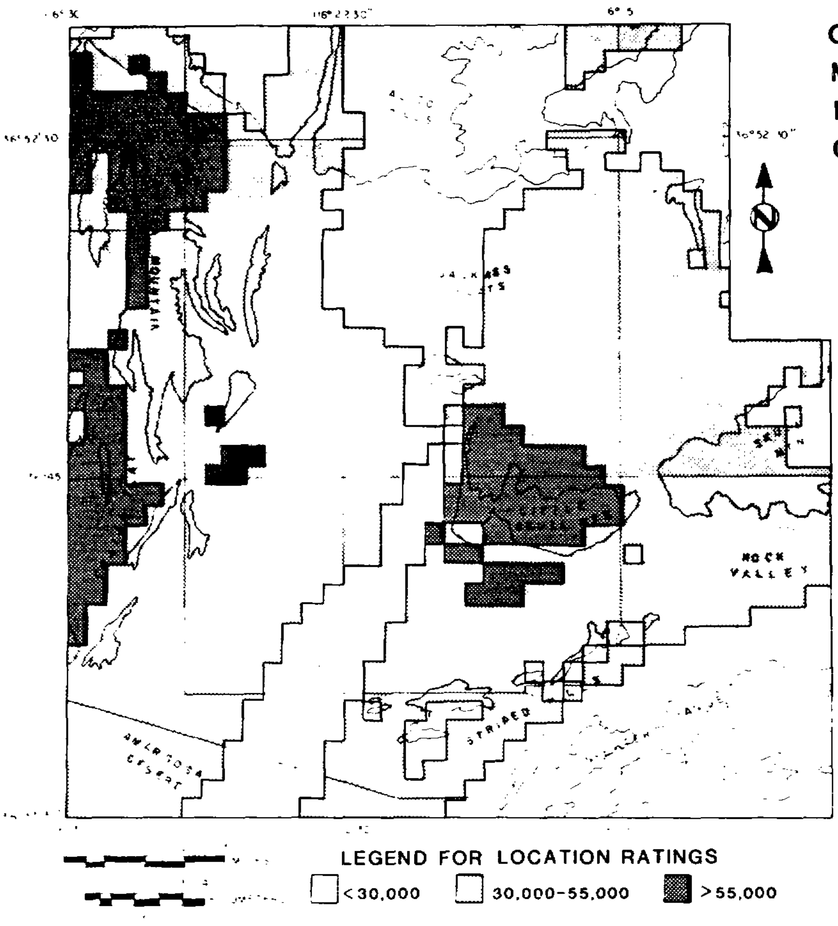
Relative Importance

Finding locations with relatively low potential for inadvertent human disturbances of isolation qualities of a repository is a moderately important objective in the screening activity. This objective is the second most important subobjective of the events branch of the isolation objectives. Human disturbance of hydrologic systems is considered the most likely means for future changes in current isolation qualities of a repository in the screening area, though the consequences may be less than tectonic disturbances. About 25% of the importance for the events branch of isolation objectives was assigned to this objective. Since about 12% was assigned to this branch, this objective accounts for about 3% of the overall importance of the screening activity. Therefore,this objective is the tenth most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

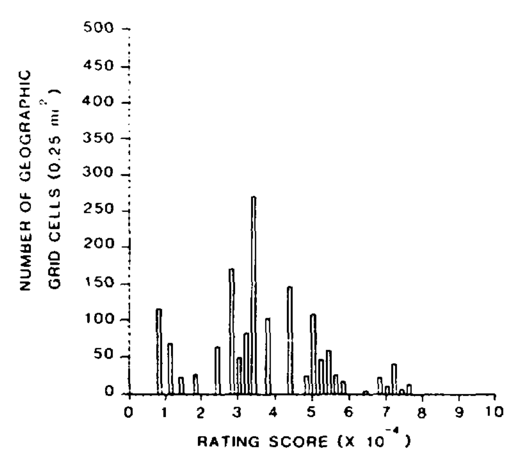
Metal Resource Potential
Groundwater Resource Potential
Weapons Seismic Potential

Three attributes were used to rate alternative locations with respect to this objective. The same rationale applies here as for Objective 1.2.4 with regard to disturbances by mining or drilling. In addition, weapon seismic potential is applicable to this objective. Human-induced ground motion may affect isolating conditions of rock masses surrounding a repository after it is backfilled. Since the effects of ground motion on isolation are judged to be low, weapons testing ground motion is considered the least important of the three attributes. Metal and water resource potentials are considered significantly more important because of their implications for potential effects on hydrologic flow systems.



ATTRIBUTES	WEIGHT %
1 VOLCANIC POTENTIAL	
2 FAULT DENSITY	50
3 FAULT TREND	
4 AGE OF FAULTING	
5 NATURAL SEISMIC POTENTIAL	
6 WEAPONS SEISMIC POTENTIAL	
7 BED ATTITUDE (ROCK DIP)	30
8 EROSION POTENTIAL	
9 FLOOD POTENTIAL	
10 TERRAIN RUGGEDNESS	20
11 BASE & PRECIOUS METAL RESOURCE POT	
12 GROUNDWATER RESOURCE POTENTIAL	
13 GROUNDWATER FLUX	
14 GROUNDWATER FLOW DIRECTION	
15 THICKNESS OF UNSATURATED ZONE	
16 SENSITIVE FLORAL SPECIES	
17 SENSITIVE FAUNAL SPECIES	
18 REVEGETATION POTENTIAL	
19 KNOWN CULTURAL RESOURCES	
20 POTENTIAL CULTURAL RESOURCES	
21 AIR POLLUTION POTENTIAL	
22 PERMITTING DIFFICULTIES	
23 PRIVATE LAND USE	
24 THERMAL CONDUCTIVITY	
25 COMPRESSIVE STRENGTH (CONTAINMENT)	
26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
27 EXPANSION-CONTRACTION	
28 MINERAL STABILITY	
29 STRATIGRAPHIC SETTING	
30 HYDRAULIC RETARDATION	
31 HYDRAULIC TRANSMISSIVITY	

(Attributes 1–23: USED TO PRODUCE MAP; attributes 24–31: USED TO PRODUCE HOST ROCK LIST)



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
OLDER	Granite	
	Argillite	
	Carbonate	

Figure 23. Objective 2.2.5—Minimize Miscellaneous Hazards and Complexity. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting site complexity, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since none of the attributes addresses credible miscellaneous events that might disrupt isolation, the ratings reflect on the complexity of locations, and since none address the responses to miscellaneous events or complexity of specific host-rock types, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

2.2.5 Minimize Potential for Miscellaneous Events or Complexity That Might Affect Isolation

Description

Locations will be selected with consideration given to other events that might alter the isolation potential. Included are meteorite crashes, airplane crashes, sabotage, and other essentially incredible events that could foreshorten hydrologic flow paths. Also included under this objective is a peripheral issue of the effects on isolation of being able to adequately characterize a site to assure confidence in its performance. A more structurally complex site is more difficult and costly to characterize at some given level of confidence than a simple site. More exploratory penetrations may be required at more complex sites, thus potentially disturbing intact isolation qualities. Complexity also increases the likelihood that anomalies with adverse properties for isolation will be undetected during site exploration. Therefore, locations with greater simplicity are desired. Greater terrain ruggedness is also less desirable because it makes drilling more difficult and costly. Rough topography also makes fielding and interpretation of geological and geophysical surveys more difficult. Thus, geologic and topographic complexity increase the difficulty in acquiring confidence that a particular site will provide the needed isolation capability. Figure 23 shows location ratings based solely on this objective; host-rock ratings are unavailable due to lack of relevant attributes.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located so that the subsurface setting can be sufficiently characterized to permit identification and evaluation of conditions that are potentially adverse or favorable to waste containment, isolation, and retrieval." [Criterion 3.4.1]

10 CFR 60 (Proposed)[6]

[Favorable Conditions]

- "Any local condition of the disturbed zone that contributes to isolation." [§60.122(j)]

Relative Importance

Finding locations with relatively low potential for miscellaneous events and with relatively easily definable characteristics is one of the least important objectives in the screening activity. Miscellaneous events are, by definition in this screening, those with very low likelihood and/or potential consequences. The difficulties encountered during site characterization caused by geologic or topographic complexity are considered only a factor in cost and schedule. This presumes that similar levels of confidence in characterization can be obtained for all areas, depending on the amount of exploration that is performed. Compared to eventual costs of building a repository, the differences in costs for required characterization efforts among alternative locations will be small. Accordingly, this objective is assigned less than one-half of a percent of the overall importance for screening. This is based on the weighting poll where an average of 3% of the importance for events branch of isolation objectives was assigned to this objective. Because about 12% was assigned to this branch, this objective accounts for less than 1% of the overall importance in screening. Therefore, this objective is the thirty-ninth most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

Fault Density
Bed Attitude
Terrain Ruggedness

Of the available attributes, fault density and bed attitude are the best indicators of the deformation and alteration at alternative locations. Steeply dipping beds may make adequate understanding of groundwater transport more difficult. Thus, these two attributes are applicable to assessing the likely complexity of alternative locations. The attribute for terrain ruggedness addresses the difficulty in fielding geological and geophysical surveys. Half the weight for evaluating this objective is given to fault density; the remainder is distributed between bed attitude and terrain ruggedness.

3.0 Identify Locations Where Safe Repository Construction, Operations, and Decommissioning Can Be Implemented Effectively With Respect to Cost

Description

Most discussions of repository safety focus on hazards associated with long-term containment and isolation of radioactive waste. However, near-term, safe, and cost-efficient construction, operation, and decommissioning of a repository are also important in a nuclear waste-isolation program. For convenience these concerns are commonly generalized as "construction" concerns throughout this chapter. Because decommissioning details are poorly defined at this time, subsequent discussion of decommissioning will be omitted unless specifically called for.

An appropriate level of worker and public protection from hazards associated with mining and surface activities as well as with radiogenic exposure during repository operations can be achieved through both careful engineering and selection of natural features that are compatible with, and conducive to, the safe construction and operation of a repository. Engineered safety measures and appropriate geographic features can provide redundant safety measures. Health and safety risks to facility personnel and the public during the construction and operation of a repository should not be greater than those allowed for other nuclear fuel cycle facilities. This is in accordance with Objective 3 of the DOE's Waste Confidence Rulemaking[11] that states

> "Risks during the operation phase of waste disposal systems should not be greater than those allowed for other nuclear fuel cycle facilities. Appropriate regulatory requirements established for other fuel cycle facilities of a like nature should be met."

Because a repository will be a mined facility, it should additionally satisfy requirements outlined in standard mining-safety regulations such as the Federal Mine Safety and Health Act of 1977 and the Code of Federal Regulations, Title 30, Chapter I. The objective for worker and public protection will be met by identifying a location where a repository can be constructed and operated safely and efficiently in terms of reasonable costs.

The screening distinguishes only among natural or land use features as a qualitative basis for rating locations for safety and relative costs of surface and subsurface facilities. Alternative engineering techniques or designs are not considered as means of improving safety or lowering costs. Hence, this objective calls for location where (engineering features being the same) lower costs and hazards can be expected, based on existing natural or land use conditions. Design details for a repository cannot be specified until a location is identified, and many must await selection of a site and emplacement horizon; therefore, this objective must focus on existing conditions. Figure 30 in Reference 2 shows location and host-rock ratings based solely on this upper-level objective for construction and operation of a repository.

This upper-level objective is divided into three component middle-level objectives. The first pertains to the surface facilities of a repository; the second and third address, respectively, subsurface facilities and waste transportation corridors. Although descriptions of the subobjectives may apply to many geographic areas, they are focused (when appropriate) on conditions in the screening area.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- "The mined geologic disposal system shall provide the facilities and capabilities necessary for waste receipt and emplacement." [Requirement 3.1.1]
- "The repository shall provide the capabilities necessary for waste handling operations and waste emplacement. The repository shall also provide design features and equipment to accomplish waste retrieval." [Requirement 3.3.1]
- "The safety of the public and the repository work force will have to be ensured during the operation of a repository. Radiological protection is the principal concern in protecting the

public health and safety, whereas safety of the repository work force includes protection from mining and other occupational hazards as well as radiological protection." [Criterion 4.1]

NWTS-33(2)[4]

- No specific correlative requirements.

10 CFR 60 (Proposed)[8]

- "The geologic repository operations area shall be designed so that, until permanent closure has been completed, radiation exposures and radiation levels and releases of radioactive materials to unrestricted areas will at all times be maintained within the limits specified in Part 20 of this chapter and any generally applicable environmental standards established by the Environmental Protection Agency." [60.111(a) (1)]
- "The geologic repository operations area shall be designed so that the entire inventory of waste could be retrieved on a reasonable schedule, starting at any time up to 50 years after waste emplacement operations are complete." [§60.111(a) (2)]
- "The structures, systems, and components located within restricted areas shall be designed to maintain radiation doses, levels, and concentrations of radioactive material in air in those restricted areas within the limits specified in Part 20 of this chapter." [§60.130(b) (1)]
- "The structures, systems, and components important to safety shall be designed so that natural phenomena and environmental conditions anticipated at the site will not result, in any relevant time period, in failure to achieve the performance objectives." [§60.130(b) (2) (ii)]
- "The surface facility shall be designed to facilitate decommissioning." [§60.131(e)]

Relative Importance

Cost-efficient construction and operation of repository facilities is generally considered less important than providing containment and isolation (Objectives 1.0 and 2.0), but more important than avoiding negative environmental impacts (Objective 4.0). Both the DOE and NRC[3-5, 11] acknowledge that repository facilities must be able to be built and excavated within budget constraints, and that worker safety must conform to mining and nuclear industry standards. Approximately one-fourth of the total importance for location screening was placed on finding locations that have characteristics compatible with efficient construction and operation of repository facilities. This is based on the weighting poll that resulted in an average assignment of 26% to the construction branch of the objectives tree. This makes construction objectives third in importance among the four upper-level objectives (Figure 3). It is apparent that those polled expressed agreement with a general consensus that construction concerns at a site, though significant, are not as important as long-term safety, expressed in this screening by Objectives 1.0 and 2.0.

Applicable Attributes

Fault Density
Natural Seismic Potential
Weapons Seismic Potential
Bed Attitude (rock dip)
Erosion Potential
Flood Potential
Terrain Ruggedness
Metal Resource Potential
Groundwater Flux
Thickness of Unsaturated Zone
Sensitive Floral Species
Sensitive Faunal Species
Known Cultural Resources
Potential Cultural Resources
Thermal Conductivity
Rock Compressive Strength
Expansion-Contraction Behavior
Mineral Stability
Hydraulic Transmissivity

Nineteen attributes were used to rate expected performance of alternative locations with respect to this objective. This was achieved by using a distinctive set of host-rock and geographical attributes for evaluating performance for 11 of the 14 subobjectives comprising the lower-level of this branch of the objectives tree (Sections 3.1.1 through 3.1.6, 3.2.1 through 3.2.6, and 3.3.1 through 3.3.2). The three remaining lower-level construction objectives are not evaluated because no discriminating attributes were defined; however, these objectives still express valid, potentially discriminating concerns. Thus, the potential for safe construction and operation activities is evaluated by summing the contributions of attributes addressing component lower-level objectives. The importance of the attributes is divided about equally between geographical and host-rock attributes. Geographical attributes address surface facilities, subsurface facilities, and transportation systems, whereas host-rock attributes address only subsurface facilities.

3.1 Screen for Locations Suitable for Safe Construction and Operation of Surface Facilities

Description

This objective calls for locations where natural conditions are either suitable or readily amenable for the safe and efficient construction of surface buildings and structures required for a repository. Surface facilities will include buildings for

Receipt of waste
Inspection of waste containers
Repackaging of damaged or leaking containers
Administrative functions
Mine-shaft hoist houses and operational-control facilities
Miscellaneous structures such as generators, office space, a public information center, personnel facilities, and others.[35]

Specialized hot-cells required for handling radioactive materials will require more careful design and construction than many commercial or industrial buildings. Accordingly, extra care may need to be taken to assure proper surface conditions for construction and operation. This middle-level objective is divided in six component lower-level objectives, each addressing a separate aspect of surface conditions conducive to construction and operation of surface facilities. Figure 31 in Reference 2 shows location ratings based solely on this middle-level objective; host-rock ratings are unavailable due to lack of relevant attributes.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- "The site shall provide a setting compatible with the type and magnitude of operations expected at the waste repository." [Requirement 3.2.1]

NWTS-33(2)[4]

- "The site and its surrounding area shall be such that surface characteristics or conditions can be accommodated by engineering and can be shown to have no unacceptable impacts on repository operation and system performance." [Criterion 3.7]

10 CFR 60 (Proposed)[5]

- "Surface facilities in the geologic repository operations area shall be designed to allow safe handling and storage of wastes at the site, whether these wastes are on the surface before emplacment or as a result of retrieval from the underground facility. The surface facilities shall be designed so as to permit inspection, repair, and decontamination of such wastes and their containers." [§60.131(a)]
- "The surface facilities shall be designed to control the release of radioactive material in effluents during normal and emergency operations. [60.131(c) (1)]

[Potentially Adverse Conditions]

- "Potential for adverse impacts on the geologic repository resulting from the occupancy and modification of floodplains." [§60.123(a) (6)]

Relative Importance

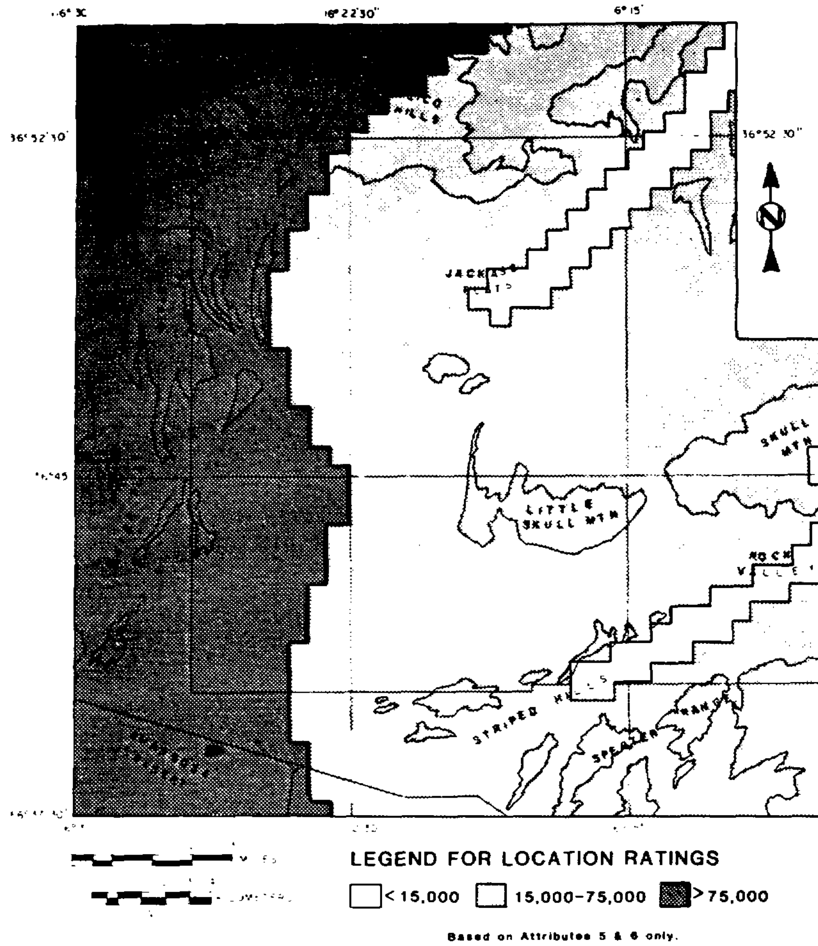
Finding surface conditions amenable to constructing and operating repository facilities is the least important of the three middle-level objectives of the construction branch of the objectives tree. It is assumed that a few hundred acres amenable for construction or operation can be found in or near any location in the screening area. This may require placing some or all of the surface facilities at locations that are remote from the geographic area of subsurface facilities. The incremental costs and operational constraints imposed by relatively unfavorable surface conditions will be relatively low compared with total cost for repository construction and operation. Thus, the importance of this objective is relatively low compared to the objective for safe and efficient subsurface facilities. About one-fourth of the total importance of the operations branch of the objectives tree was assigned to surface facilities. This is based on the weighting poll that resulted in an average assignment of 27% to the surface facility branch of construction objectives. Because the upper-level construction objective was assigned 26%, the objective for safe, efficient surface facilities accounts for about 7% of the total importance for screening. This makes surface facility concerns seventh in importance among the 12 middle-level objectives (Figure 3).

Applicable Attributes

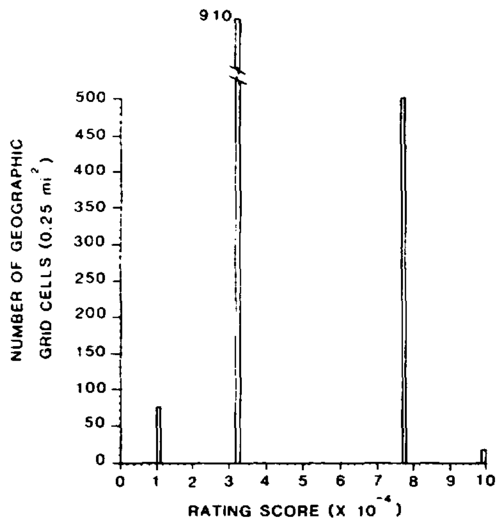
Natural Seismic Potential
Weapons Seismic Potential
Erosion Potential
Flood Potential
Terrain Ruggedness
Sensitive Floral Species
Sensitive Faunal Species
Known Cultural Resources
Potential Cultural Resources

Nine attributes were used to rate expected performance of alternative locations with respect to this objective. This was achieved by using a distinctive set of attributes for evaluating performance for each of the six subobjectives that comprise the lower-level of this branch of construction objectives (Sections 3.1.1 through 3.1.6). These attributes predominantly address seismic and terrain conditions that might influence construction costs, though minor attention is given to environmental conditions that might influence the cost of surface monitoring systems. Thus, this middle-level objective is evaluated by summing the contributions to safe and efficient surface activities provided by surface attributes addressing component lower-level objectives.

OBJECTIVE 3.1.1
MINIMIZE SURFACE SEISMIC HAZARDS



	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	90
	6 WEAPONS SEISMIC POTENTIAL	10
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

Figure 24. Objective 3.1.1—Minimize Surface Seismic Hazards. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting surface seismicity, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since none of the attributes addresses seismic response at the surface because of specific subsurface rock types, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

3.1.1 Minimize Seismic Hazards at Surface Facilities

Description

Locations will be sought where seismic motions arising from earthquakes or human-made explosions are mitigatable at surface facilities. Surface ground motion caused by seismic activity in the vicinity of a repository may damage surface facilities and/or create hazards for repository personnel.[19] This may result in costly schedule disruptions of normal activities at a repository because of the need to repair or mitigate the damage. To minimize the potential for schedule disruptions and safety hazards, vital surface facilities will be designed to structurally withstand the ground motions caused by seismic disturbances expected in the vicinity of a repository. The cost of constructing structures to withstand such disturbances can be significant if expected ground motions are large. Therefore, preference should be given to locations where the magnitude of expected seismic ground motion is low. Figure 24 shows location ratings based solely on this objective; host-rock ratings are unavailable due to lack of relevant attributes.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located so that ground motion associated with the maximum credible earthquake will not have unacceptable impact on system performance." [Criterion 3.5(5)]

10 CFR 60 (Proposed)[5]

[Potentially Adverse Conditions]

- "Earthquakes which have occurred historically that if they were to be repeated could affect the geologic repository significantly." [60.123(a) (4)]
- "More frequent occurrence of earthquakes or earthquakes of higher magnitude than is typical of the area in which the geologic setting is located." [60.123(b) (9)]
- "Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or magnitude of earthquakes may increase." [§60.123(b) (10)]

Relative Importance

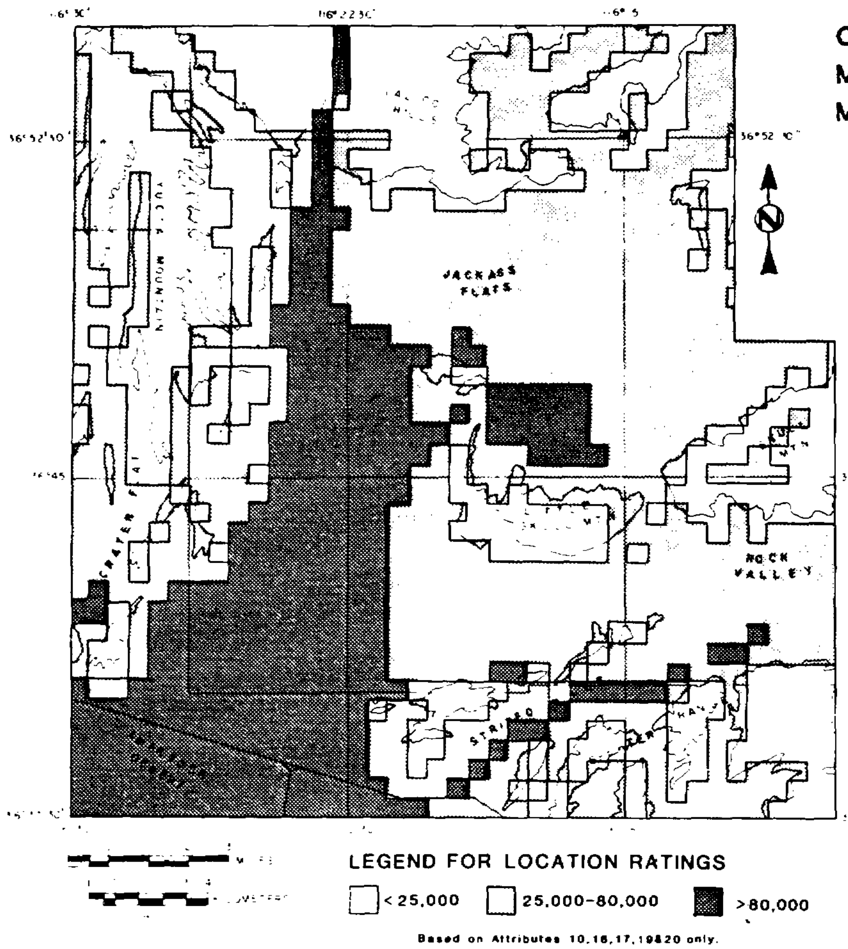
Finding locations where seismic hazards to surface facilities are relatively low is of low importance in the screening activity. Maximum expected seismic accelerations in the screening area can be accommodated by properly designed surface facilities. The incremental cost for hardening surface facilities to safely withstand maximum expected ground accelerations will be small compared to the overall cost of repository construction.[36] In addition, risks to workers and the general public from seismically induced damage to repository surface facilities are very small. This is based on the weighting poll that resulted in the assignment of ~21% of the importance for surface facility objectives to seismic hazards. Since the surface facility branch of the construction objectives was assigned 7%, this objective accounts for less than 2% of the overall importance in the screening activity, making this objective the twenty-second in importance among the 40 lower-level objectives (Figure 3).

Applicable Attributes

Natural Seismic Potential
Weapons Seismic Potential

Two attributes were used to directly rate alternative locations with respect to this objective. Seismic hazards for surface facilities result from the potential for natural seismicity and weapons testing. Weapons testing is predicted to produce less than 0.25-g ground acceleration anywhere in the screening area.[37] This is less than the maximum predicted natural accelerations of 0.3 to 0.7 g within the same area.[38] Therefore, weapon-induced seismic hazards will not control the design basis ground motion. Additionally, weapons tests are controlled in terms of schedules and magnitudes. Repository operations can be curtailed during the tests, and necessary precautions could be taken before the test to secure critical machinery. Postulated higher ground motions from natural earthquakes will dominate the seismic design of critical surface facilities. This, together with the general uncertainty about the timing and magnitude of natural earthquakes, indicates that higher importance should be associated with natural seismic potential.

OBJECTIVE 3.1.2 MINIMIZE SURFACE MONITORING COSTS



	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	70
	11 BASE & PRECIOUS METAL RESOURCE POT	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	3
	17 SENSITIVE FAUNAL SPECIES	7
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	5
	20 POTENTIAL CULTURAL RESOURCES	15
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	

HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

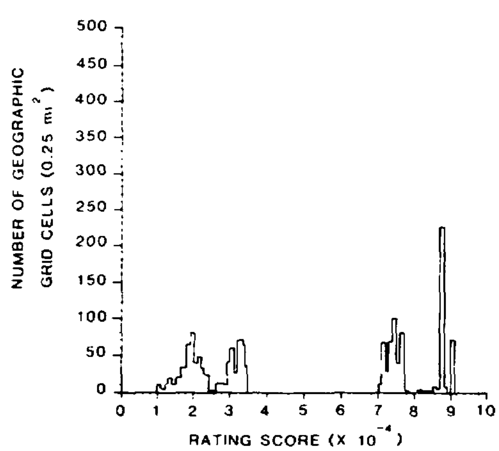


Figure 25. Objective 3.1.2—Minimize Surface Monitoring Costs. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting the cost or difficulty of monitoring the impacts of surface operations, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since none of the attributes addresses the effects of specific rock types on monitoring requirements, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

3.1.2 Minimize Cost for Surface Monitoring and Baseline Characterization

Description

Locations will be sought where the difficulty and costs are low for monitoring the aesthetic and health effects on humans and ecological systems of surface radioactive and particulate effluents from a repository. Some portions of the screening area have high radiation levels relative to normal background levels (because of previous activities). If a repository were located in such areas, it would be more difficult to determine if subsequently discovered radiogenic hot spots in the area were the result of previous activities or if they were associated with accidental releases of radioactivity from the repository. To avoid the cost of installing expensive systems to monitor radioactivity in such an area, preference should be given to locations that are not near sites of previous radioactive contamination. During operations a monitoring system must be established to assure compliance with existing environmental standards for both radiologic and other effluents. Of foremost concern for this objective is the ease with which the effects of these effluents can be determined. In addition, natural conditions will be sought where the costs for characterizing baseline environmental conditions or monitoring impacts on human and ecological environments are relatively low. Figure 25 shows location ratings based solely on this objective; host-rock ratings are unavailable due to lack of relevant attributes.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- "The repository shall contribute to the containment and isolation capabilities of the mined disposal system by (1) limiting adverse impacts of repository development and operation on waste package and site performance, (2) using engineered barriers that maintain the natural capabilities of the disposal system, (3) *monitoring the system performance*, and (4) providing measures to protect against human intrusion." (Emphasis Added) [Requirement 3.3.2]

NWTS-33(2)[4]

- "The site shall be located in an area where surface topographic features do not unacceptably affect repository operation." [Criterion 3.7(2)]

10 CFR 60[6]

- "Instrumentation and control systems shall be designed to monitor and control the behavior of engineered systems important to safety over anticipated ranges for normal operation and for accident conditons." [§60.130(q)]
- "The effluent monitoring systems shall be designed to measure the amount and concentration of radionuclides in any effluent with sufficient precision to determine whether releases conform to the design requirement for effluent control." [§60.131(c) (2)]

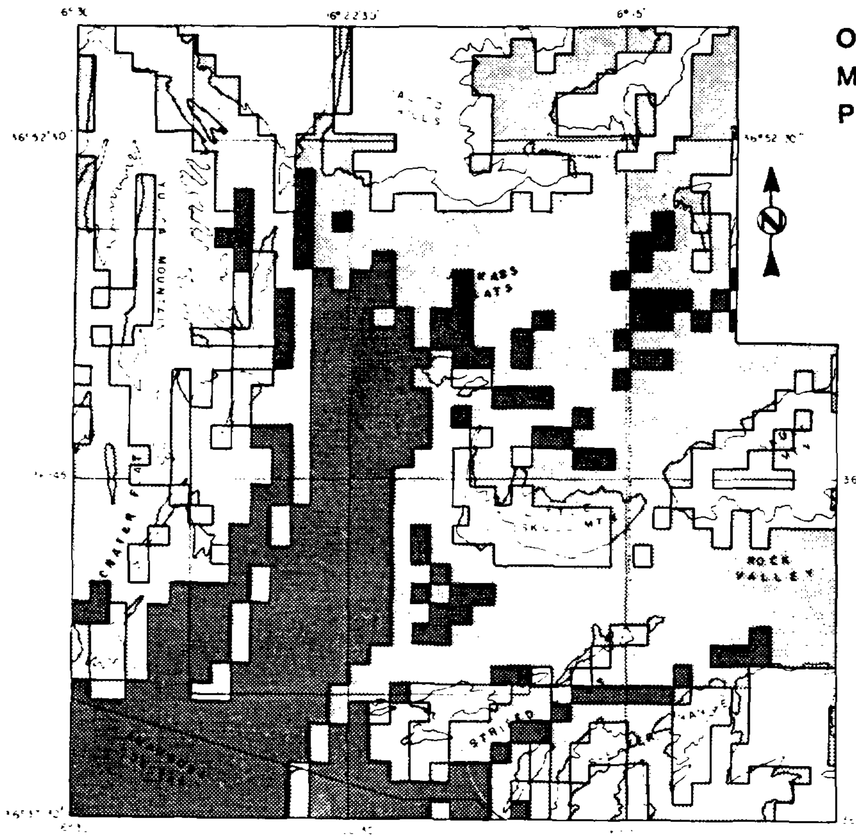
Relative Importance

Finding locations where baseline characterization and monitoring costs for surface facilities are relatively low is one of the least important objectives in the screening. This is based on the weighting poll that resulted in an average assignment to this objective of about 11% of the importance for surface facility objectives. Because surface facility objectives were assigned 7%, this objective accounts for one-half of one percent of the overall importance for screening. Therefore, this objective is the thirty-second in importance among the 40 lower-level objectives (Figure 3).

Applicable Attributes

Terrain Ruggedness
Sensitive Floral Species
Sensitive Faunal Species
Known Cultural Resources
Potential Cultural Resources

Five attributes were used to indirectly rate alternative locations with respect to this objective. The ruggedness of terrain will strongly influence the ease of emplacing and servicing monitoring equipment, and of collecting baseline data prior to monitoring. The characterization of cultural resources and surveys for sensitive species will be baseline characterization efforts required prior to monitoring the effects of a repository. Because terrain ruggedness influences both baseline characterization costs and subsequent monitoring costs, this attribute is assigned the most weight for evaluating this objective. The importance assigned to the other attributes was based, in part, on the proposed costs for characterizing the respective element of the environment.



OBJECTIVE 3.1.3
MINIMIZE FOUNDATION PROBLEMS

	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	10
	9 FLOOD POTENTIAL	20
	10 TERRAIN RUGGEDNESS	70
	11 BASE & PRECIOUS METAL RESOURCE POT	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	

LEGEND FOR LOCATION RATINGS

☐ < 25,000 ☐ 25,000–82,000 ■ > 82,000

Based on Attributes 8–10 only.

HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

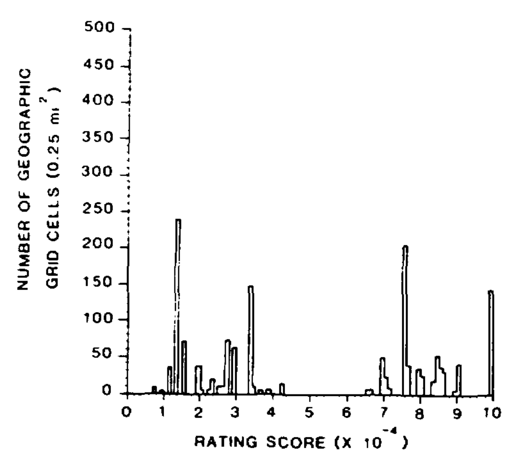


Figure 26. Objective 3.1.3—Minimize Foundation Problems. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting foundation costs, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since none of the attributes addresses the effects of specific types of subsurface rocks on foundation construction, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

3.1.3 Minimize Adverse Foundation Conditions

Description

Locations will be sought that have favorable foundation conditions for surface buildings. The potential for ground subsidence, the bearing capacity of soils, the likelihood of damage from flooding and erosion, and other surface factors determine foundation conditions. Adverse conditions of these surface features should be avoided because the potential damage caused by their existence will increase the cost of special engineering measures to avoid or mitigate such damage. Topographic irregularity is a condition that should be avoided, if possible. Construction of surface structures along gullies, steep slopes, and sharp precipices can contribute to higher costs for site development and surface facility construction. Another adverse condition to avoid, if possible, is bedrock sufficiently close to the surface to affect the cost of foundation excavation. Higher construction costs generally are associated with locations where bedrock rather than unconsolidated materials must be excavated to construct building foundations. Therefore, this objective seeks locations where natural features are amenable to excavation and construction of secure foundations for surface buildings. Figure 26 shows location ratings based solely on this objective; host-rock ratings are unavailable due to lack of relevant attributes.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located in an area where surface topographic features do not unacceptably affect repository operation." [Criterion 3.7(2)]

10 CFR 60 (Proposed)[5]

- No specific correlative requirements.

Relative Importance

Finding locations with relatively suitable foundation conditions for surface repository facilities was of moderate to low importance in the screening activity. Cost differences because of different foundation conditions at alternate locations in the screening area will be relatively small compared to overall repository development costs. Accordingly, this objective is of relatively low importance. However, it is the most important lower-level objective of the surface facility branch of the operational objectives. This reflects the assumption that topographic conditions (herein considered a factor of foundation conditions) will be a major constraining factor in determining the layout, location, and cost of surface facilities for a repository in the screening area. The weighting poll resulted in an average assignment to this objective of about 25% of the importance for surface facility concerns. Because surface facility objectives were assigned about 7%, this objective accounts for nearly 2% of the overall importance in screening. Therefore, this objective is the eighteenth most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

Terrain Ruggedness
Erosion Potential
Flood Potential

Three attributes were used to rate alternative locations with respect to this objective. Topographic irregularities will lead to higher foundation costs and should be avoided; thus the attribute for terrain ruggedness is used to indirectly indicate potential foundation problems. Detailed classification of soil characteristics necessary for a foundation analysis is generally available only where there are existing facilities. Soils information is generally inadequate elsewhere, including almost all portions of the screening area; therefore, this factor cannot be directly assessed. Erosion potential provides indirect evidence of threats to foundation stability. Though engineering measures can be taken to rectify potentially serious flood conditions, flood potential is an attribute that nevertheless addresses suitability for proper foundations.

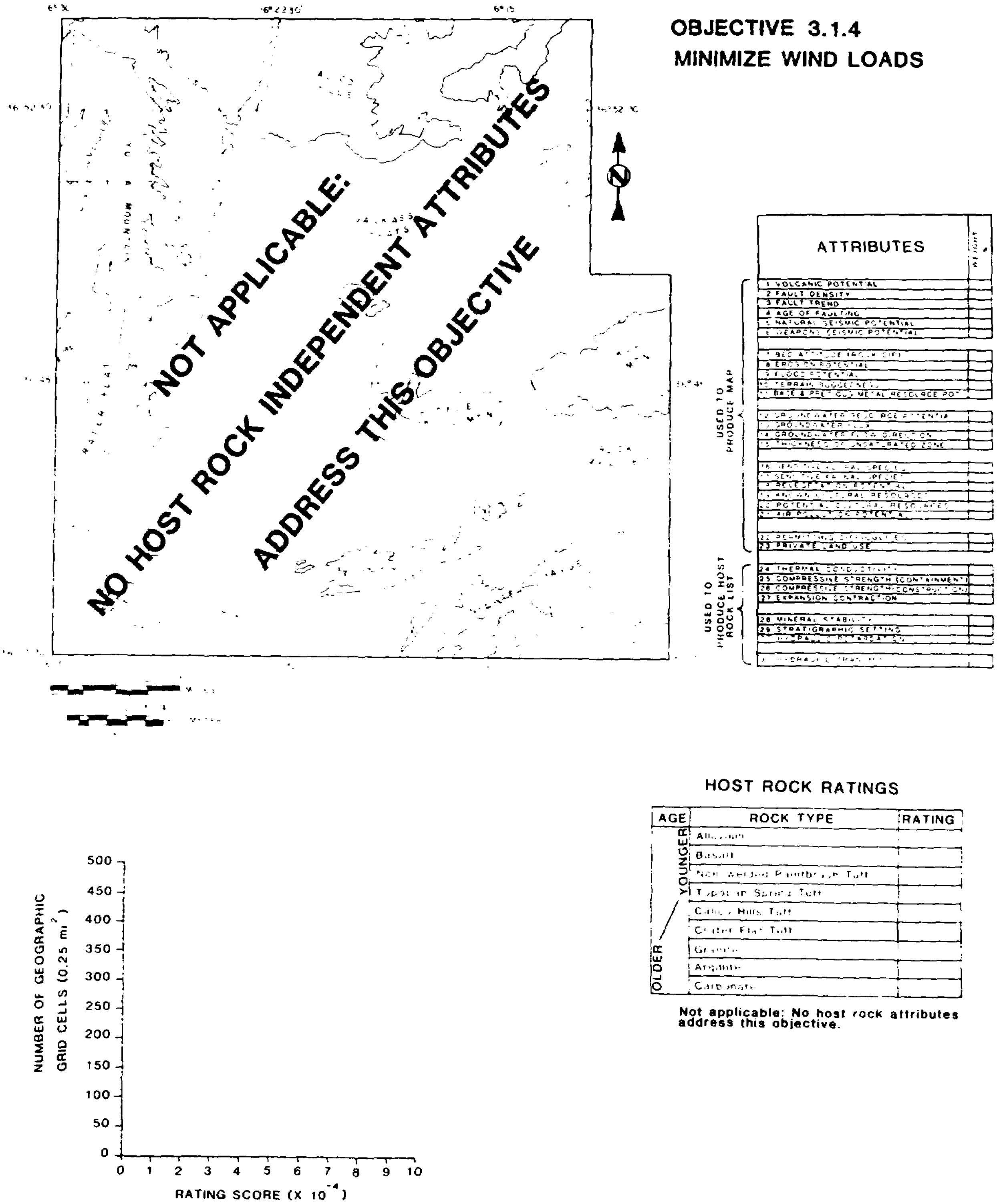


Figure 27. Objective 3.1.4—Minimize Wind Loads. Since the attributes did not address potential wind loads on surface structures (attribute list, upper right), neither location ratings (upper left) and associated histogram (lower left) nor host-rock ratings (lower right) were obtained for this objective. Therefore, this objective could not be used to help discriminate among alternative locations or host rocks.

3.1.4 Minimize Wind Loads on Surface Structures

Description

Locations will be sought where wind loads on surface structures are not expected to exceed design strengths of building walls and roofs. Vital surface facilities at a repository should be designed to withstand credible wind velocities expected at a repository location. Because the cost associated with constructing surface structures to resist damage from high winds increases with expected wind velocities, preference should be given to locations where wind velocities are expected to be small. Figure 27 shows that no ratings were obtained for this objective due to lack of relevant attributes. Thus, their objective did not contribute to discrimination among locations and host rocks.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located where meteorological phenomena can be accommodated by engineering measures and can be shown to have no unacceptable effect on repository operation." [Criterion 3.7(3)]

10 CFR 60 (Proposed)[6]

- No specific correlative requirements.

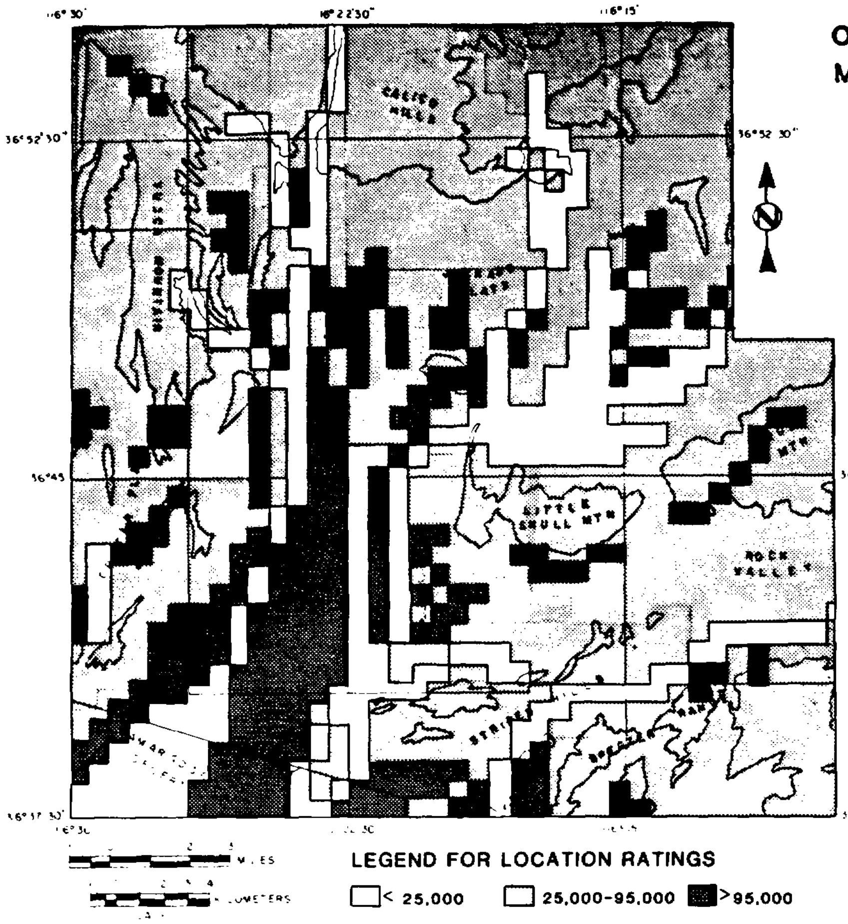
Relative Importance

Finding locations with relatively low potential for wind damage to surface facilities was one of the least important objectives in the screening activity. The lack of tornadoes and violent, large-scale storms in southern Nevada make the likelihood of severe wind damage exceedingly small in this area. This is reflected by the weighting poll that resulted in an average assignment of about 10% of the importance for surface facilities to wind loads. Because surface facility objectives were assigned 7%, this objective accounts for somewhat more than one-half of a percent of the total importance in screening. Therefore, this objective is the thirty-third most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

No attributes were developed to discriminate different wind loads throughout the screening area. Thus, no attributes are used to rate alternative locations with respect to this objective. Therefore, the weight associated with this objective did not contribute to the ratings of alternative locations. However, no significant variations are expected in surface facility design as a function of different expected wind loads for different parts of the screening area. Variations in wind directions and magnitudes are expected at different locations but these are not expected to greatly influence structural design.

OBJECTIVE 3.1.5
MINIMIZE FLOODING HAZARDS

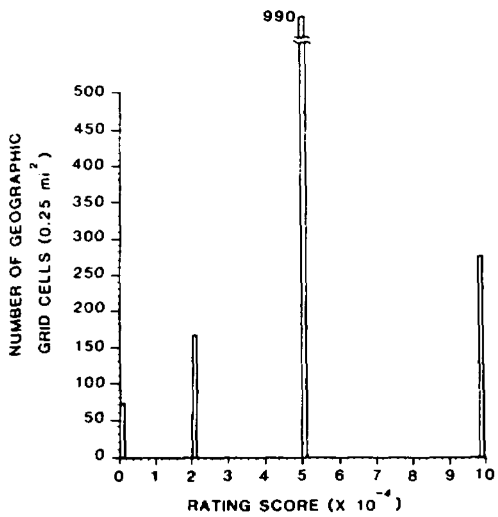


LEGEND FOR LOCATION RATINGS

□ < 25,000 □ 25,000-95,000 ■ >95,000

Based on Attribute #9 only.

ATTRIBUTES	WEIGHT %
Used to produce map	
1 VOLCANIC POTENTIAL	
2 FAULT DENSITY	
3 FAULT TREND	
4 AGE OF FAULTING	
5 NATURAL SEISMIC POTENTIAL	
6 WEAPONS SEISMIC POTENTIAL	
7 BED ATTITUDE (ROCK DIP)	
8 EROSION POTENTIAL	
9 FLOOD POTENTIAL	100
10 TERRAIN RUGGEDNESS	
11 BASE & PRECIOUS METAL RESOURCE POT	
12 GROUNDWATER RESOURCE POTENTIAL	
13 GROUNDWATER FLUX	
14 GROUNDWATER FLOW DIRECTION	
15 THICKNESS OF UNSATURATED ZONE	
16 SENSITIVE FLORAL SPECIES	
17 SENSITIVE FAUNAL SPECIES	
18 REVEGETATION POTENTIAL	
19 KNOWN CULTURAL RESOURCES	
20 POTENTIAL CULTURAL RESOURCES	
21 AIR POLLUTION POTENTIAL	
22 PERMITTING DIFFICULTIES	
23 PRIVATE LAND USE	
Used to produce host rock list	
24 THERMAL CONDUCTIVITY	
25 COMPRESSIVE STRENGTH (CONTAINMENT)	
26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
27 EXPANSION-CONTRACTION	
28 MINERAL STABILITY	
29 STRATIGRAPHIC SETTING	
30 HYDRAULIC RETARDATION	
31 HYDRAULIC TRANSMISSIVITY	



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
OLDER	Granite	
	Argillite	
	Carbonate	

Figure 28. Objective 3.1.5—Minimize Flooding Hazards. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting flooding potential, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since the attributes do not address the effects of specific rock types on flooding potential, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

3.1.5 Minimize Flooding Hazards at Surface Facilities

Description

Locations will be sought where floods are unlikely to affect surface buildings. Flooding of repository surface structures may disrupt normal repository activities. This disruption could be very brief, forcing personnel to temporarily interrupt their routine duties until the flood waters recede; or very long, if facilities or equipment are damaged by a flood to the point that repairs or replacements must be made before activity can recommence. If a repository is constructed at a location prone to flooding, special engineering features such as dikes or dams may have to be constructed to minimize potential damage. To avoid high costs for flood control measures, preference should be given to locations not subject to recurrent flooding. Potential changes during the next century in drainage patterns and attendant flood areas should be considered when evaluating flood potential. Preference for surface facilities above the highest water level that is reasonably expected should be given to locations during the construction and operation of a repository. Safety problems also may develop if surface flooding introduces water through mine shafts and boreholes and into subsurface repository workings. Figure 28 shows location ratings based solely on this objective; host-rock ratings are unavailable due to lack of relevant attributes. The implication of flooding of underground facilities is discussed in the section for Objective 3.2.2, "Minimize Flooding Hazards in Subsurface Facilities."

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located so that the surficial hydrological system, both during anticipated climatic cycles and during extreme natural phenomena, will not cause unacceptable impacts on repository operations or system performance." [Criterion 3.7(1)]

10 CFR 60 (Proposed)[5]

[Potentially Adverse Conditions]

- "Potential for failure of existing or planned man-made surface water impoundments that could cause flooding of the geologic repository operations area." [§60.123(a) (1)]

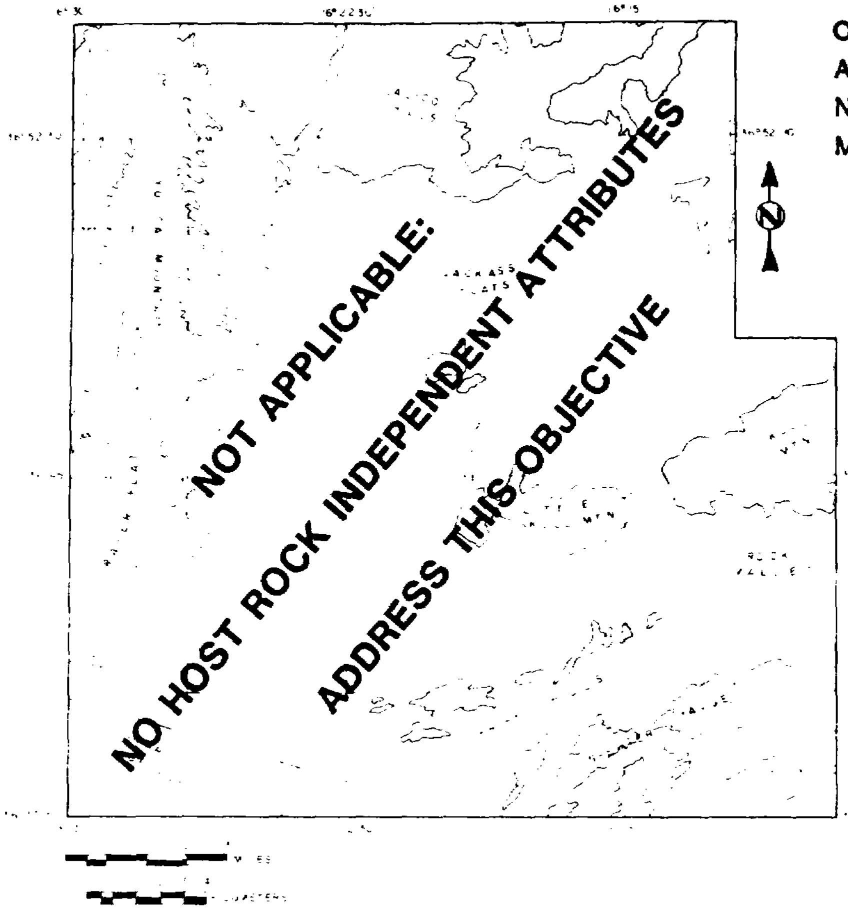
Relative Importance

Finding locations with relatively low flooding hazards to surface repository facilities was of moderately low importance in the screening activity. Though large portions of the screening area are subject to occasional floods along ephemeral washes, the expected flood magnitudes[39 40] permit proper engineering features to be included in surface facilities to adequately mitigate the hazards. The expected cost of flood control features is small relative to total repository development costs. About one-sixth of the importance for surface facilities was assigned to flood avoidance. This was based on the weighting poll that resulted in an average assignment to this objective of about 17% of the importance of surface facility objectives. Because surface facility objectives were assigned 7%, this objective accounts for a little more than 1% of the overall importance for screening, making this objective the twenty-sixth most important of the 40 lower-level objectives (Figure 3).

Applicable Attribute

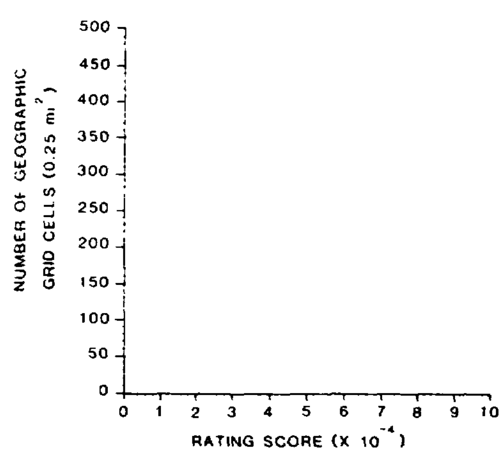
Flood Potential

Only one attribute (flood potential) was used to rate alternative locations with respect to this objective. This attribute provides a straightforward, direct measure of the flooding hazard at various locations.



OBJECTIVE 3.1.6
ASSURE AVAILABILITY OF NEARBY CONSTRUCTION MATERIALS

	ATTRIBUTES	WEIGHT
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT	
	12 GROUNDWATER RESOURCE POTENTIA	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

Not applicable: No host rock attributes address this objective.

Figure 29. Objective 3.1.6—Assure Availability of Nearby Construction Materials. Since the attributes do not address the occurrence of construction materials or utility hookups (attribute list, upper right), neither location ratings (upper left) and associated histogram (lower left) nor host-rock ratings (lower right) were obtained for this objective. Therefore, this objective could not be used to help discriminate among alternative locations or host rocks.

3.1.6 Assure Availability of Natural Resources and Utilities Needed to Construct and Operate a Repository

Description

Locations will be sought where construction materials, water, and power sources are readily available or obtainable. Four types of natural resources (water, energy, construction materials, and land) need to be locally available at reasonable cost and in sufficient quantities to allow cost-efficient construction and operation of a repository. The first three resources are likely to be equally available in all portions of the screening area since they either occur near all locations, or can be delivered to them for approximately the same cost. The fourth resource, land, may not be equally available at all alternative locations because of potential permitting considerations (section on Objective 4.4.2). Figure 29 shows that no ratings were obtained for this objective due to lack of relevant attributes. Thus, this objective did not contribute to discriminating among locations and host rocks.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- "The safe disposal and isolation of radioactive wastes shall be achieved in a manner that provides effective utilization of resources." [Objective 2.6]

NWTS-33(2)[4]

- "The site shall be located where present and projected effects from nearby industrial, transportation, and military installations and operations can be accommodated by engineering measures and can be shown to have no unacceptable impacts on repository operations." [Criterion 3.7(4)]
- "The site shall be located so that adequate access and utility capability required for the repository either exists or can be provided without unacceptable impact on affected communities." [Criterion 3.10(2)]

10 CFR 60 (Proposed)[6]

- No specific correlative requirements.

Relative Importance

Finding locations where natural resources and utilities are more readily available or more easily obtained was of minor importance in the screening activity. Such resources can be obtained with about the same degree of ease at all locations in the screening area. Accordingly, this objective was assigned low importance. About one-eighth of the importance for surface facility objectives was assigned to this objective. This was based on the weighting poll that resulted in an average assignment of about 13% to this subobjective of the surface facility branch of the objectives tree. Because surface facility objectives were assigned 7%, this objective accounts for somewhat less than 1% of the overall importance for screening. Therefore, this objective is the twenty-ninth most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

No attributes were to rate alternative locations with respect to this objective, because required natural resources and utility services are assumed to be equally available to all locations within the screening area. Thus, this objective is nondiscriminating. Accordingly, the weight associated with this objective did not contribute to the ratings of alternative locations.

3.2 Screen for Locations Suitable for Safe Construction and Operation of Subsurface Facilities

Description

This objective calls for locations where natural conditions are either suitable or readily amenable for the safe and efficient construction and operation of mined repository facilities. Subsurface facilities required include access shafts and corridors; waste emplacement rooms; personnel facilities; waste receipt, transportation, and emplacement equipment; utilities; ventilation systems; and water drainage systems.[35] Natural features of interest are those that allow mine openings to be safely and efficiently made and then maintained for the duration of repository operations. Figure 32 in Reference 2 shows location and host-rock ratings based solely on this middle-level objective. This middle-level objective is divided into six component lower-level objectives, each addressing a separate aspect of subsurface conditions conducive to construction and operation of underground facilities.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- "The mined geologic disposal system shall provide the capability to adequately contain and isolate radionuclides to ensure that no releases resulting in unacceptable doses to the public occur." [Requirement 3.1.2]
- "The repository shall contribute to the containment and isolation capabilities of the mined disposal system by (1) limiting adverse impacts of repository development and operation on waste package and site performance, (2) *using engineered barriers that maintain the natural capabilities of the disposal system*, (3) monitoring the system performance, and (4) providing measures to protect against human intrusion." (Emphasis Added) [Requirement 3.3.2]

NWTS-33(2)[4]

- "The site shall be located so that development, operation, and closure of underground areas can be accomplished without undue hazard to repository personnel." [Criterion 3.4(3)]

10 CFR 60 (Proposed)[5]

- "To the extent that DOE is not subject to the Federal Mine Safety and Health Act of 1977, as to the construction and operation of the geologic repository operations area, the design of the geologic repository operations area shall nevertheless include such provisions for worker protection as may be necessary to provide reasonable assurance that all structures, systems, and components important to safety can perform their intended function." [§60.130(10)]
- "The underground facility shall be designed so as to perform its safety functions assuming interactions among the geologic setting, the underground facility, and the waste package." [60.132(a) (1)]
- "The underground facility shall be designed so that the effects of disruptive events such as intrusions of gas, or water, or explosions, will not spread through the facility." [§60.132(a) (4)]
- "Shaft and boreholes seals shall be designed so that:

  Shaft and boreholes seals can accommodate potential variations of stress, temperature, and moisture." [60.133(h) (4)]
- "The materials used to construct the seals are appropriate in view of the geochemistry of the rock and groundwater system, anticipated deformations of the rock, and other in situ conditions." [60.133(b) (5)]

[Potentially Adverse Conditions]

- "Rock or groundwater conditions that would require complex engineering measures in the design and construction of the underground facility or in the sealing of boreholes and shafts." [§60.123(b) (16)]

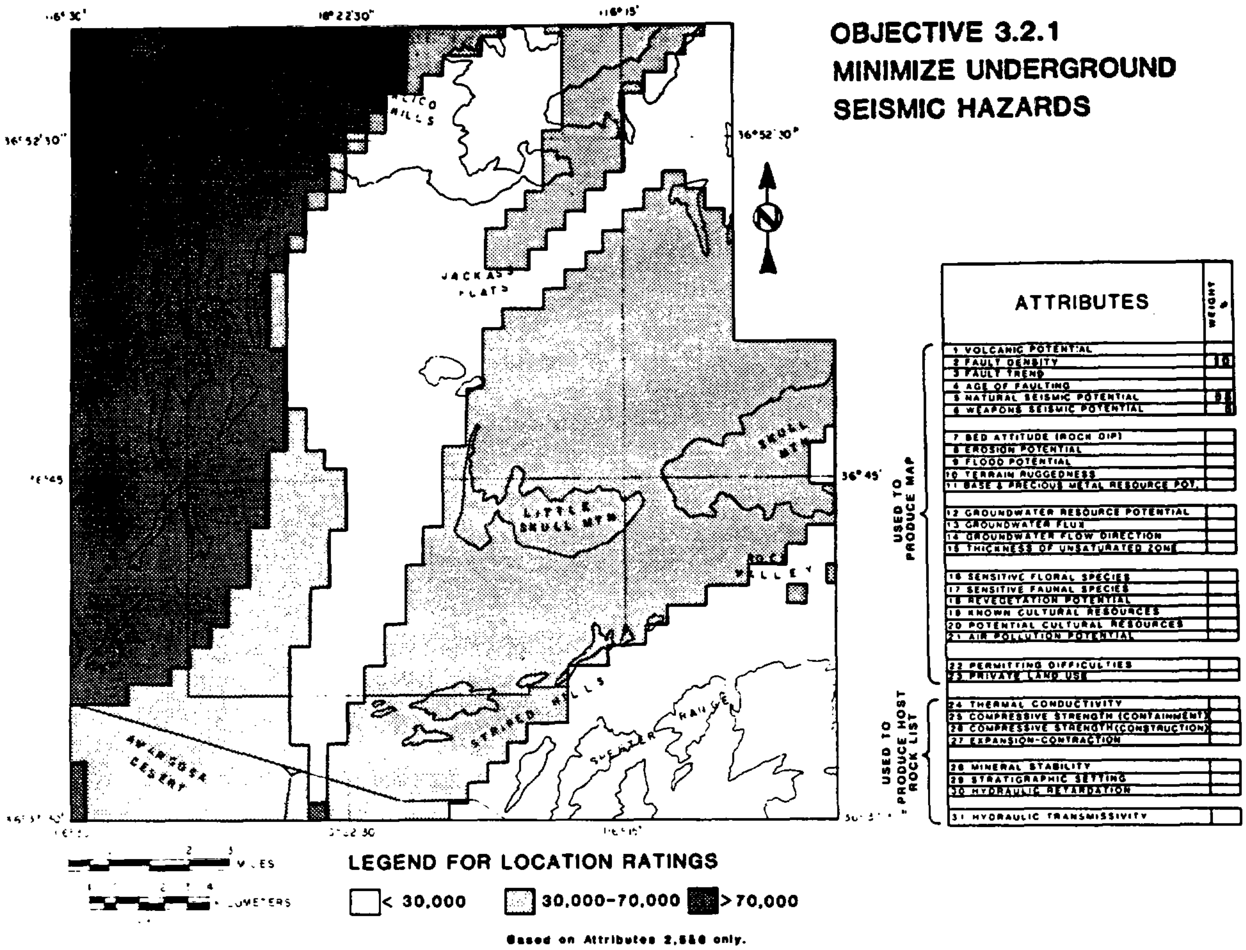
Relative Importance

Finding conditions amenable to safe construction and operation of underground repository facilities is the most important of the three middle-level objectives of the construction branch of the objectives tree. Up to 2000 acres of suitable rocks at potential repository depths should be available in which mined openings can be excavated and maintained in workable condition under an imposed thermal load for tens to perhaps a hundred years. Because most repository activity will be conducted underground, and because the area required for mined openings far exceeds the area required for surface facilities, the costs of developing and operating underground facilities will be much greater than those for surface facilities. Accordingly, greater importance is assigned to finding conditions compatible with underground facilities than to suitable, above-ground conditions. Nearly half of the total importance of the construction branch of the objectives tree was assigned to subsurface facilities. This was based on the weighting poll that resulted in an average assignment of 43% to the subsurface facility branch of construction objectives. Because construction objectives were assigned 26%, this objective accounts for about 11% of the overall importance for screening. This makes concerns about subsurface facilities fifth in importance among the 12 middle-level objectives, and the most important middle-level objective with the exception of those concerned with containment and isolation (Figure 3).

Applicable Attributes

Fault Density
Natural Seismic Potential
Weapons Seismic Potential
Bed Attitude (rock dip)
Flood Potential
Metal Resource Potential
Groundwater Flux
Thickness of Unsaturated Zone
Thermal Conductivity
Rock Compressive Strength
Expansion-Contraction Behavior
Mineral Stability
Hydraulic Transmissivity

Thirteen attributes were used to rate the expected performance of alternative locations with respect to this objective. This was done by using a distinctive set of attributes for evaluating performance for each of the six subobjectives that comprise the lower level of this branch of the objectives tree (Sections 3.2.1 through 3.2.6). These thirteen attributes address both geographical and host-rock features that may affect subsurface rock conditions. Thus, this middle-level objective is evaluated by summing the contributions to mineability and mine maintenance provided by attributes addressing component lower-level objectives.



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

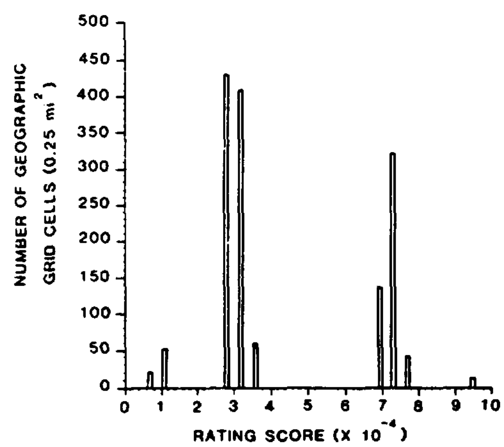


Figure 30. Objective 3.2.1—Minimize Underground Seismic Hazards. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting subsurface seismicity, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since the attributes do not address the seismic responses of specific rock types, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

3.2.1 Minimize Seismic Hazards to Subsurface Facilities

Description

Locations will be sought where seismic hazards to underground openings are low. Subsurface ground motion caused by seismic activity in the vicinity of a repository could damage underground shafts, drifts, and/or equipment necessary for repository construction or operation. Water may be introduced into the subsurface facilities if ground shaking damages the liner of a shaft where it penetrates an aquifer. Conveyance equipment within the shaft may be damaged or realigned to the point that it will not function properly. These effects could disrupt repository operations and threaten the workers trapped in the subsurface facilities. Additionally, seismic activity may move temporarily stored transfer casks awaiting emplacement, or overturn waste-transport vehicles (also threatening worker safety). Ground motion or natural geological displacements may combine with heat-generated rock displacements to disturb stress equilibria established along mine and shaft openings, resulting in rock spalling or rock bursts that threaten workers or disrupt construction or operational activities. The cost of hardening subsurface structures to withstand seismic hazards associated with surface accelerations of 0.7 g are estimated to add between 10% and 30% to the overall cost of constructing the subsurface structures.[36] To avoid high incremental costs, preference should be given to locations with low expected ground motions caused by earthquakes or man-made explosions. An additional but unlikely seismic risk to the repository is the potential for formation of a new tectonic fault or movement along an existing, but currently healed, fault within the storage area. This could cause severe operational problems in terms of rock spalling or infusion of water through newly formed fissures. Therefore, independent of ground motion concerns, areas of more likely faulting should be avoided. Figure 30 shows location ratings based solely on this objective; host-rock ratings are unavailable due to lack of relevant attributes.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located so that ground motion associated with the maximum credible earthquake will not have unacceptable impact on system performance." [Criterion 3.5(5)]

10 CFR 60 (Proposed)[5]

[Potentially Adverse Conditions]

- "Earthquakes which have occurred historically that if they were to be repeated could affect the geologic repository significantly." [60.123(a) (4)]
- "More frequent occurrence of earthquakes or earthquakes of higher magnitude than is typical of the area in which the geologic setting is located." [60.123(b) (9)]
- "Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or magnitude of earthquakes may increase." [§60.123(b) (10)]

Relative Importance

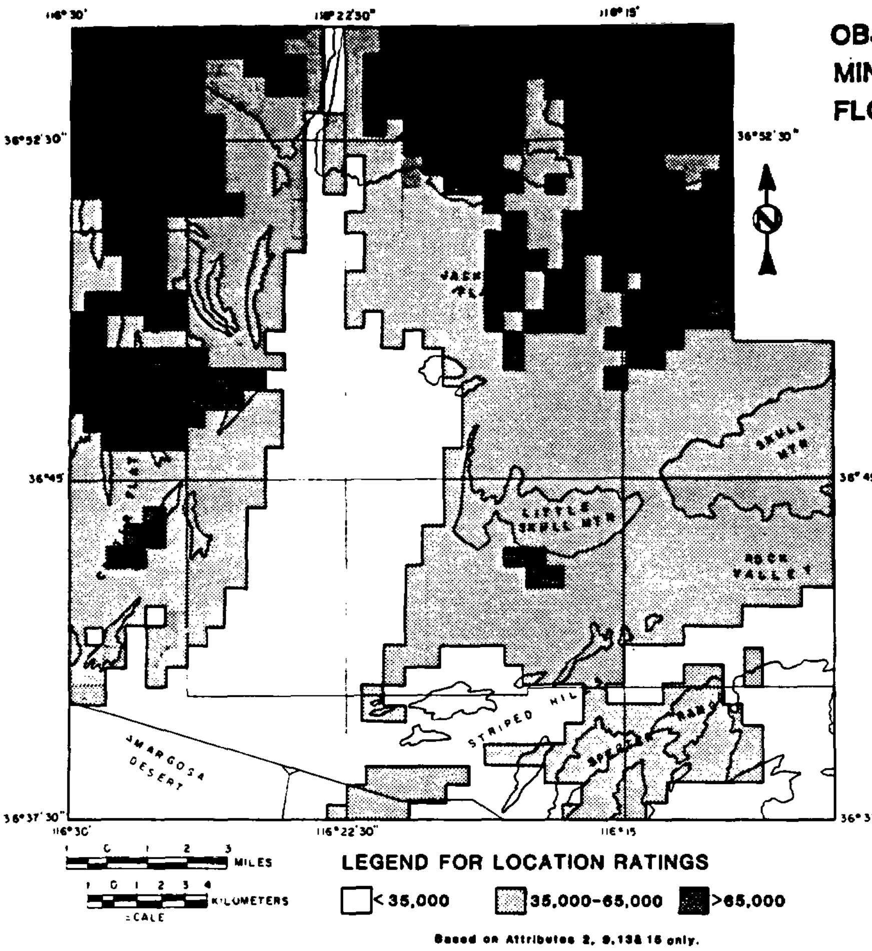
Finding locations where seismic hazards for underground facilities are relatively low was of moderate importance in the screening activity. Subsurface ground accelerations caused by earthquakes are in most cases less than those experienced at the surface. Many mines have remained open and workable while sustaining little or no damage during nearby large earthquakes. There is no reason to suspect that repository mined openings will uniquely respond to earthquakes in a contrary manner that is unduly hazardous to underground workers.[41] [42] If special tunnel-hardening features are required, they can be installed for a relatively small proportion of the total excavation costs. Accordingly, this objective is considered relatively unimportant. About one-sixth of the importance for subsurface facilities was assigned to this objective. This was based on the weighting poll that resulted in an average assignment to this objective of about 13% of the importance for the subsurface facility branch of construction objectives. Because the subsurface facility branch was assigned 11%, this objective accounts for slightly less than 2% of the overall importance in screening. Therefore, this objective is the twentieth most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

Natural Seismic Potential
Weapons Seismic Potential
Fault Density

Three attributes are used to rate alternative locations with respect to this objective. Natural seismic and weapons seismic potentials are directly applicable, though the relationship between surface and at-depth ground motion must be considered. Natural seismic potential is assigned a greater importance than the weapons testing potential because of the lower accelerations predicted for weapons tests and the opportunity of applying precautionary measures for the scheduled tests should such measures be necessary. The greater the fault density, the greater will be the likelihood of hazards associated with creep, abrupt slippage, or increased groundwater flow along existing faults. Thus, this attribute is used to indirectly address the potential for fault slippage within underground repository workings.

OBJECTIVE 3.2.2
MINIMIZE UNDERGROUND FLOODING HAZARDS



	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	10
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	5
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT.	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	15
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	10
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	60

HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	50,000
	Basalt	50,000
	Non-welded Paintbrush Tuff	80,000
	Topopah Spring Tuff	10,000
	Calico Hills Tuff	100,000
	Crater Flat Tuff	80,000
	Granite	100,000
	Argillite	100,000
OLDER	Carbonate	10,000

Based on Attribute 31 only.

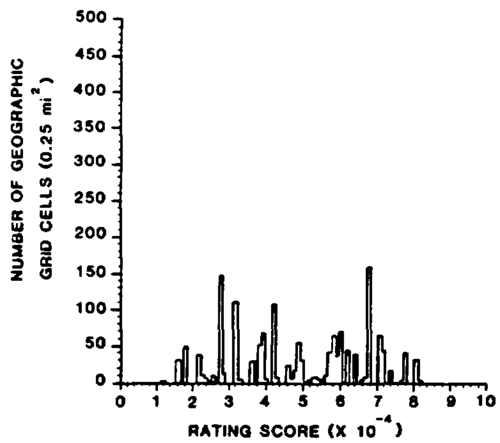


Figure 31. Objective 3.2.2—Minimize Underground Flooding Hazards. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting the potential for subsurface flooding, weighted according to the attribute list (upper right). Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map; table (lower right) shows the rating values of nine potential host-rock types based on rock attributes affecting potential subsurface flooding, also weighted according to the attribute list (upper right). The sum of attribute weights is 100%; the maximum possible rating value for locations or host rocks is 100 000.

3.2.2 Minimize Flooding Hazards in Subsurface Facilities

Description

Locations will be sought where the potential for flooding of underground workings is low. Preference will be given to locations where subsurface facilities (including access shafts) do not intersect highly permeable, water-bearing strata. This will reduce the risk of flooding in the subsurface facilities because of a damaged mine-shaft liner as well as reduce the costs of engineered drainage systems to maintain workable conditions. Possible changes in groundwater flow conditions induced by mining of subsurface cavities, which will be at essentially atmospheric pressure, should be considered in evaluating subsurface flooding hazards. If high hydraulic heads are encountered in highly transmissive zones during construction, these heads could possibly be bled off rather rapidly, thus alleviating attendant flooding problems. Perhaps subsequent continual pumping will be required to remove water inflow under newly induced equilibrated heads surrounding the openings. By avoiding locations in flood plains and locations with interconnected fissures extending from the surface to the subsurface strata, it is unlikely that surface water will be introduced inadvertently into the subsurface facilities. However, the subsurface flooding hazard can be reduced by giving preference to locations meeting the objective for minimizing surface flooding hazards (Objective 3.1.5). Figure 31 shows location and host-rock ratings based solely on this objective.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located so that the geohydrological regime allows construction of repository shafts and maintenance of shaft liners and seals." [Criterion 3.2(3)]

10 CFR 60 (Proposed)[5]

- "The underground facility shall be designed to provide for structural stability, *control of groundwater movement*, and control of radionuclide releases, as necessary to comply with the performance objectives of §60.111." (Emphasis Added) [§60.132(a) (2)]
- "Barriers shall be located where shafts could allow access for groundwater to enter or leave the underground facility." [§60.132(i) (1)]
- "*Water* and gas *control systems* shall be designed to be of sufficient capability and capacity to reduce the potentially adverse effects of *groundwater intrusion, service water intrusion*, or gas flow into the underground facility." (Emphasis Added) [§60.132(g) (1)]
- "If the intersection of aquifers or water-bearing geologic structures is anticipated during construction, the design of the underground facility shall include plans for cutoff or control of water in advance of the excavation." [§60.132(g) (5)]

[Favorable Conditions]

- "A host rock that provides the following groundwater characteristics—(1) low groundwater content; (2) inhibition of groundwater circulation in the host rock; (3) *inhibition of groundwater flow between hydrogeologic units or along shaft, drifts, and boreholes*; and (4) groundwater travel times, under prewaste emplacement conditions, between the underground facility and the accessible environment that substantially exceed 1000 years." (Emphasis Added) [§60.122(f) (3)]

Relative Importance

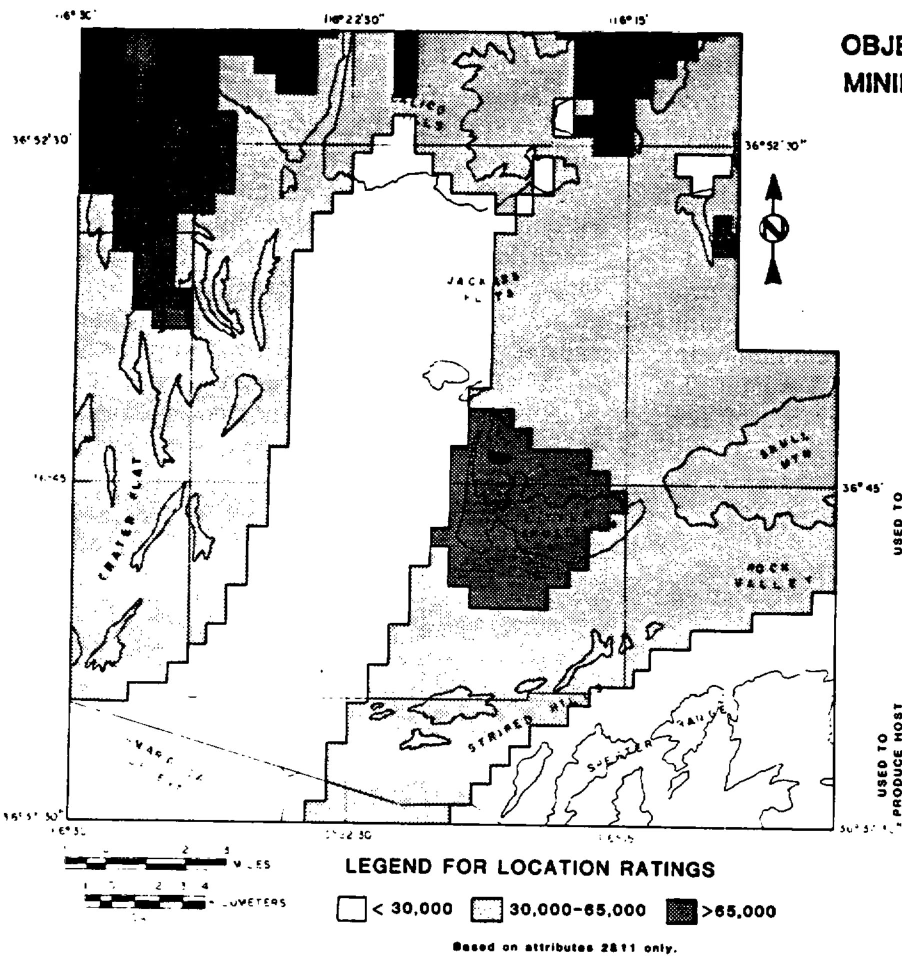
Finding locations where subsurface flooding hazards are relatively low was moderately important in the screening activity. Subsurface flooding could cause unexpected problems during excavation of repository tunnels, but mitigating, engineered procedures and mine drainage systems can reduce hazards to repository personnel to very low levels. About one-fifth of the importance of subsurface facility concerns was assigned to this objective. This was based on the weighting poll that resulted in an average assignment of about 20% of the importance for the subsurface branch of construction objectives to this lower-level objective. Because the subsurface branch was assigned 11%, this objective accounts for about 2% of the overall importance for screening. Therefore, this objective is the thirteenth most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

Hydraulic Transmissivity
Groundwater Flux
Fault Density
Thickness of the Unsaturated Zone
Flood Potential

Five attributes were used to rate alternative locations with respect to this objective. These attributes address flooding hazards associated with both surface and subsurface conditions. The potential for subsurface flooding is addressed by attributes that may correlate with zones of prolific aquifers. Hydraulic transmissivity and groundwater flux are used to assess the potential magnitude of water flow into underground workings. Hydraulic transmissivity is a property of the emplacement medium and directly indicates the ease with which groundwater could flow into mined openings. It is given the highest weight. The other attributes are less direct indicators of flood potential. Areas of high groundwater flux may indicate a continual and replenishing source of water that could intrude the underground workings. Fault density might indicate the potential for subsurface flooding, presuming that it correlates with fracture density and that greater fracture densities will transmit more water. A thicker unsaturated zone offers more vertical thickness for locating a repository in rocks devoid of groundwater moving under hydraulic heads, thereby reducing to minimal levels the flood hazards, assuming perched aquifers are either not encountered or are small. Surface flooding only indirectly addresses subsurface flooding hazards by assuming that surface floodwaters may pour through the shaft to subsurface facilities. The attribute for flood potential addresses this concern, though it is given very low weight.

OBJECTIVE 3.2.3
MINIMIZE MINING PROBLEMS



Group	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	20
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT.	10
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	10
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	40
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	10
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	10

HOST ROCK RATINGS

AGE	ROCK TYPE	RATING*
YOUNGER	Alluvium	44,000
	Basalt	70,000
	Non-welded Paintbrush Tuff	48,000
	Topopah Spring Tuff	82,000
	Calico Hills Tuff	47,000
	Crater Flat Tuff	87,000
	Granite	88,000
	Argillite	56,000
OLDER	Carbonate	87,000

*Based on Attributes 24,26,28&31 only; none of these attributes account for depth dependancy of mining conditions

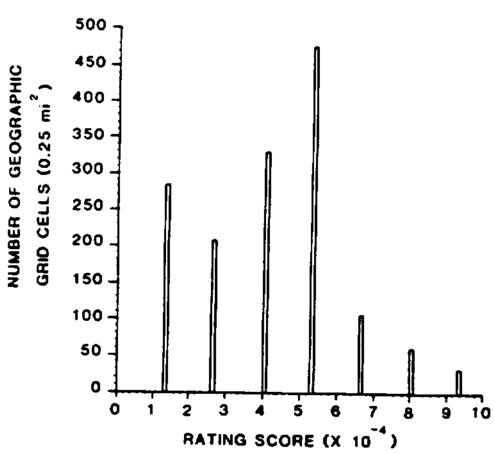


Figure 32. Objective 3.2.3—Minimize Mining Problems. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting the potential for ease of mining and maintaining stable tunnels, weighted according to the attribute list (upper right). Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map; table (lower right) shows the rating values of nine potential host-rock types based on rock attributes affecting potential mining activities and tunnel stability, also weighted according to the attribute list (upper right). The sum of attribute weights is 100%; the maximum possible rating value for locations or host rocks is 100 000.

3.2.3 Minimize Adverse Mining Conditions

Description

Locations will be sought where underground conditions are suitable or readily amenable to safe and efficient mining. A host rock selected for a repository and the strata lying between it and the surface should be amenable to conventional mining and shaft-sinking techniques. Locations that present unusual mining conditions should be avoided because the cost of providing adequate safety measures in such situations could be large. Therefore, preference will be given to locations that can be mined without expensive and unique mining techniques. This implies that the host rock for the mined openings should be neither very hard nor very soft. Hard rock requires more costly drilling and blasting techniques, while soft rock requires more costly support systems to keep mined areas adequately open. The depth of the host rock beneath the surface also is important because longer vertical haulage of tailings is more expensive. In addition, ambient temperatures and stresses increase at greater depths, thereby increasing the need for costly ventilation and support structures.[43 44] High stresses cause obvious rock-spalling and mine-collapse safety problems; higher temperatures generally make rocks weaker[45] and thus more difficult to support. Higher ambient temperatures add to heat that will be induced by waste emplacement, making it more costly to achieve required working temperatures by ventilation of the mined area. Figure 32 shows location and host-rock ratings based solely on this objective.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located so that development, operation, and closure of underground areas can be accomplished without undue hazard to repository personnel." [Criterion 3.4(3)]

10 CFR 60 (Proposed)[5]

- "The underground facility shall be designed to provide for *structural stability*, control of groundwater movement, and control of radionuclide releases, as necessary to comply with the performance objectives of §60.111." (Emphasis Added) [§60.132(a) (2)]
- "Subsurface openings shall be designed to maintain stability throughout the construction and operation periods. If structural support is required for stability, it shall be designed to be compatible with long-term deformation, hydrologic, geochemical, and thermomechanical characteristics of the rock, and to allow subsequent placement of backfill." [§60.132(e) (1)]
- "Subsurface openings shall be designed to reduce the potential for deleterious rock movement or fracturing of overlying or surrounding rock over the long term." [§60.132(e) (3)]
- "The design of the underground facility shall incorporate excavation methods that will limit damage to and fracturing of rock." [§60.132(f)]

[Potentially Adverse Conditions]

- "Processes that would reduce sorption, *result in degradation of the rock strength, or adversely affect the performance of the engineered system.*" (Emphasis Added) [60.123(b) (15)]
- "Geomechanical properties that do not permit design of stable underground openings during construction waste emplacement, or retrieval operations." [§60.123(b) (17)]

Relative Importance

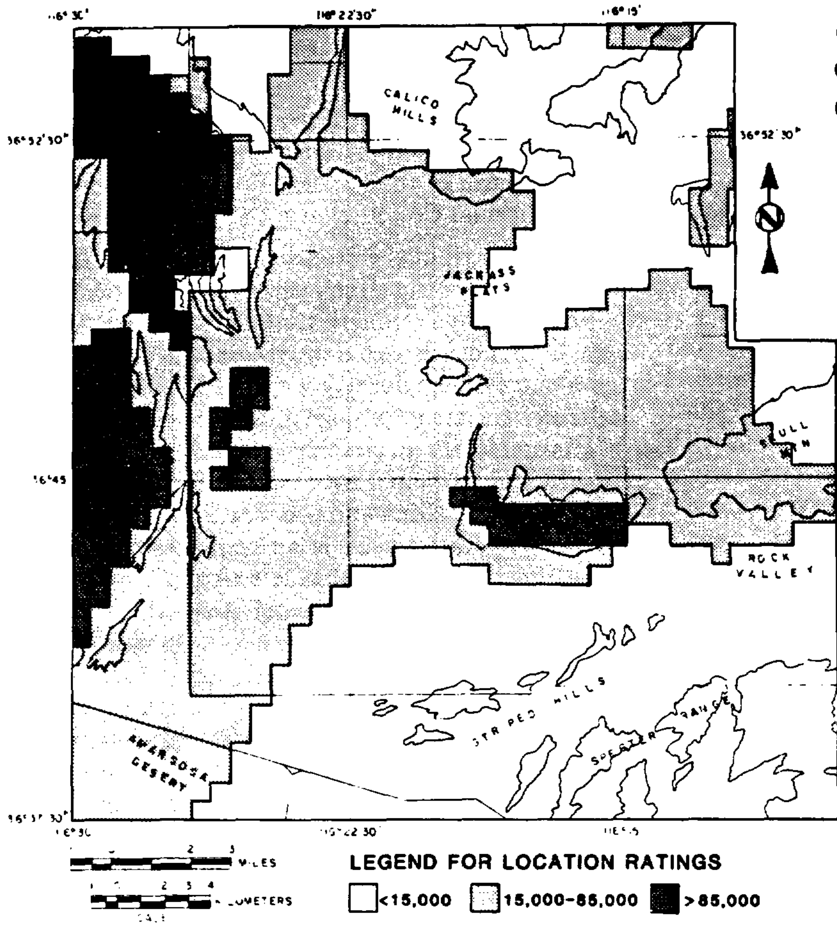
Finding locations where rocks at repository depths and above are amenable to mining and shaft sinking was moderately important in the screening activity. Conditions of the rocks at repository depths are the dominant physical conditions of a site that will control the eventual cost of repository development. The costs of mine advancement, stabilizing measures, ventilation, and drainage systems all depend on in situ rock conditions at mining depths. Retrievability options depend on the stability of mine openings and emplacement holes. It is assumed from an operational viewpoint that all impediments to safe mine and shaft excavation and maintenance can be overcome with appropriate expenditures for hardening, ventilation, and drainage, but these costs may be excessive in some environments. Because of the significant cost impacts of different in situ mining conditions, this objective is relatively important. More than one-fourth of the total importance for subsurface facility objectives was assigned to general mining conditions. This was based on the weighting poll that resulted in an average assignment of 27% of the importance of the subsurface facility branch of construction objectives to this objective. Because this branch was assigned 11%, this objective accounts for about 3% of the overall importance for screening, making this the second most important lower-level objective for the entire construction branch of the objectives tree, and the ninth most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

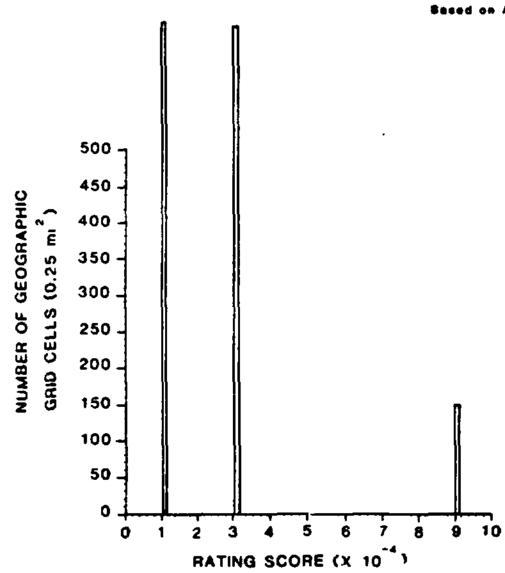
Compressive Strength (construction)
Fault Density
Thickness of the Unsaturated Zone
Hydraulic Transmissivity
Mineral Stability
Thermal Conductivity

Six attributes were used to rate alternative locations with respect to this objective. A critical attribute is compressive strength that addresses the ability of a rock to hold up under stresses around the mined openings. Fault density is an attribute that indirectly defines the structural setting of the area to be mined. It is useful in determining mineability, since more faulted and fractured rock is generally more susceptible to rock spalling and pillar failure. The thickness of the unsaturated zone is an important consideration specifically related to shaft sinking. The thicker the unsaturated zone, the greater is the thickness of rock where groundwater infiltration into the shafts will be of no concern. Mineral stability and thermal conductivity are host-rock attributes, though not related to actual mining conditions, that do address the ability to maintain underground openings for extended time periods. Thermal conductivity of the host rock also influences the ventilation required to maintain working temperatures. Hydraulic transmissivity may indirectly relate to the potential for and severity of pressurized water bursts into the mine during mine advancement and to water inflow rates after mining. In situ stress and in situ temperature are important factors that should be considered before mine designs are completed, but discriminating data on these are currently unavailable for alternative locations within the screening area.

OBJECTIVE 3.2.4 OPTIMIZE HOST ROCK GEOMETRY



	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	100
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT.	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

Figure 33. Objective 3.2.4—Optimize Host-Rock Geometry. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting host-rock geometry, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since the attributes do not address impacts of specific rock types on host-rock geometry, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

3.2.4 Optimize the Geometry (thickness and lateral extent) of the Host Rock

Description

Locations will be sought where the three-dimensional geometry of host rocks is suitable for a repository. Lateral extent, thickness, and inclination of a host rock must all be compatible with efficient mine development. In the screening area, all these factors vary, in cases even across the area of occurrence of single rock types. Costs for repository development and operations will depend somewhat on these variable, host-rock factors. A host rock should be sufficiently thick to allow space for mine workings and a zone around the excavated openings of induced rock disturbances. The thickness of a host rock should also allow for dissipation of heat from the waste. This simplifies modeling and presumably enhances confidence. A host rock should have sufficient lateral extent to accommodate mine workings required to emplace about 50 000 to 70 000 metric tons of waste.[46] One facet in optimizing the geometry of repository workings is to minimize the distance waste canisters are transported underground. Widespread distribution of the waste-emplacement operations conflicts with efficiency mandates to concentrate wastes and thereby more easily manage the repository. Assuming a thermal output of 1 kW/metric ton of waste and an emplacement density of 50 kW/acre, a subsurface area of about 1000 to 1500 acres would be required for a repository. Including an ~1.5-mi zone around the emplaced waste, the required area rises to about 3000 acres or 4.5 sq mi. A trade-off exists between the structural dip of a host rock and its thickness, if horizontal workings are preferred. Horizontal workings can be located in a single, relatively thin host rock if the dip is very low. However, if the dip is large, subsurface facilities must be "stepped," or the host rock must be relatively thick in order to horizontally contain all the underground workings. Because stepped subsurface facilities would be more costly than facilities in a single horizonal plane, preference should be given to locations that possess (1) a nearly horizontal host rock, (2) a host rock that is sufficiently thick to accommodate single-level subsurface facilities given a particular dip, or (3) two or more host-rock types that occur in a nearly horizontal plane and are compatible with safe construction and operation of a mined repository. Figure 33 shows location ratings based solely on this objective; host-rock ratings are unavailable due to lack of relevant attributes.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located in a geologic environment that physically separates the radioactive wastes from the biosphere and that *has geometry adequate for repository placement*." (Emphasis Added) [Criterion 3.1]
- "The thickness and lateral extent of the geologic system surrounding the waste emplacement area shall be sufficient to accommodate the repository and a buffer zone and to ensure that impacts induced by construction of the repository and by waste emplacement will not unacceptably affect system performance." [Criterion 3.1(2)]

10 CFR 60 (Proposed)[5]

- "The orientation, geometry, layout, and depth of the underground facility, and the design of any engineered barriers that are part of the underground facility shall enhance containment and isolation of radionuclides to the extent practicable at the site." [§60.132(a) (3)]

[Favorable Conditions]

- "Conditions that permit the emplacement of waste at a minimum depth of 300 meters from the ground surface." [§60.122(i)]

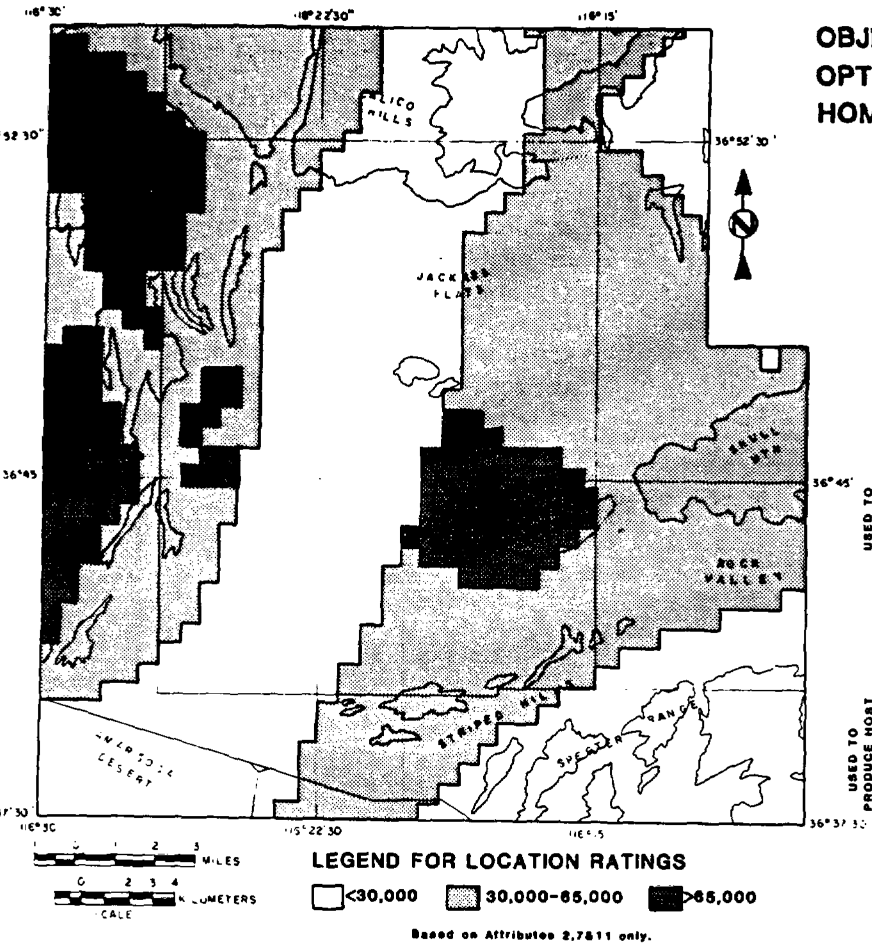
Relative Importance

Finding locations where host-rock geometry is relatively more compatible with simple mine development over the required area was of moderately low importance in the screening activity. It is assumed from a design viewpoint that all impediments caused by host-rock geometry can be overcome with appropriate expenditures. Perhaps waste storage on the surface to allow increased cooling can be used to increase the emplacement density for waste canisters if the lateral extent seems limiting. Incremental costs caused by compensation measures for host-rock geometry may be significant, though probably only some small fraction of total development costs in an ideal medium. About one-sixth of the importance for subsurface facility objectives was assigned to this objective. This was based on the weighting poll that resulted in an average assignment of about 15% of the importance of the subsurface facility branch of construction objectives to this objective. Because this branch was assigned 11%, this objective accounts for somewhat less than 2% of the overall importance for screening. Therefore, this objective is the twenty-first most important of the 40 lower-level objectives (Figure 3). Figure 34 shows location ratings based solely on this objective; host-rock ratings are unavailable due to lack of relevant attributes.

Applicable Attribute

Bed Attitude (rock dip)

Only one attribute (bed attitude) was used to rate alternative locations with respect to this objective. This attribute addresses the desire to construct horizontal facilities at minimal cost. No attributes are available for addressing host-rock thickness, though all rock types considered in screening are at least 100 ft thick. Likewise, all rock types considered have a lateral extent greater than 10 000 acres. Thus, bed attitude is the only relevant attribute that may make the rock types considered less than desirable in terms of local size for a horizontal repository.



ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	
1 VOLCANIC POTENTIAL	
2 FAULT DENSITY	50
3 FAULT TREND	
4 AGE OF FAULTING	
5 NATURAL SEISMIC POTENTIAL	
6 WEAPONS SEISMIC POTENTIAL	
7 BED ATTITUDE (ROCK DIP)	40
8 EROSION POTENTIAL	
9 FLOOD POTENTIAL	
10 TERRAIN RUGGEDNESS	
11 BASE & PRECIOUS METAL RESOURCE POT.	10
12 GROUNDWATER RESOURCE POTENTIAL	
13 GROUNDWATER FLUX	
14 GROUNDWATER FLOW DIRECTION	
15 THICKNESS OF UNSATURATED ZONE	
16 SENSITIVE FLORAL SPECIES	
17 SENSITIVE FAUNAL SPECIES	
18 REVEGETATION POTENTIAL	
19 KNOWN CULTURAL RESOURCES	
20 POTENTIAL CULTURAL RESOURCES	
21 AIR POLLUTION POTENTIAL	
22 PERMITTING DIFFICULTIES	
23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	
24 THERMAL CONDUCTIVITY	
25 COMPRESSIVE STRENGTH (CONTAINMENT)	
26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
27 EXPANSION-CONTRACTION	
28 MINERAL STABILITY	
29 STRATIGRAPHIC SETTING	
30 HYDRAULIC RETARDATION	
31 HYDRAULIC TRANSMISSIVITY	

HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

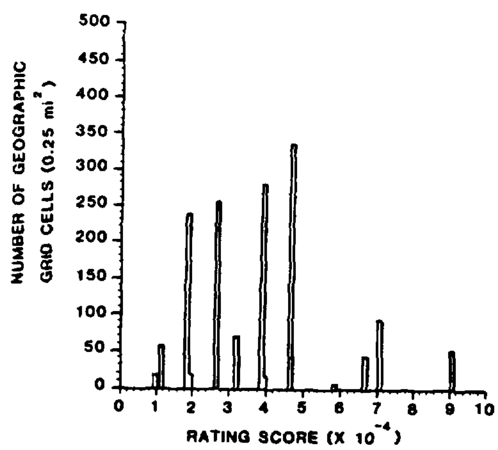


Figure 34. Objective 3.2.5—Optimize Host-Rock Homogeneity. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting host-rock homogeneity, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since the attributes do not address relative homogeneity of specific rock types, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

3.2.5 Optimize Host-Rock Homogeneity

Description

Engineering designs and features for a mined repository will be simpler if multiple rock types are not encountered during construction. Homogeneity of a host rock will allow similar or identical repository design parameters to be used throughout the total area of waste emplacement. Mining in rock with as few discontinuities as possible is desirable, since different rock types encountered because of geologic complexities could result in the need to change mining techniques, thus resulting in additional costs, and perhaps schedule delays. Incompetent zones between geologic contacts or along rock structures may need to be avoided, bypassed, or sealed, resulting in additional mining distance or remedial measures. Homogeneity of a host rock implies relative simplicity. This, in turn, indicates a medium that presumably can be modeled more accurately, thus enhancing confidence that cost and schedule estimates for mine development will not be exceeded during construction.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative criteria.

NWTS-33(2)[4]

- "The site shall be located so that development, operation, and closure of underground areas can be accomplished without undue hazard to repository personnel." [Criterion 3.4(3)]

10 CFR 60 (Proposed)[5]

- No specific correlative requirement.

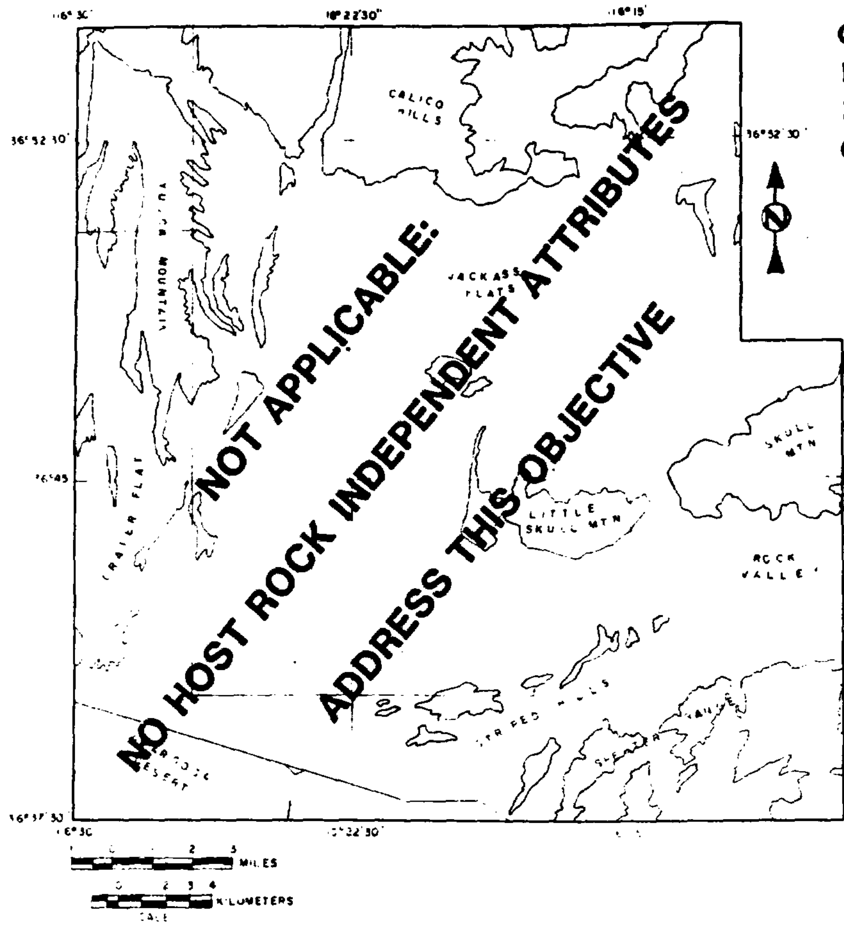
Relative Importance

Finding locations where a repository host rock is relatively homogeneous was of low importance in the screening activity because the cost of tailoring design parameters to local rock conditions that may vary throughout the waste emplacement area will probably be small relative to total repository costs. This low importance was based on the weighting poll that resulted in an average assignment to this objective of about 12% of the importance for the subsurface facility branch of construction objectives. Because this branch was assigned 11%, this objective accounts for a little more than 1% of the overall importance for screening, making this objective the twenty-fifth most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

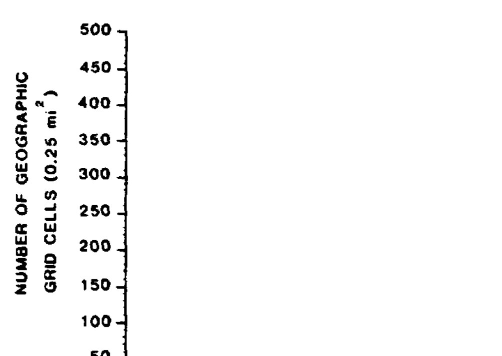
Fault Density
Bed Attitude (rock dip)
Metal Rescurce Potential

Three attributes were used to rate alternative locations with respect to this objective. Fault density directly addresses the homogeneity of the host-rock environment. Greater density of faults increases the likelihood of encountering breccia zones, other structural discontinuities, or stratigraphic offsets during construction. Bed attitude indirectly addresses a general association between steep dips and other structural discontinuities. Another indirect measure of complexity, considered of lesser importance, is base and precious metal resource potential. The implications of this attribute for homogeneity are that an area rich in metal resources is one that may have undergone hydrothermal alteration, creating pockets of gangue, complex mineralization, and other compositional discontinuities.



OBJECTIVE 3.2.6 MAXIMIZE WASTE PACKAGE–HOST ROCK COMPATABILITY

	ATTRIBUTES	WEIGHT
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

Not applicable: No host rock attributes address this objective.

Figure 35. Objective 3.2.6—Maximize Waste Package - Host Rock Compatibility. Since the attributes do not address the compatibility of waste packages with host rocks (attribute list, upper right), neither location ratings (upper left) and associated histogram (lower left) nor host-rock ratings (lower right) were obtained for this objective. Therefore, this objective could not be used to help discriminate among alternative locations or host rocks.

3.2.6 Maximize Compatability of the Host Rock With a Standard Waste Package

Description

Design characteristics of waste packages for specific host rocks have not yet been determined; flexibility in waste-package design is being maintained. However, some features of host rocks can be identified as generally conducive to satisfactory waste-package performance. Standardization will ensure that different waste-package components will not be required in different parts of a repository, or perhaps even in different repositories. This will alleviate problems associated with tailoring each package to its local environment, a costly prospect. Compatibility between a host rock and waste package is also essential during the operating phase, including retrieval, if necessary. The hole into which the waste container is placed should not significantly degrade before the end of the period set aside for retrievability. The rocks in which the packages are to be emplaced must dissipate the waste-generated heat while maintaining a sufficient degree of structural integrity to ensure that intact waste containers could be readily retrieved, if necessary, without resorting to costly mineback techniques. This objective seeks locations where natural conditions are more amenable to efficient emplacement of packages and possible retrieval of waste containers. Figure 35 shows that no ratings were obtained for this objective due to lack of relevant attributes. Thus, this objective did not contribute to discrimination among locations and host rocks.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- "The waste package, in conjunction with the repository waste handling systems, shall provide the means for safe handling of the waste at the repository and for retrieving the waste, if necessary. In addition, the waste package must provide a means of identifying the waste it contains." [Requirement 3.4.1]
- "The waste package shall be designed to provide waste containment for a specified period and provide, beyond that period, a long-term barrier to radionuclide release into the geologic environment." [Requirement 3.4.2]
- "The repository shall contribute to the containment and isolation capabilities of the mined disposal system by (1) *limiting adverse impacts of repository development and operation on waste package and site performance, (2) using engineered barriers that maintain the natural capabilities of the disposal system,* (3) monitoring the system performance, and (4) providing measures to protect against human intrusion." (Emphasis Added) [Requirement 3.3.2]

NWTS-33(2)[4]

- No specific correlative requirements.

10 CFR 60 (Proposed)[6]

- "The underground facility shall be designed so as to perform its safety functions assuming interactions among the geologic setting, the underground facility, and the waste package." [§60.132(a) (1)]
- "The orientation, geometry, layout, and depth of the underground facility, and *the design of any engineered barriers that are part of the underground facility* shall enhance containment and isolation of radionuclides to the extent practicable at the site." (Emphasis Added) [§60.132(a) (3)]
- "Barriers shall create a waste package environment which favorably controls chemical reactions affecting the performance of the waste package." [§60.132(i) (2)]
- "The waste package shall be designed so that the in situ chemical, physical, and nuclear properties of the waste package and its interactions with the emplacement environment do not compromise the function of the waste packages." [§60.135(a) (1)]
- "The waste package shall be designed so that the in situ chemical, physical, and nuclear properties of the waste package and its interactions with the emplacement environment do not compromise the performance of the underground facility or the geologic setting." [§60.135(a) (2)]
- "Waste packages shall be designed to maintain waste containment during transportation, emplacement, and retrieval." [§60.135(e) (3)]

Relative Importance

Finding locations where the properties of a host rock and local hydrologic systems are relatively compatible with waste packages was of low importance in the screening activity. From an operational point of view, the cost impacts of different local conditions on waste emplacement, backfill, and retrieval will be negligible compared to overall repository development costs. Based on the weighting poll, this objective was assigned about 11% of the importance of the subsurface facility branch of construction objectives. Because this branch was assigned 11%, this objective accounts for ~1% of the overall importance for screening. This makes this objective the twenty-seventh most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

Thermal Conductivity
Mineral Stability
Expansion-Contraction Behavior

Three attributes were used to rate alternative locations with respect to this objective. Rock properties that indicate the ability of the rock to resist mineralogic or volumetric alterations when exposed to an induced thermal gradient are important. The attributes used to measure such properties are mineral stability and expansion/contraction behavior. Mineralogic or volumetric alterations may degrade the walls of emplacement holes and make retrieval difficult. The ability of a rock to conduct heat influences the temperatures to which the rock will be subjected and, as a result, the degree of heat-induced structural alteration of emplaced holes. Therefore, thermal conductivity was also used in evaluating this objective, but was given less weight.

3.3 Screen for Locations Suitable for Safe Transport of Radioactive Waste to Repository Facilities

Description

This objective calls for locations that are accessible at reasonable cost to large trucks or rail cars required to transport radioactive waste to a repository. Both the engineered features of waste transport equipment and the logistics of transport volumes and routes are important. For location screening, only discriminating natural features that affect transport routes were relevant. Objectives concerning transport of wastes from their point of generation to the screening area were not considered because they do not discriminate among alternative locations within the screening area. Locations were sought with relatively straight, flat, short ingress routes that present few or more tolerable obstacles. Both curves and steep grades enhance chances of transportation accidents as well as increase construction and fuel costs. Costs also increase with the distance required for construction of new corridors from existing roads or rail lines. Therefore, relatively flat, smooth terrain near existing highways or rail lines is desired.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located such that risk to the population *from transportation of radioactive wastes* and from repository operation can be reduced below acceptable levels to the extent reasonably achievable." (Emphasis Added) [Criterion 3.8(2)]

10 CFR 60 (Proposed)[6]

- No specific correlative requirements.

Relative Importance

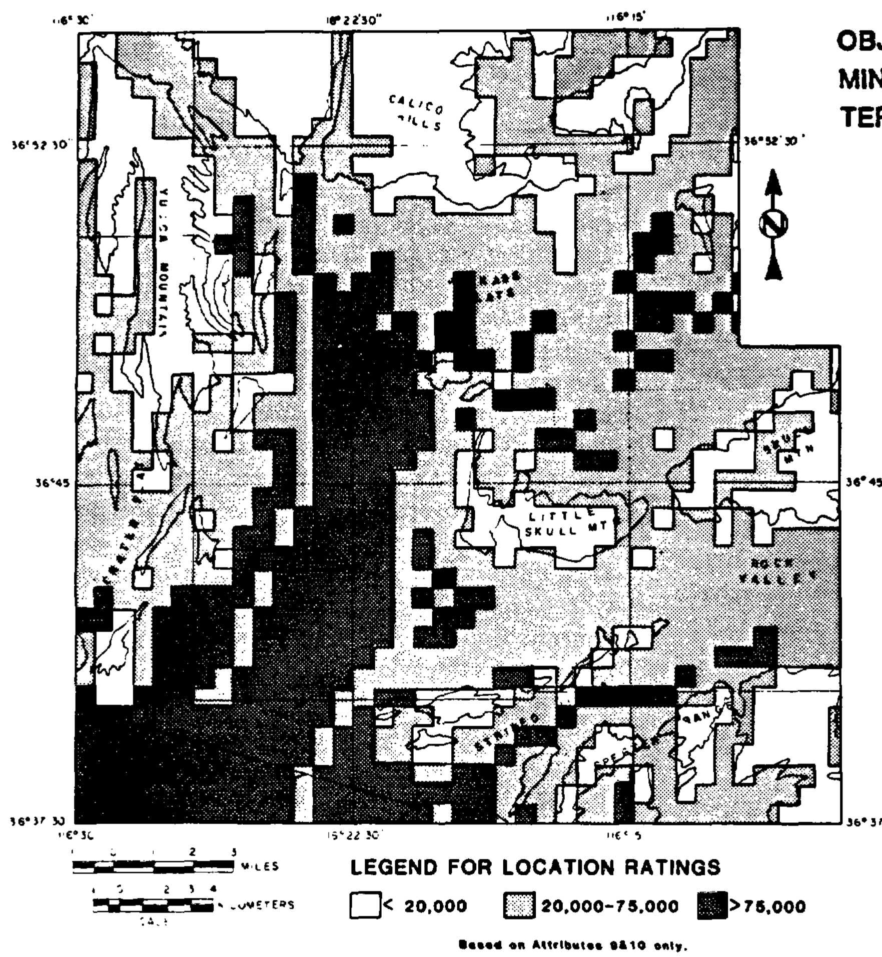
Finding locations where surface conditions are amenable to safe and efficient transportation of nuclear wastes was the second most important of the three middle-level objectives of the construction branch of the objectives tree. During the operational phase, potential radiological hazards to the general public are likely to be dominated by those associated with transporting wastes to a repository. However, the hazards and cost of mitigating measures associated with waste transport within the screening area are unlikely to vary much among alternative locations. Accordingly, the importance of this objective is relatively low compared to the overall screening. About one-tenth of the importance of the screening activity was assigned to this objective. This was based on the weighting poll where an average of about 30% of the importance for construction objectives was assigned to the transportation objectives. Because construction objectives are assigned about 26%, this objective accounts for about 8% of the overall importance in screening; this objective is the sixth most important among the 12 middle-level objectives (Figure 3).

Applicable Attributes

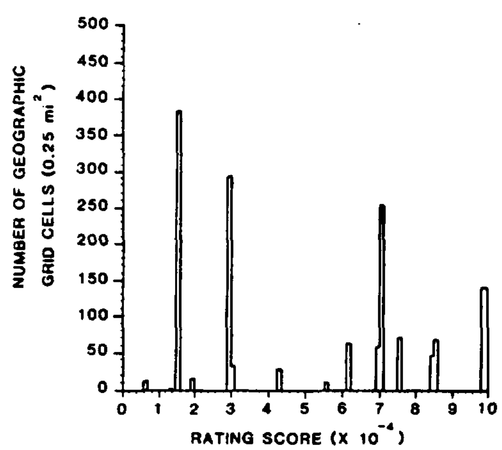
Flood Potential
Terrain Ruggedness

Two attributes were used to rate the performance of alternative locations with respect to this middle-level objective. This was achieved by using these attributes to evaluate performance for only one of the two subobjectives terrain conditions comprising the lower level of this branch of the objectives tree (Objective 3.3.1). The other lower-level objective in this branch (distance to existing routes) was considered nondiscriminating in terms of transport costs, and was not evaluated by any attributes (Objective 3.3.2). Therefore, the weight associated with the lower-level objective for minimal transport distance did not contribute to the evaluation of this middle-level objective.

OBJECTIVE 3.3.1 MINIMIZE ADVERSE TERRAIN CONDITIONS



Used to	ATTRIBUTES	WEIGHT %
PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	30
	10 TERRAIN RUGGEDNESS	70
	11 BASE & PRECIOUS METAL RESOURCE POT.	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

Figure 36. Objective 3.3.1—Minimize Adverse Terrain Conditions. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting terrain conditions, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since the attributes do not address the effect of specific rock types on terrain, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

3.3.1 Minimize Adverse Terrain Along Potential Waste Transport Routes

Description

Locations will be sought where potential access routes are along terrain suitable or readily amenable for construction of roads or rail lines. Terrain that poses undue hazards or significant difficulty to the transport of nuclear wastes should be avoided for both safety and cost reasons. The likelihood of an accident, the severity of the consequences, and the cost for mitigating the effects of a potential accident are greater if the ingress route to a repository passes over gullies, steep slopes, landslide zones, or other irregular terrain conditions. Additionally, it is more costly to construct and maintain a highway or railroad over rugged or flood prone terrain. Construction in adverse terrain may require expensive blasting, bridge and culvert construction, and slope stabilization, while maintenance may include clearing landslides, repairing bridges, and controlling erosion. Hazards created by meteorological conditions should also be avoided. Areas with frequent windstorms or flash floods, for example, should be avoided to minimize the potential for and costs of mitigating accidents caused by high winds or flood waters. Figure 36 shows location ratings based solely on this objective; host-rock ratings are unavailable due to lack of relevant attributes.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located in an area where surface topographic features do not unacceptably affect repository operation." [Criterion 3.7(2)]

10 CFR 60 (Proposed)[6]

- No specific correlative requirements.

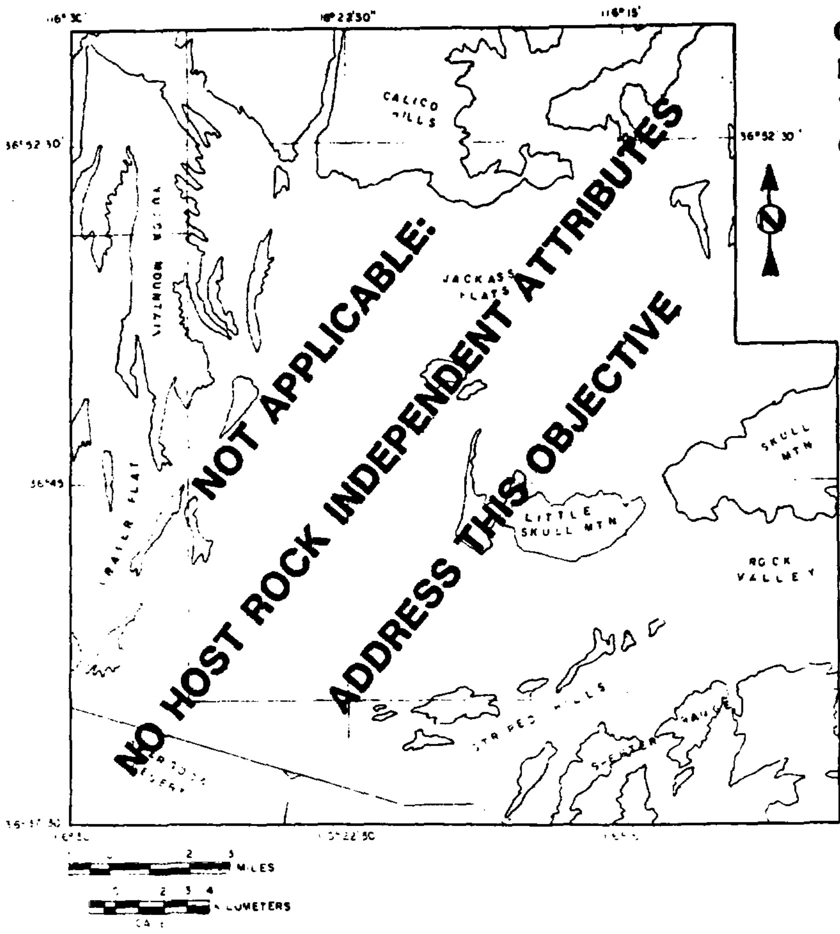
Relative Importance

Finding locations where terrain impediments to transporting wastes to a repository are relatively low was of high importance in the screening activity. This ranking is probably artificially high because of the way in which the construction branch of the objectives tree was formulated. In this branch, only two lower-level objectives were defined; therefore, the total importance of each is high, relative to the six lower-level objectives in the other two branches of construction objectives. Because the total weight of the lower-level objectives in each middle-level branch must sum to the weight of the branch, the weight of the transportation branch must be distributed among only two subobjectives, whereas weights of the other middle-level construction objectives must be distributed among six lower-level objectives. The lower-level objective for terrain factors was assigned an average value of about 71% of the importance of the transportation branch of construction objectives by the weighting poll. Because this branch was assigned 8%, this objective accounts for about 5.5% of the overall importance of the screening activity. Therefore, this objective is the fifth most important of the 40 lower-level objectives (Figure 3). A more reasonable weight of terrain factors as an element of transportation concerns might be in the range of 1% to 2% of the overall screening since cost impacts of modifying adverse terrain along transport routes in the screening area would be small compared to overall repository development costs. However, the weights obtained from the poll were used without subjective modification on the part of Sandia National Laboratories personnel responsible for performing the location evaluations.

Applicable Attributes

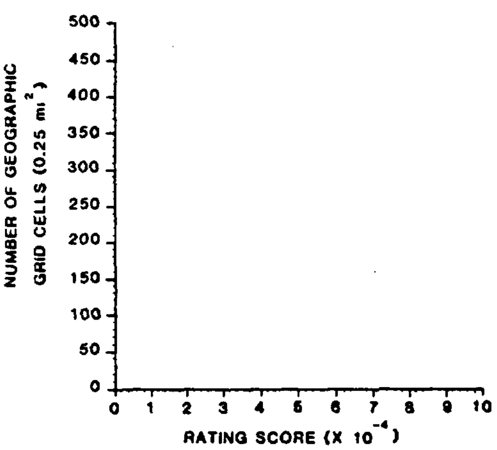
Terrain Ruggedness
Flood Potential

Two attributes were used to rate alternative locations with respect to this objective. Both address possible additional costs required to construct an ingress route over adverse terrain. The other concern addressed by each of these attributes is that poor terrain factors would decrease the safety of transport routes. Flood potential indicates where bridges and dikes may be needed. Terrain ruggedness indicates areas that may be inaccessible by rail and accessible only with great difficulty and many curves and switch backs by road. Terrain ruggedness was considered the most important because it identified slope grades that directly limit where rail lines can be constructed. Flood potential indicated locations where expensive culverts, trestles, and bridges may be required and where some classes of transport structures cannot be used.



OBJECTIVE 3.3.2 MINIMIZE DISTANCE TO EXISTING TRANSPORT CORRIDORS

	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

Not applicable: No host rock attributes address this objective.

Figure 37. Objectives 3.3.2—Minimize Distance to Existing Transport Corridors. Since the attributes do not address the location of or distance to transport corridors (attribute list, upper right), neither location ratings (upper left) and associated histogram (lower left) nor host-rock ratings (lower right) were obtained for this objective. Therefore, this objective could not be used to help discriminate among alternative locations or host rocks.

3.3.2 Optimize the Distance From Existing Transportation Corridors

Description

Locations will be sought close to existing transport corridors that are suitable for carrying radioactive wastes. Preference should be given to locations relatively close to existing rail or highway corridors, because access can be more cheaply provided to a repository location if nearby corridors are already in place. If they are not, the costs of constructing lengthy rail lines or highways will need to be added to the total repository system costs. However, the difference in the cost of providing safe access to alternative locations in the screening area will be small compared to the overall costs of transporting wastes from distant storage or generation sites to the screening area. Figure 37 shows that no ratings were obtained for this objective due to lack of relevant attributes. Thus, this objective did not contribute to discrimination among locations and host rocks.

Corresponding DOE and NRC Criteria

- No specific correlative requirements in NWTS-33(1), NWTS-33(2), or proposed 10 CFR 60 (References 3, 4, and 5, respectively).

Relative Importance

Finding locations with nearby, existing transport corridors was of moderate importance in the screening activity. As for terrain factors (Objective 3.3.1), this ranking is probably artificially high because of the structure of the construction branch of the objectives tree. An existing road suitable for transport exists along US Highway 95, just south of the screening area. The nearest railhead is just north of Las Vegas (about 80 mi to the southeast). Because the costs of access to alternative locations within the screening area will be small compared to total transport costs from points of waste origin, this objective should have a low weight. However, because of the structure of the objectives tree, it was weighted as moderately important. The weighting poll resulted in an average assignment to this objective of about 29% of the importance for the transportation branch of construction objectives. Because this branch was assigned a weight of about 8%, this objective accounts for somewhat more than 2% of the overall importance for screening, making this objective the fifteenth most important of the 40 lower-level objectives (Figure 3). Though the weight of 2% + was used in the screening analysis, a more reasonable value is probably less than 1%.

Applicable Attributes

No attributes were used to rate alternative locations with respect to this objective, because the discriminating capability of transport distances within the screening area is negligible. Therefore, the weight associated with this objective does not contribute to the screening analysis.

4.0 Identify Locations for Which Environmental Impacts Can Be Mitigated to the Extent Reasonably Achievable

Description

This objective requires that environmental impacts be identified and considered when selecting a repository location. Unavoidable impacts should be mitigated to the extent reasonably achievable; i.e., the mitigating measures must be considered in terms of their costs and benefits before they are implemented. This objective corresponds to Objective 4 of the Department of Energy's Waste Confidence Rulemaking,[11] which states

> "The environmental impacts associated with waste disposal systems should be mitigated to the extent reasonably achievable."

Environmental concerns addressed by this objective are restricted to those accompanying site characterization, construction, operation, and decommissioning of the surface and subsurface facilities. Though long-term releases of radioactive substances into the groundwater and perhaps eventually to the biosphere are, in the strictest sense, environmental issues, they are considered sufficiently different from the short-term environmental issues to merit distinction. Accordingly, the upper-level objectives for containment and isolation (Objectives 1.0 and 2.0) are distinguished from this objective as environmental issues uniquely associated with repositories. This objective addresses the more traditional environmental issues generally associated with large-scale construction projects and, as such, terminates when human activities at a repository site are finished. It should be observed that not all impacts associated with large-scale construction projects are necessarily adverse on the environmental systems at issue. Figure 33 in Reference 2 shows location ratings based solely on this upper-level environmental objective.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- "Siting, developing, and operating the mined geologic disposal system shall be conducted in a manner that preserves the quality of the environment to the extent reasonably achievable and complies with current environmental legislation. The environmental impacts associated with the mined geologic disposal system shall be mitigated to the extent reasonably achievable." [Criterion 4.3]

NWTS-33(2)[4]

- "The site shall be located with due consideration to: potential environmental impacts; air, water, and land use; and ambient environmental conditions." [Criterion 3.9]
- "The site shall be located with due consideration to potential environmental impacts." [Criterion 3.9(1)]
- "The site shall be located to reduce the likelihood or consequence of air, water, and land use conflicts." [Criterion 3.9(2)]

10 CFR 60 (Proposed)[5]

- "The structures, systems, and components important to safety shall be designed to be compatible with anticipated site characteristics and to accommodate the effects of environmental conditions, so as to prevent interference with normal operation, maintenance and testing during the entire period of construction and operations." [§60.130(b) (2) (i)]

Relative Importance

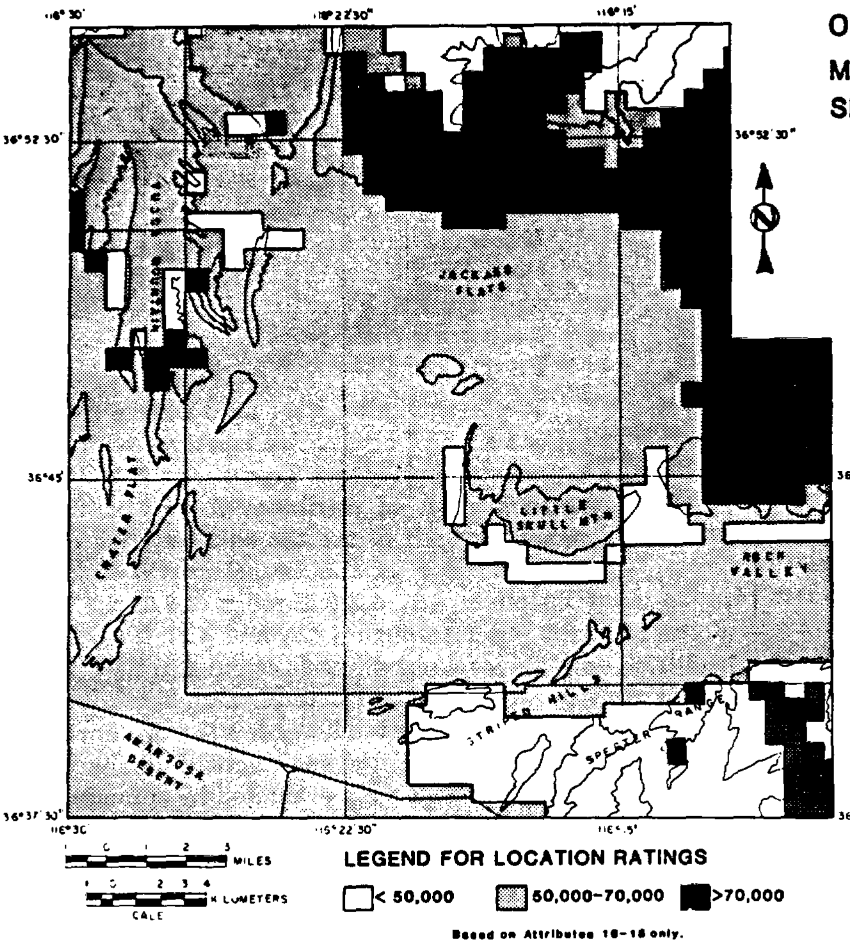
Environmental concerns were relatively minor in the screening activity. However, the DOE and the NRC[3-5, 11] recognize that potential environmental impacts must be considered when siting a repository. About one-tenth of the total importance for location screening was placed on finding locations where environmental impacts are expected to be low or easily mitigated. This was based on the weighting poll that resulted in an average assignment of 9% to the environmental branch of the objectives tree, making environmental concerns the least important among the four upper-level screening objectives (Figure 3). It is apparent that participants in the poll considered environmental objectives relatively unimportant. The basic reason for this low importance is that most potential environmental impacts of repository development are similar to those associated with relatively common, large mining and surface construction projects, and, historically, these impacts have been acceptable. Appropriate environmental safeguards are readily available to preserve environmental qualities as necessary.

Applicable Attributes

Flood Potential
Terrain Ruggedness
Groundwater Resource Potential
Sensitive Floral Species
Sensitive Faunal Species
Revegetation Potential
Known Cultural Resources
Potential Cultural Resources
Air Pollution Potential
Permitting Difficulties
Private Land Use

Eleven attributes were used to rate the expected performance of alternative locations with respect to environmental impacts. This was achieved by using a distinctive set of attributes for evaluating performance for each of the ten subobjectives comprising the lower level of this branch of the objective tree (Objectives 4.1, 4.2.1 through 4.2.3, 4.3.1 through 4.3.3, 4.4.1 through 4.4.2, and 4.5). Two of the five middle-level objectives (4.1 and 4.5) have no component lower-level objectives, and, accordingly, serve also as two of the ten lower-level environmental objectives. Thus, potential environmental impacts of alternative locations were evaluated by summing the contributions to environmental performance provided by attributes addressing component lower-level objectives. The importance of the attributes was divided between ecological, cultural-historical, physical, and institutional features. No host-rock attributes were used because no discriminating impacts caused by differences among alternative rock types are expected.

OBJECTIVE 4.1 and 4.1.1
MINIMIZE IMPACTS ON SENSITIVE SPECIES



ATTRIBUTES		WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT.	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	40
	17 SENSITIVE FAUNAL SPECIES	50
	18 REVEGETATION POTENTIAL	10
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	

HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
OLDER	Granite	
	Argillite	
	Carbonate	

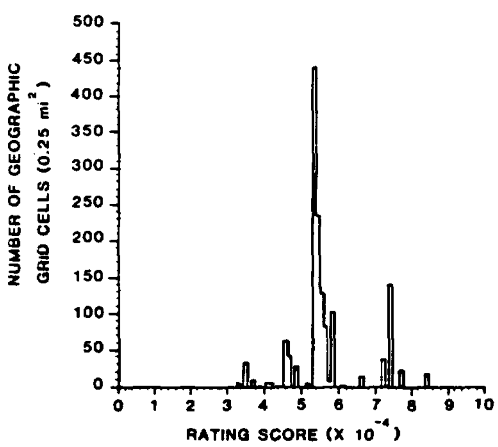


Figure 38. Location Ratings Based Solely on Biotic Systems (minimal impacts on sensitive flora and fauna). Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting the distribution of sensitive flora and fauna, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since the attributes do not address the effects of specific rock types on sensitive flora or fauna, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks. Because this middle-level objective has no component lower-level objectives, it serves for location rating purposes as a lower-level objective.

4.1 Minimize Adverse Impacts on Biotic Systems

(It serves as both a middle- and lower-level objective.)

Description

This objective calls for locations where potential impacts on biological communities will be acceptably small. Biological communities of particular concern are herein considered "sensitive" and include

1. Commercially or recreationally valuable systems
2. Endangered, threatened, or sensitive species
3. Symbiotic species that affect the well-being of sensitive species in 1 or 2, and
4. Nuisance species

The greatest impact on ecosystems because of repository development will be from surface modifications directly caused by construction and from related effects such as increased erosion and sedimentation. Modifications resulting from increased support services on and adjacent to the screening area could include the conversion of grazing land and natural habitats to residential and commercial uses. Other potential impacts on biotic systems are considered minor and nondiscriminating for screening. These include

1. Leaching of a spoils pile which could alter the chemistry of soils and arroyo beds,
2. Long-term thermally induced topographic changes caused by thermal expansion and subsequent contraction of the subsurface rocks,
3. Particulate and chemical atmospheric pollutants caused by construction activities.

Two final but interrelated issues are the effects on biological communities of water effluents from the mined workings and the withdrawal and use of water for repository activities. The importance of these issues depends on the hydrologic characteristics of the potential repository host rock and its relationship to the regional groundwater system. The presence of sensitive biotic systems could cause delays because of extended consultations with federal and state agencies and private interests about proper mitigation strategies. Some federal projects have experienced significant delays because of the projected impacts on certain species, indicating that careful planning must be factored into site characterization and construction phases of the repository development. Impacts on sensitive species will occur from site-development activities. Avoidance of sensitive species' habitats is perhaps the most effective way of accomplishing this objective. Figure 38 shows location ratings based solely on this objective.

Corresponding DOE and NRC Criteria

- Not specifically addressed in NWTS-33(1), NWTS-33(2), or proposed 10 CFR 60 (References 3, 4, and 5, respectively).

Relative Importance

The importance given to all the middle-level environmental objectives varies by <6%. Impacts on biotic systems, however, were assigned the highest importance of the middle-level environmental objectives. Some participants in the weighting poll considered this objective relatively unimportant because there are no known threatened or endangered species within the screening area. Others gave it higher weight since there are ten identified sensitive floral species and four sensitive faunal species, one of which (the desert tortoise) is being considered for endangered status. Based on the weighting poll, the percentage importance of this objective with respect to other middle-level environmental objectives is 22%. Because the environmental branch of the tree was assigned 8%, this objective accounts for about 2% of the overall importance in screening, making this objective the eighth most important of the 12 middle-level objectives. Because it has no lower-level component objectives, it also serves as lower-level Objective 4.1.1 which is the seventeenth most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

Sensitive Floral Species
Sensitive Faunal Species
Revegetation Potential

Three attributes were used to rate alternative locations with respect to this objective. This middle-level objective has no component lower-level objectives, so these three attributes were used to directly evaluate its performance. The distributions of sensitive floral and faunal species is addressed by the two corresponding attributes. Partial destruction of habitats can possibly be offset by the natural capabilities for repopulation of the habitats. Revegetation potential is an attribute that addresses this capability. This attribute provides indirect information and is given low importance. Because the attribute for sensitive faunal species indicates a potential candidate for endangered species in the screening area, it was considered the most important attribute for evaluating this objective.

4.2 Minimize Adverse Impacts on Abiotic Systems

Description

This middle-level objective calls for locations where aesthetic or commercial interests in land, water, or air will not be significantly affected by repository development. It refers to potential impacts on nonliving elements of the environment. This, together with Objective 4.1, comprises the nonhuman portion of the environmental branch of the objectives tree. Potential impacts on the abiotic system include physical and chemical changes that may affect air, water, and land quality. Physical changes can occur because of direct or indirect modifications caused by repository construction. Examples include scraping of the land for roadbeds or building pads and atmospheric dispersal of particulates by construction equipment or from the spoils pile. Chemical changes include airborne dispersal of combustion products and their further chemical transformations in the atmosphere. If a waste package were to fail and release radionuclides to the groundwater, this release could be considered an impact. This objective is composed of three component lower-level objectives for land, water, and air quality, respectively.

Corresponding DOE and NRC Criteria

- Not specifically addressed in NWTS-33(1), NWTS-33(2), or proposed 10 CFR 60 (References 3, 4, and 5, respectively).

Relative Importance

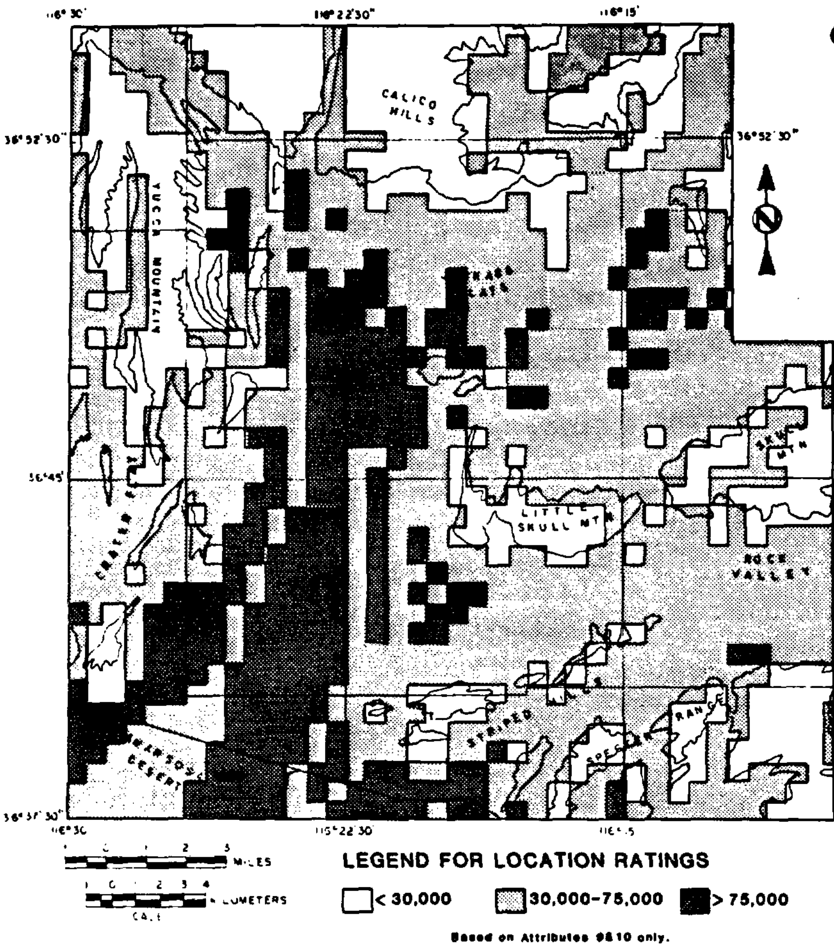
This objective is equal in importance to the objective for institutional issues (Objective 4.4) and, as such, ties as the second most important objective within the middle-level of the environmental objectives. Impacts on the abiotic system are significant because these impacts can affect biotic, aesthetic, socioeconomic, and cultural resources. Based on the weighting poll, an average importance of 21% was assigned to this objective relative to the total importance of the environmental branch of the objective tree. Because this branch was assigned 8%, this objective accounts for about 2% of the overall importance in screening. Therefore, this objective is the ninth most important of the 12 middle-level objectives (Figure 3).

Applicable Attributes

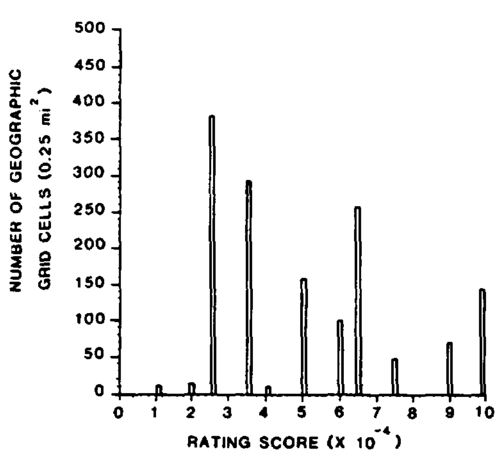
Flood Potential
Terrain Ruggedness
Groundwater Resource Potential
Air Pollution Potential

Four attributes were used to rate expected performance of alternative locations with respect to this objective. This was achieved by using a distinctive set of attributes for evaluating performance for each of three subobjectives that comprise the lower-level of this branch of environmental objectives (Objectives 4.2.1 through 4.2.3). These attributes address surface features, water courses, groundwater, and air quality. Thus, this middle-level objective is evaluated by summing the contributions to abiotic impacts provided by attributes addressing component lower-level objectives.

OBJECTIVE 4.2.1 MINIMIZE IMPACTS ON SURFACE GEOLOGIC FEATURES



	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	50
	10 TERRAIN RUGGEDNESS	50
	11 BASE & PRECIOUS METAL RESOURCE POT.	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

Figure 39. Objective 4.2.1—Minimize Impacts on Surface Geologic Features. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting the environmentally sensitive aspects of surface geology, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since the attributes do not address the effects of specific rock types on surface features, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

4.2.1 Minimize Impacts on Surface Geologic Features

Description

Locations will be sought where physical impacts on surface features caused by repository characterization and construction will be low. Primary and secondary impacts on surface geology such as terrain modifications, erosion, leaching of the spoils pile, upheaval and subsidence, and increased soil temperature can occur. Primary impacts expected are terrain modifications from construction of roads and preparation of foundations for surface facilities. Secondary impacts, such as increased erosion and runoff and alteration of drainage patterns and infiltration rates, may result from the surface modifications. An impact associated with the spoils pile from the mined rock could be its leaching, resulting in chemical alteration of the surrounding soils and water. Because leaching of the mined rock will probably be very low, given the climate, and because the area surrounding the spoils pile will probably be physically altered by other activities as well, discriminating capabilities based on the leachability of various rock types is considered negligible. Surface upheaval, subsidence, and temperature increases are long-term possibilities caused by waste heat. They are not addressed in this screening except as they relate to long-term isolation or containment (Objectives 1.0 and 2.0). Commitment of material and energy resources for a repository will require increased mining activity in other parts of the country. Though this will impact surface and subsurface geology, it will occur outside the screening area and, therefore, cannot distinguish among alternative locations. Impacts on surface geologic systems will be local and, if proper mitigation strategies are applied during decommissioning, no permanent significant impact on the geologic system will occur. Figure 39 shows location ratings based solely on this objective.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The evaluation of such impacts will include assessment of air, water, *land*, *aesthetic*, ecological, noise, *resource*, and historical factors appropriate to repository construction, operation, and isolation." (Emphasis Added) [Criterion 3.9(1)]

10 CFR 60 (Proposed)[6]

- No specific correlative requirements.

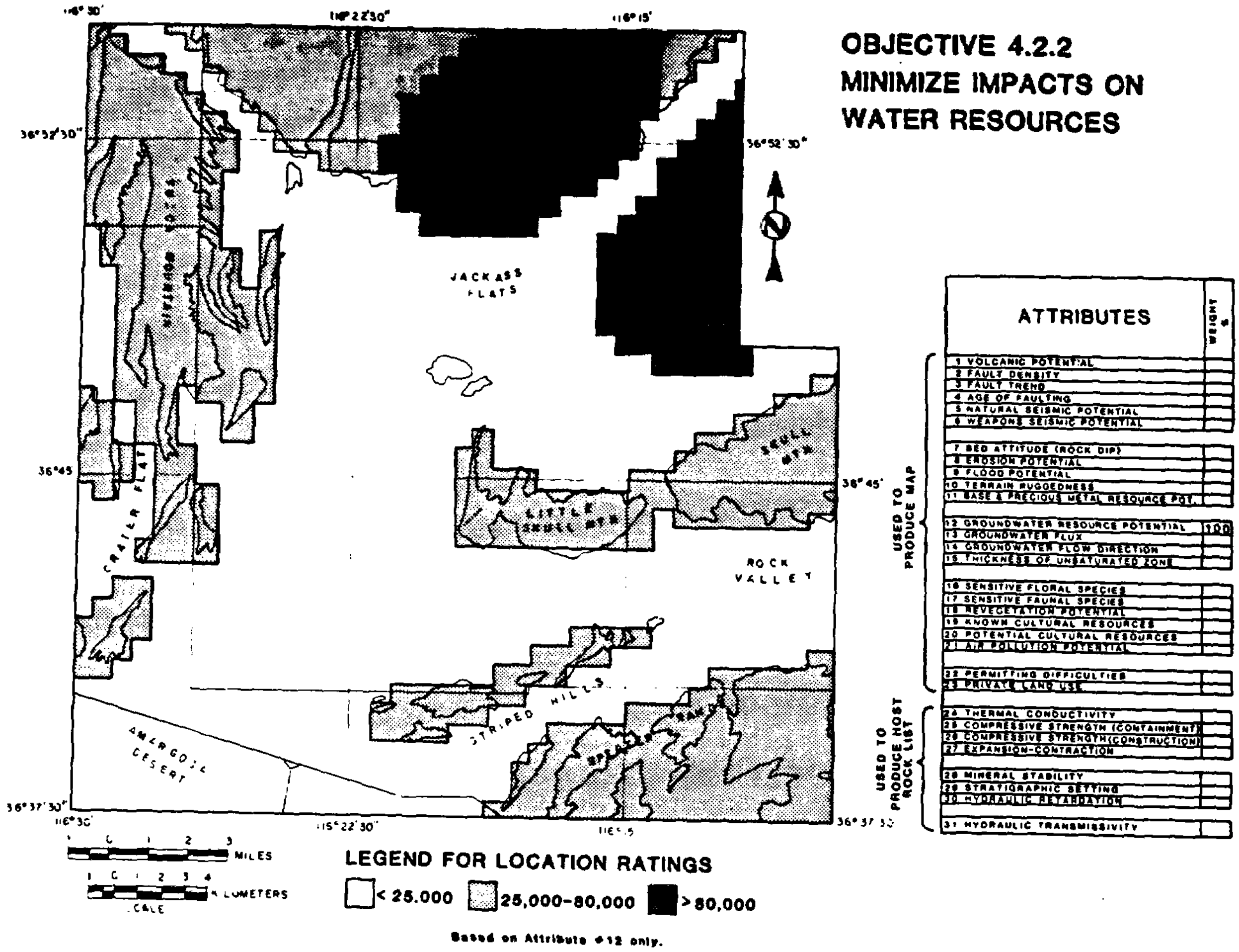
Relative Importance

This objective is one of the least important objectives in screening, because surface impacts can be successfully mitigated if proper care is taken and if potential effects are identified prior to construction. The weighting poll resulted in an average assignment to this objective of 22% of the abiotic branch of environmental objectives. Because this branch accounts for about 2%, this objective accounts for less than one half of one percent of the overall importance in screening, making this objective the thirty-seventh most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

Terrain Ruggedness
Flood Potential

Two attributes were used to rate alternative locations with respect to this objective. These attributes, terrain ruggedness and flood potential, indirectly indicate possible impacts on surface geology. Terrain ruggedness is considered because steep slopes will require deep cuts to support roads or buildings, altering not only the topography but also runoff. Generally, the steeper the slope, the greater the susceptibility of soils to erosion. Flood potential is considered because alteration of ephemeral drainage caused by construction activity will result in a modification of currently stable drainage patterns. Both of these attributes were considered of equal importance.



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

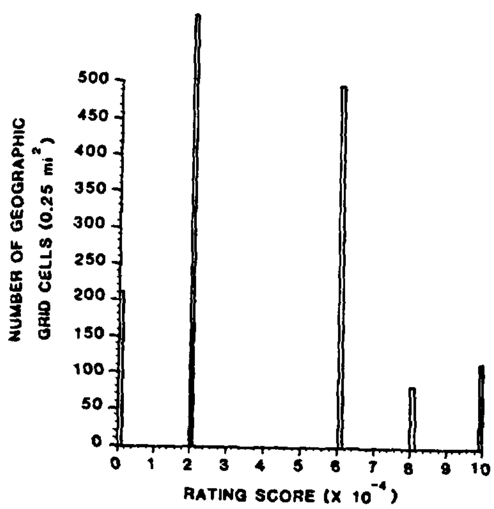


Figure 40. Objective 4.2.2—Minimize Impacts on Water Resources. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting water resources, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since the attributes do not address the environmental effects of specific rocks on water resources, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

4.2.2 Minimize Impacts on Water Quality and Availability

Description

Locations will be sought where physical impacts on the quality and quantity of local groundwater because of respository characterization and construction will be low. Water supply in the screening area is adequate for the development of a repository. Wells J-12 and J-13 in Jackass Flats are estimated to be capable of providing 370 000 to 680 000 m^3 annually.[47] Water use for the construction of an HLW repository is estimated to range from 2.4 $\times 10^5$ to 7.1 $\times 10^5$ m^3 over a 7-yr period (34 000 to 101 000 m^3/yr).[48] This assumes an 800-ha repository and thermal characteristics of four alternative rock types. Considering the existing supply of water available from Wells J-12 and J-13 (which are currently not used to capacity) and the potential for developing other wells in the same aquifer, uses of groundwater for a repository should not significantly tax local supplies. Groundwater quality could be affected if radionuclides, drilling mud, or other contaminants were introduced to the groundwater system. Chemical perturbations of the hydrologic system could directly or indirectly impact sensitive biotic systems or humans. Impacts on human health or biotic systems, however, will not occur if withdrawal of the groundwater does not occur; withdrawal for human use is less likely where groundwater quality is poor. Protective measures will be factored into siting by locating a site with long groundwater flow time to the off-site accessible environment and with highly sorptive rocks along flow paths to absorb any radioactive or other containments (Objective 2.0). Figure 40 shows location ratings based solely on this objective.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The evaluation of such impacts will include assessment of air, *water*, land, aesthetic, ecological, noise, resource, and historical factors appropriate to repository construction, operation, and isolation." (Emphasis Added) [Criterion 3.9(1)]

10 CFR 60 (Proposed)[5]

- No specific correlative requirements.

Relative Importance

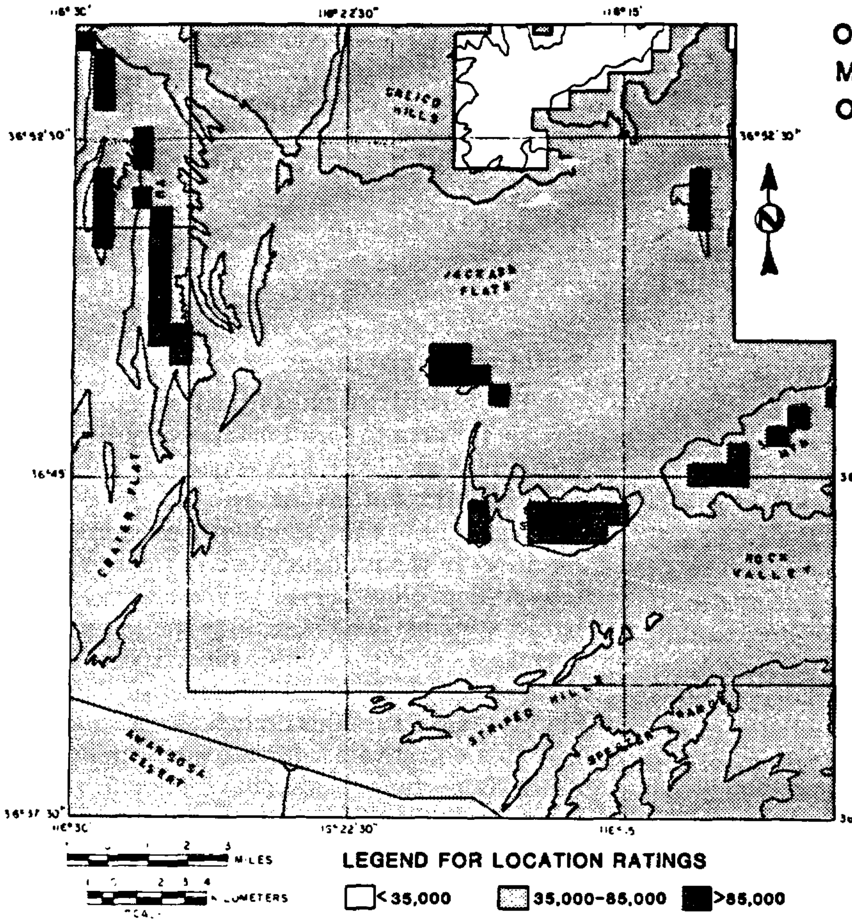
This objective is one of the least important objectives in the area-to-location screening. However, modification of the hydrologic system is considered the most important of the three abiotic lower-level objectives because of the generally scarce nature of water resources in the arid climate and their importance to the southern Nevada economy, sociology, and natural biotic systems. The weighting poll resulted in an average assignment to this objective of 46% of the importance of the abiotic branch of environmental objectives. Because this branch was assigned less than 2%, this objective accounts for less than 1% of the overall importance in screening. Therefore, this objective is the thirtieth most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

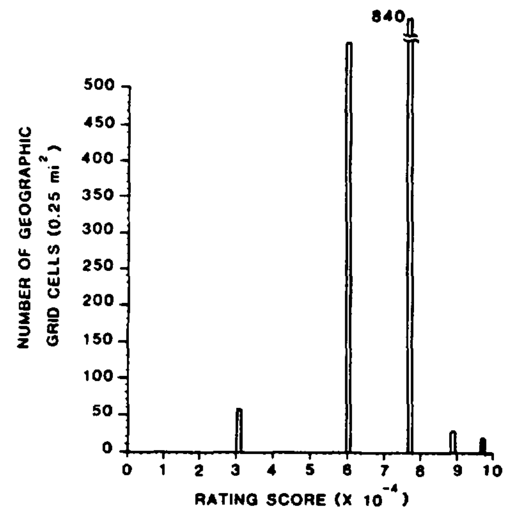
Groundwater Resource Potential

Only one attribute (groundwater resource potential) was used to rate alternative locations with respect to this objective. Impacts on groundwater quality would be inconsequential in zones of poor groundwater development potential, because water wells would either not be drilled or, if drilled, would be abandoned after it was found out that only low-producing or poor water-quality aquifers were available. The attribute for groundwater resource potential addresses both the quality and quantity of groundwater available for production.

OBJECTIVE 4.2.3 MINIMIZE IMPACTS ON AIR QUALITY



	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT.	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	100
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

Figure 41. Objectibve 4.2.3—Minimize Impacts on Air Quality. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting potential air quality, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since the attributes do not address the effects of specific rock types on air quality, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

4.2.3 Minimize Impacts on Air Quality

Description

Locations will be sought where repository characterization, construction, and operations will have low impacts on local air quality. The expansive vistas of southern Nevada are an aesthetic resource for which preservation is desirable. Nonradioactive effluents will constitute the bulk of airborne containments released from a repository site. The sources of these releases are emissions from deisel equipment; dust from construction and haulage of mined materials over dirt roads; and coal-, gas-, or oil-fired powerplant emissions if access to regional electrical and heating sources is not available at reasonable costs. Another potential source of airborne particulates is the spoils pile. The type of rock mined, the mining technique, and the ultimate disposition of the spoils pile will determine the extent of airborne disposal of spoil materials. For example, competent rock is less likely to produce respirable particles (≤ 5 μm) than the noncompetent rock. Airborne particulates from spoils can be reduced by proper stabilization of the spoils pile or by siting in a location where atmospheric circulation is conducive to minimum dispersion. It is possible to reduce these impacts to comply with the applicable airborne release limits by using available pollution and dust control measures. Small, enclosed basins where stagnant air can collect are the least desirable locations, whereas large open areas where the wind is not restricted are more desirable. The risk involved to offsite populations from an accidental airborne release of radioactivity is extremely low. An evaluation of several postulated accidents revealed that the most serious accident (a spent-fuel canister dropped down a repository shaft) would have a frequency of 1×10^{-5}/yr and result in a 70-yr, total-body dose to the "maximum individual" (a permanent resident 1600 m from the discharge stack) of 1.4×10^{-4} rem.[48-50] Under normal conditions, radiological emissions will be caused primarily by natural radon and its daughter products. Releases also will correlate with the thorium and uranium contents of the mined rock. The largest annual total body dose computed for a "maximum individual" was 1.5×10^{-5} rem.[49] Because these doses are so low and nondiscriminating among the rock types considered, radioactive emissions from mining activities were not used for screening. Figure 41 shows location ratings based solely on this objective.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The evaluation of such impacts will include assessment of *air*, water, land, aesthetic, ecological, noise, resource, and historical factors appropriate to repository construction, operation, and isolation." (Emphasis Added) [Criterion 3.9(1)]

10 CFR 60 (Proposed)[5]

- No specific correlative requirements.

Relative Importance

This was one of the least important objectives in the screening. Degradation of the atmosphere is generally important in any nuclear context. However, when considering the importance of this objective, it is important to realize

- Atmospheric impacts will be widespread but transitory
- Air quality can be corrected for the brief periods when the air-quality standards are exceeded
- All potential locations are in remote areas which will reduce the impact on human life
- Fugitive dust and other air quality degradation will be restricted to the construction and operations period
- Mitigative measures will be implemented to achieve proper air quality standards

The weighting poll resulted in an average assignment to this objective of 32% of the importance of the abiotic branch of environmental objectives. Because this branch was assigned less than 2%, this objective accounts for about one-half of one percent of the overall importance in screening, making this objective the thirty-fifth most important of the 40 lower-level objectives (Figure 3).

Applicable Attribute

Air Pollution Potential

Only one attribute (air pollution potential) was used to rate alternative locations with respect to this objective. This attribute was compiled specifically to discriminate among the potentials of alternative locations in the screening area for experiencing air pollution caused by repository activities.

4.3 Minimize Adverse Impacts on the Socioeconomic Status of Individuals in the Affected Area

Description

This middle-level objective calls for locations where development of a repository will not significantly and adversely affect the socioeconomic status of individuals in nearby communities. "Socioeconomic status" refers to a composite of human environmental factors, including both social and economic components. The social setting includes characteristics of the population and the social structure (such as the density, age, and ethnicity of the population, local community and religious organizations, and the employment, job-availability structure). The economic setting includes such factors as the community's financial resources, income distribution, local trades, housing patterns, land use, and industrial diversity. Communities affected by a repository in the screening areas include the greater Las Vegas metropolitan area, and smaller population centers between the NTS and Las Vegas and between the screening area and the California-Nevada border (specifically, Indian Springs, Cactus Springs, Beatty, Pahrump, and Amargosa Farms). This middle-level objective is divided into three component lower-level objectives for screening purposes, dealing respectively with local economics, life styles, and private land use. Conduct of repository activities is likely to have a significant relative impact on small, local communities and a relatively small impact on Las Vegas. Such impacts may be controversial. However, they are comparable to any large mining project and are thus large only in the context of the small, rural communities in the vicinity of the screening area. Many impacts are likely to be beneficial (e.g., increased employment and related spinoffs), so this objective only seeks to reduce or mitigate adverse impacts.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located to minimize the potential risk to and potential conflict with the population." [Criterion 3.8]
- "The site shall be selected giving due consideration to social and economic impacts on communities and regions affected by the repository." [Criterion 3.10]

10 CFR 60 (Proposed)[5]

- No specific correlative requirements.

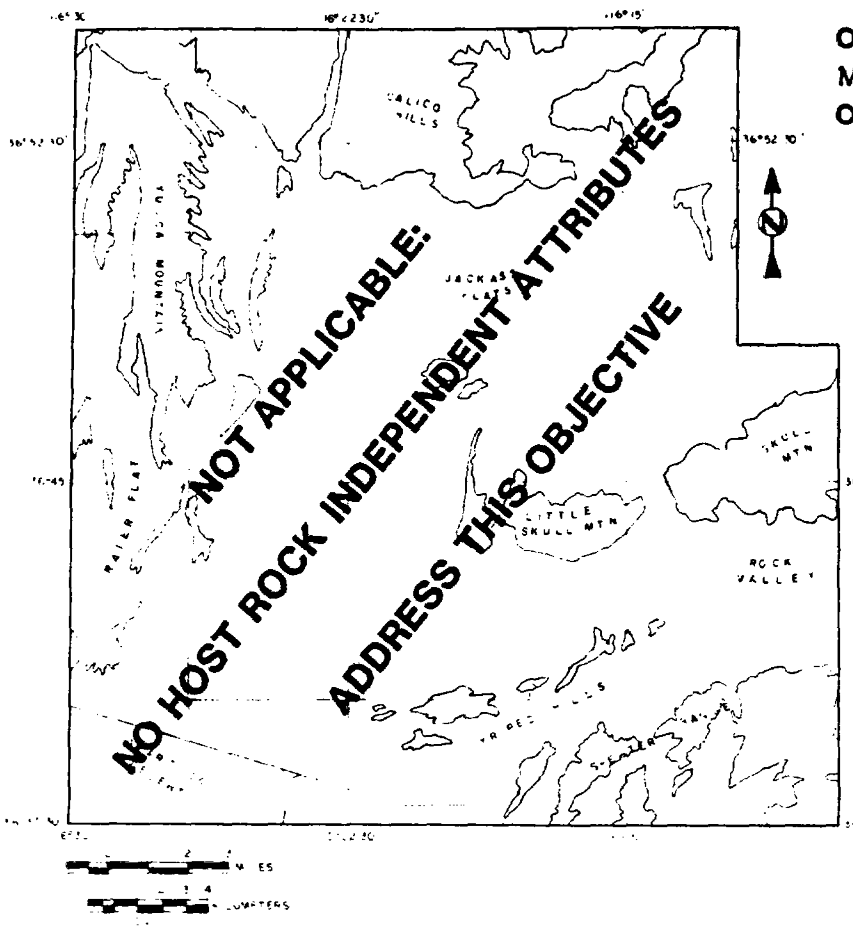
Relative Importance

This was one of the least important middle-level objectives in screening. Minimizing socioeconomic impacts is the third most important of the five middle-level objectives of the environmental branch of the objectives tree. The weighting poll resulted in an average assignment to this objective of about 20% of the importance of environmental concerns. Because these concerns were assigned about 8%, this objective accounts for less than 2% of the overall importance in screening, making this the tenth most important of the 12 middle-level objectives (Figure 3).

Applicable Attribute

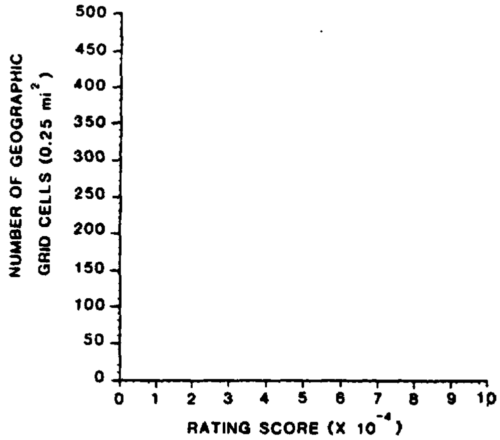
Private Land Use

Only one attribute was used to rate expected performance of alternative locations with respect to this middle-level objective. This was achieved by using it to evaluate performance for one (land use) of the three component lower-level objectives of this branch of environmental objectives. To evaluate the other two lower-level socioeconomic objectives, existing settlement patterns, social environments, economic bases, fiscal capacities, land uses, aesthetics, community services, housing and transportation facilities, and applicable laws and regulations would need to be characterized. Because this has not been done, no attributes were available for lower-level economic or life style objectives. Thus, this middle-level objective contributes to screening only the importance associated with the land use lower-level objective (Objective 4.3.3). The weights associated with the other two subobjectives of this branch of the tree did not contribute to the ratings of alternative locations because no attributes were available for evaluating them.



OBJECTIVE 4.3.1
MINIMIZE ADVERSE EFFECTS ON LOCAL ECONOMY

	ATTRIBUTES	WEIGHT
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
OLDER	Granite	
	Argillite	
	Carbonate	

Not applicable: No host rock attributes address this objective.

Figure 42. Objective 4.3.1—Minimize Adverse Effects on the Local Economy. Since the attributes do not address potential economic impacts on local communities (attribute list, upper right), neither location ratings (upper left) and associated histogram (lower left) nor host-rock ratings (lower right) were obtained for this objective. Therefore, this objective could not be used to help discriminate among alternative locations or host rocks.

4.3.1 Minimize Adverse Impacts on Local Economies

Description

Locations will be sought where local economic impacts caused by repository development are mainly beneficial. For negative economic impacts, the objective is to minimize or alleviate their effects. This objective is closely related to the one that seeks minimal adverse impacts on lifestyles (Objective 4.3.2). For example, more jobs and a stronger economy could offset possible negative reactions to lifestyle changes. Economic impacts will also change community land use patterns that, in turn, may influence lifestyles. Quantitative evaluation of the economic impact of repository development on nearby communities has not been done; therefore, it is difficult to assess the financial impact on the local communities. However, hundreds of mining jobs and additional hundreds of support service jobs would be created for local economies. These jobs will in all likelihood have a significant, positive effect on the economy of local communities. If properly managed, the loss of jobs during the final stages of repository operations can be accommodated smoothly with no abrupt impacts. Since the required work force will not live on the NTS, this objective does not allow discrimination among alternative locations within the screening area; therefore, this objective will result in essentially identical economic concerns regardless of which location is selected. Figure 42 shows that no ratings were obtained for this objective due to lack of relevant attributes. Thus, this objective did not contribute to discrimination among locations.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located so that adverse social and/or *economic impacts* resulting from repository construction and operation can be accommodated by mitigation or compensation strategies." (Emphasis Added) [Criterion 3.10(1)]

10 CFR 60 (Proposed)[5]

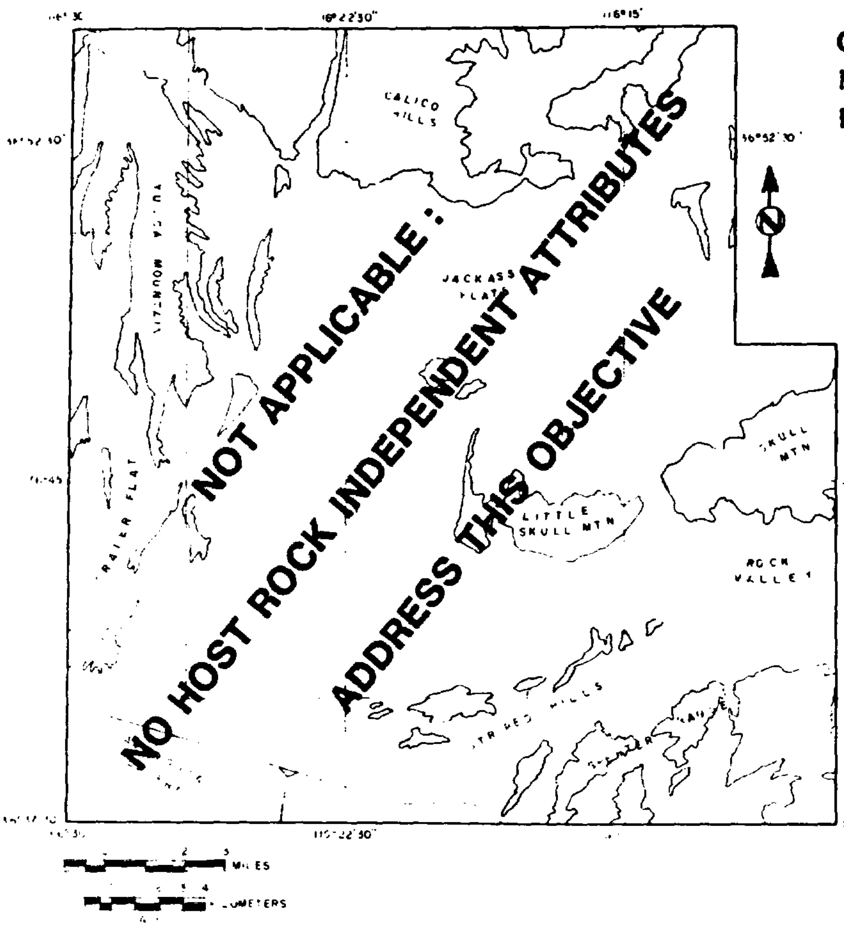
- No specific correlative requirements.

Relative Importance

This objective was one of the least important objectives in screening. Assessing the importance of any of the socioeconomic objectives is complicated by the paucity of studies specific to the area under investigation. The importance associated with these objectives is drawn primarily from general information about construction projects in other areas. The weighting poll resulted in an average assignment to this objective of 41% of the importance of the socioeconomic branch of environmental objectives. Because this branch was assigned about 2%, this objective accounts for less than 1% of the overall importance in screening, making this objective the thirty-third most important of the 40 lower-level objectives (Figure 3).

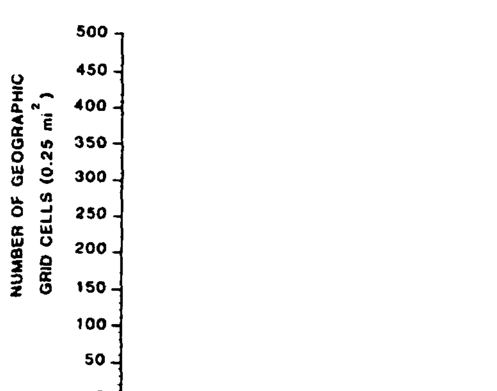
Applicable Attributes

No attributes were used to rate alternative locations with respect to this objective. Since the exact location for a repository within the screening area will not matter in terms of the types or amount of local economic impacts. Also, quantitative data are not available on local economic communities at this time. Thus, the weight associated with this objective did not contribute to the screening analysis.



OBJECTIVE 4.3.2 MINIMIZE ADVERSE EFFECTS ON LIFE STYLES

	ATTRIBUTES	WEIGHT*
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT.	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

Not applicable: No host rock attributes address this objective.

Figure 43. Objective 4.3.2—Minimize Adverse Effects on Life Styles. Since the attributes do not address life styles (attribute list, upper right), neither location ratings (upper left) and associated histogram (lower left) nor host-rock ratings (lower right) were obtained for this objective. Therefore, this objective could not be used to help discriminate among alternative locations or host rocks.

4.3.2 Minimize Adverse Impacts on Life Styles

Description

Locations will be sought where repository operations will have minimal adverse effects on the lifestyles of individuals who live nearby. Lifestyles are defined as living, cultural customs; visual and sound aesthetics; and the physical and psychological patterns of the population. Impacts on lifestyles could occur if a repository were located close to an existing community. Information is not available to measure these impacts on local communities. Besides the psychological fears commonly associated with waste disposal in general and radioactive waste in particular, lifestyle impacts of a repository will be similar to those accompanying other large-scale mining activities. The impacts on lifestyles will be small if the work force resides primarily in Las Vegas, with the exception that long commuting distances will be required as it is for other work activities at the NTS. This generalization, however, may not apply if the work force resides in the small local communities; these communities are small compared to the size of the expected work force. If an increase in population of these nearby communities occurred because of the construction force, the impacts on the rural, low-density lifestyles might be dramatic. Consideration would need to be given to the ability and willingness of the preconstruction population to adapt to new living situations, compensation, or relocation. Because the work force will not live at the repository location, impacts on lifestyles will most likely be the same for all locations within the screening area. Thus, this objective is probably not useful for discriminating among alternative locations. Figure 43 shows that no ratings were obtained for this objective due to lack of relevant attributes. Thus, this objective did not contribute to discrimination among locations.

Corresponding DOE and NRC Criteria

- Not specifically addressed by NWTS-33(1), NWTS-33(2), or proposed 10 CFR 60 (References 3, 4, and 5, respectively).

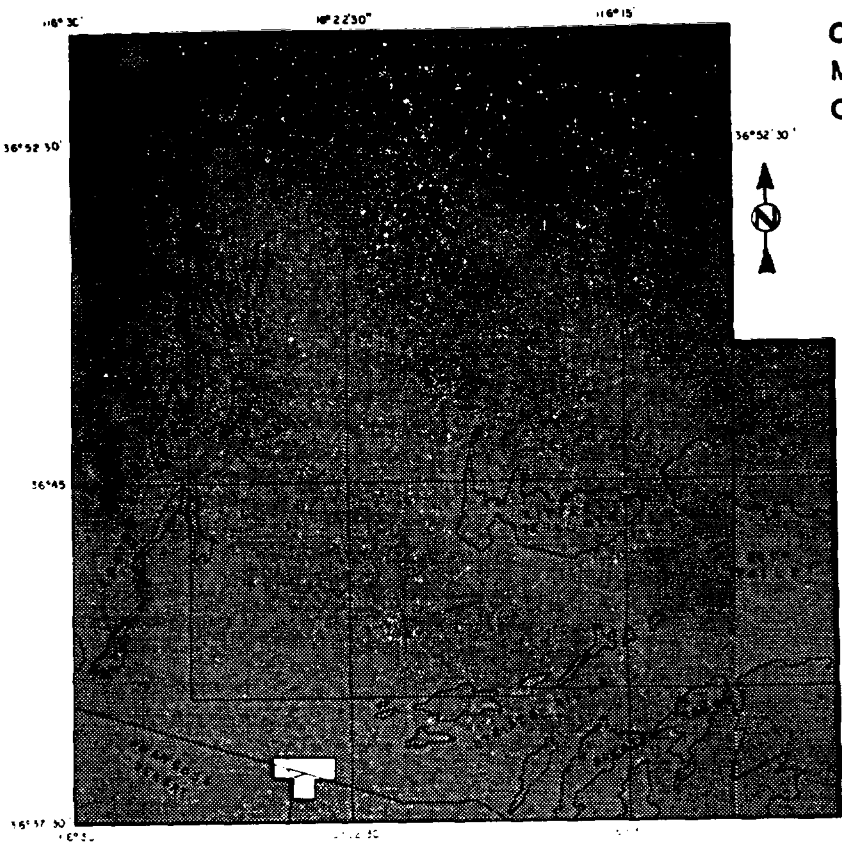
Relative Importance

This objective was one of the least important in screening. The weighting poll resulted in an average assignment to this objective of 42% of the socioeconomic branch of environmental objectives. Because this branch was assigned less than 2%, this objective accounts for less than 1% of the overall importance in screening, making this objective the thirty-second most important of the 40 lower-level objectives (Figure 3).

Applicable Attributes

No attributes were used to rate alternative locations with respect to this objective. Lifestyles are strongly related to the local economy, physical environment, and psychological elements of the community. No attributes are available to directly measure these elements. Also, regardless of where a repository is located in the screening area, the impact on life styles in nearby communities will be similar. Attributes to evaluate this objective, if they were available, would not discriminate among alternative locations. The weight associated with this objective therefore did not contribute to the screening analysis.

OBJECTIVE 4.3.3
MINIMIZE SCHEDULE IMPACTS OF FEDERAL REGULATIONS

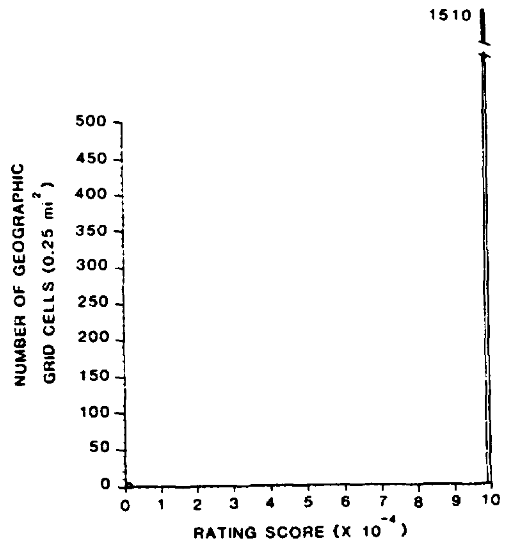


LEGEND FOR LOCATION RATINGS

☐ <5,000 ☐ 5,000–95,000 ■ >95,000

Based on Attribute #23 only.

	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 GEO ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT.	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	100
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
OLDER	Granite	
	Argillite	
	Carbonate	

Figure 44. Objective 4.3.3—Minimize Schedule Impacts of Federal Regulations. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting the distribution of private land, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since the attributes do not address the effects of specific rock types on land ownership, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

4.3.3 Maximize Cooperation With Private Property Owners

Description

Locations will be sought where cooperation can be achieved with private land owners and other private interests in the vicinity of a repository. Potential conflicts depend upon the status of private land use in the repository vicinity and on competing land use requirements for repository development. Possible effects on private property include primary impacts such as acquiring the land for repository use or disturbance by vehicles. Secondary impacts are also possible such as groundwater withdrawal affecting nearby private users. A small amount (less than three quarter-sections in the Lathrop Wells area) of the screening area is privately owned land. The rest of the screening area is public land, some withdrawn from public access. Where a repository is built, the federal government will acquire the rights necessary to ensure it has control over land use. Certain access routes may also require federal or state acquisition of private land for right-of-way. Avoidance of locations where large amounts of private land must be acquired is desirable. Considering the availability of land controlled by federal agencies in the screening area, it is unlikely that it would be necessary to procure private lands for any location in the screening area. Figure 44 shows location ratings based solely on this objective.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located on land for which the federal government can obtain ownership, control access, and obtain all surface and subsurface rights necessary to ensure that surface and subsurface activities at the site will not cause unacceptable impact on system performance." [Criterion 3.6(2)]

10 CFR 60 (Proposed)[6]

- "The geologic repository operations area shall be located in and on lands that are either acquired lands under the jurisdiction and control of DOE, or lands permanently withdrawn and reserved for its use." [§60.121(a)]

Relative Importance

This was the least important objective in screening. Accordingly, it is the least important lower-level objective in the socioeconomic branch. Conflicts should be minimal because the screening area includes little private land. The weighting poll resulted in an average assignment to this objective of 17% of the importance of the socioeconomic branch of environmental objectives. Since this branch was assigned less than 2%, this objective accounts for much less than 1% of the overall importance in screening, making this the least important of the 40 lower-level objectives (Figure 3).

Applicable Attribute

Private Land Use

Only one attribute was used to rate alternative locations with respect to this objective. This attribute identifies where private land occurs in the screening area and thus allows discrimination among alternative locations based on whether they contain private land. Because no attributes were used to evaluate locations for the other two lower-level socioeconomic objectives, this attribute serves as the only measure of performance for the middle-level socioeconomic branch of environmental objectives. However, its weight was that associated only with this lower-level objective.

4.4 Assure Institutional Cooperation on Repository Issues

Description

This objective calls for locations where repository development can proceed in a smooth and timely manner by cooperation between the DOE and other interested or affected federal, state, and private agencies.

Institutional issues (as used here) refer primarily to the administrative, licensing, environmental, and political aspects of siting a high-level radioactive waste repository. Responsibility for resolving the inevitable issues that will arise before they become sensitive falls primarily on federal (including Congress) and state agencies. Therefore, the siting, construction, and operation of a repository is a multigroup, cooperative endeavor. Federal agencies involved in this process include the Bureau of Land Management, US Air Force, US Department of Energy, the US Environmental Protection Agency, the US Nuclear Regulatory Commission, and the US Army Corps of Engineers. The institutional issues currently foreseen concern the availability of land for repository use and the impact of regulations on repository development. Concerns in the State of Nevada over the extent of land control by the federal government may make dedicating additional federal land for a repository difficult. The impacts of licensing, NEPA proceedings, and other public hearings on development schedules may be significant, though they are difficult to predict at this time. To resolve issues that arise, it will be necessary to coordinate repository development with the procedures for acquiring land to be dedicated for a repository, and with the procedures for obtaining various permits required to construct and operate a repository. Repository development schedules have been modified during the past few years partly because of a change in administrations. Accordingly, future changes cannot be ruled out. The current schedule calls for a site characterization effort that will provide input to a site characterization report in early 1984 and a detailed license application in the mid to late 1980s. Sinking of an initial exploratory shaft is scheduled to begin in 1984, leading to underground testing in an at-depth facility by about 1985. Appropriate state and federal procedures must be followed to obtain the necessary permits for land withdrawal and land disturbances associated with each of these steps of the characterization and siting process. This objective calls for timely recognition and cooperative resolution of issues by all parties in order to proceed smoothly toward solving a national problem.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- "The NWTS program shall be conducted in a manner that will promote institutional and societal participation and acceptance of the program plans and activities." [Objective 2.2]

NWTS-33(2)[4]

- "The site shall be located to reduce the likelihood or consequence of air, water, and *land use* conflicts." (Emphasis Added) [Criterion 3.9(2)]

10 CFR 60 (Proposed)[5]

- "Appropriate controls shall be established outside of the geologic repository operations area. DOE shall exercise any jurisdiction and control over surface and subsurface estates necessary to prevent adverse human actions that could significantly reduce the site or engineered system's ability to achieve isolation." [§60.121(b)]

Relative Importance

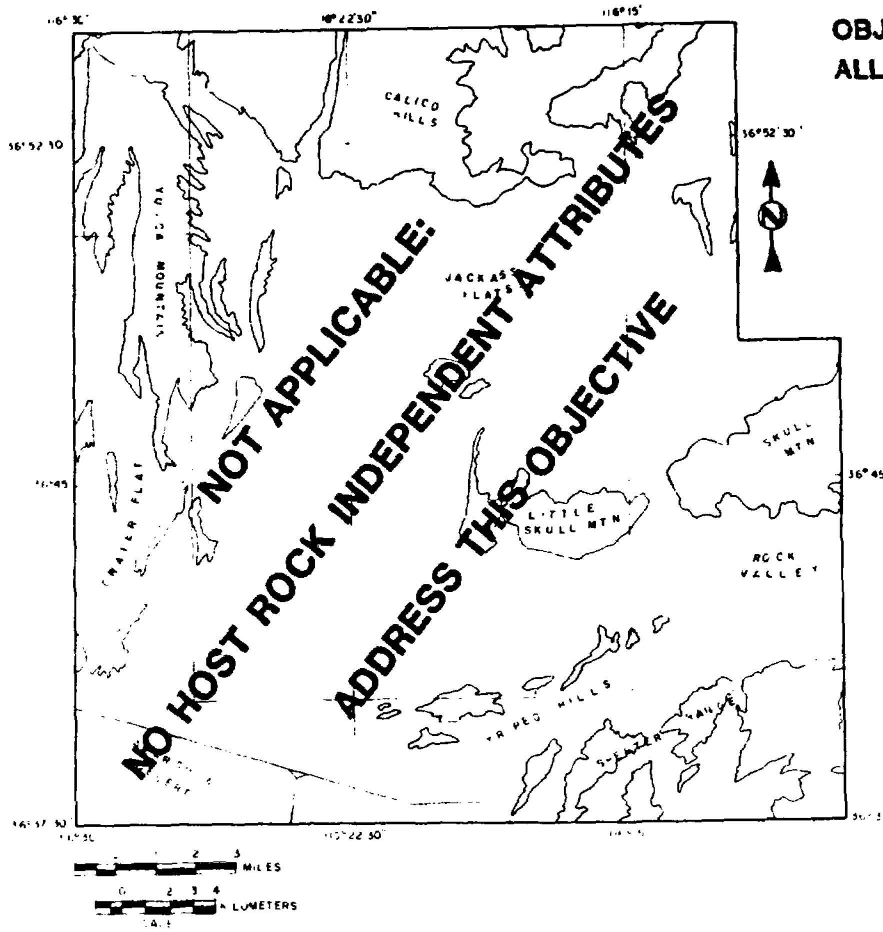
This is one of the least important middle-level objectives in screening. However, the importance associated with reducing impacts of institutional issues is relatively high compared with other middle-level environmental objectives. In Nevada, public concern about control of so much land by the Federal government is very high. Any proposal to temporarily or permanently withdraw additional land from public use may be strongly opposed, and result in costly and lengthly public hearings. Institutional issues are rated higher than other environmental objectives due in part to their potential for stopping or delaying the project, or for exacerbating misunderstandings and political conflicts. The weighting poll resulted in an average assignment to this objective of 21% of the importance of the environmental branch of the objectives tree. Because this branch was assigned 8%, this objective accounts for a little more than 1.5% of the overall importance in screening, making this the ninth most important of the 12 middle-level objectives (Figure 3).

Applicable Attribute

Permitting Difficulties

Only one attribute (permitting difficulties) was used to rate expected performance of alternative locations with respect to this middle-level objective. This was achieved by using this attribute to evaluate performance of one of the two component lower-level objectives (schedule impacts). To evaluate the other lower-level institutional objective, cooperation with state and private agencies, an unambiguous definition of the political milieu would be required. Because this is outside the realms of expertise of contributors to the NNWSI screening activity, an attribute addressing the effects cooperation among affected agencies is not available. Thus, this middle-level objective contributes to screening only the importance associated with the lower-level objective for schedule impacts (Objective 4.4.2). The weight associated with the other lower-level objective of this branch of the objectives tree did not contribute to the ratings of alternative locations.

OBJECTIVE 4.4.1
ALLEVIATE STATE ISSUES



	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	

HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

Not applicable: No host rock attributes address this objective.

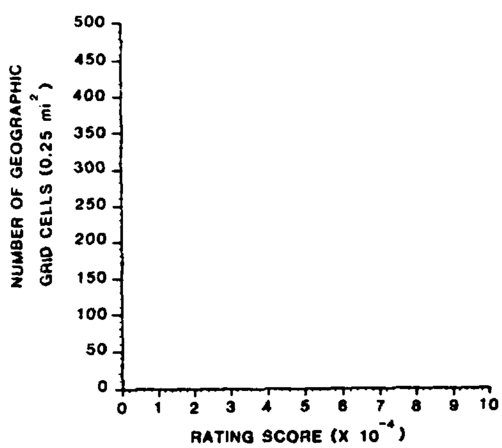


Figure 45. Objective 4.4.1—Alleviate State Issues. Since the attributes do not address the environment of institutional cooperation with local parties (attribute list, upper right), neither location ratings (upper left) and associated histogram (lower left) nor host-rock ratings (lower right) were obtained for this objective. Therefore, this objective could not be used to help discriminate among alternative locations of host rocks.

4.4.1 Cooperate With State and Private Agencies and Other Interested Parties

Description

Locations will be sought where cooperation with state and private interests concerning repository development can be obtained to the mutual benefit of all parties. Each state confronted with the opportunity of having a radioactive waste repository within its borders is concerned about the benefits and attendant risks associated with its siting and development. Because a formal role for the states and local parties is not yet defined legally, it is difficult to address this objective. Any potential conflicts about land use among federal agencies, the State of Nevada, and private parties should be identified early so they can be circumvented or resolved as early in the siting process as possible. State issues are expected to be political and philosophical as well as technical in nature. Because Nevadans may be concerned that their state is becoming a radioactive waste disposal site for the nation, efforts must be undertaken to communicate to the public the true health risks from a repository as well as the counterbalancing economic benefits. Thus, this objective seeks to communicate the best understanding of risks and benefits to all interested parties in a manner that allows constructive dialogue about whether the benefits are worth the risks. This objective applies equally to all locations in the screening area, and cannot be used to discriminate among alternative locations. Figure 45 shows that no ratings were obtained for this objective due to lack of relevant attributes. Thus, this objective did not contribute to discrimination among locations.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The site shall be located on land for which the federal government can obtain ownership, control access, and obtain all surface and subsurface rights necessary to ensure that surface and subsurface activities at the site will not cause unacceptable impact on system performance." [Criterion 3.6(2)]
- "The consideration of air, water, and land use must include both surface use, subsurface use, and resource denial as currently regulated by local, state, and federal legislation." [Criterion 3.9(2)]

10 CFR 60 (Proposed)[6]

- No specific correlative requirements.

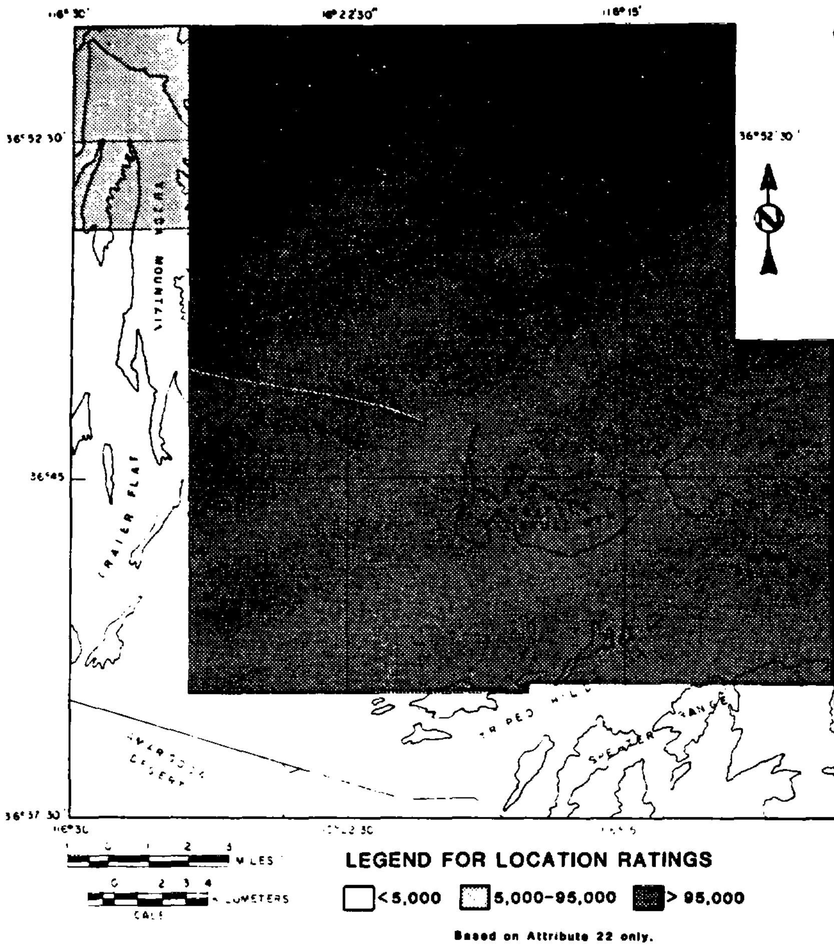
Relative Importance

This was one of the least important objectives in the screening. This screening addressed technical factors for enhancing safety, and placed low emphasis on political or psychological perceptions of safety. It is likely this objective will assume much more importance in social decisions than given in this technical screening. The weighting poll resulted in an average assignment to this objective of 53% of the importance for the institutional branch of environmental objectives. Since this branch was assigned about 2%, this objective accounts for about 1% of the overall importance in screening, making this objective the twenty-seventh most important of the 40 lower-level objectives (Figure 3).

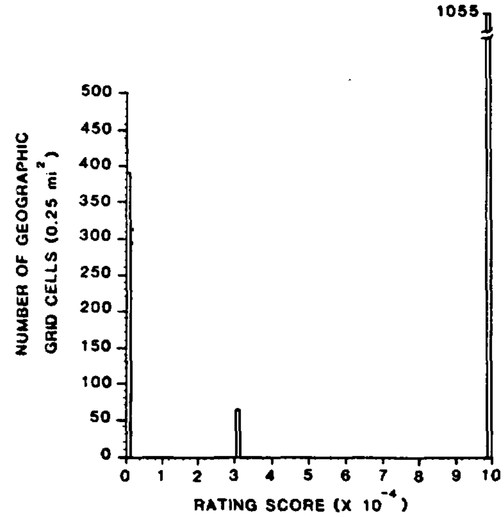
Applicable Attributes

No attributes were available to rate alternative locations with respect to this objective. As mentioned in the objective description, the formal roles of states and localities as well as issues of controversy between states, localities, and federal agencies are poorly defined. Since these issues will probably not vary between alternative locations, it is impossible to address this objective for screening. Thus, this objective did not contribute to ratings of alternative locations.

OBJECTIVE 4.4.2
REDUCE SCHEDULE DELAYS DUE TO LAND USE ISSUES



	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT.	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	
	20 POTENTIAL CULTURAL RESOURCES	
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	100
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	



HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
	Granite	
	Argillite	
OLDER	Carbonate	

Figure 46. Objective 4.4.2—Reduce Schedule Delays Due to Land Use Issues. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting the potential ease of federal land withdrawal, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since the attributes do not address the effects of specific rock types on meeting federal regulations, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks.

4.4.2 Assure Timely Repository Development Compatible With Federal Regulations and Procedures

Description

Locations will be sought where repository development can occur smoothly and on schedule while meeting all federal regulations and procedures. The licensing process and land withdrawal will involve many federal, state, and local groups in a detailed review of long-term safety, and operational and environmental issues.[51] This objective addresses the specific issues that will require federal interagency resolution. Federal issues will primarily be a matter of complying with various regulations. Licensing and NEPA proceedings will be the primary vehicles for identifying and resolving these issues. The courts may become a forum for issue resolution if interagency mechanisms are incapable of obtaining consensus. A factor in such issues is land use because the approvals, agreements, and permits depend, in part, on current land custodianship. Site characterization activities may require state permits on private or state land, whereas federal permits may be required on BLM land. On Air Force or DOE withdrawn land, existing EISs may provide sufficient approval for activities. Permanent land withdrawal for a repository, regardless of the land status, may require Congressional action. Repository construction and operation will require permits from NRC (licensing) and proper environmental review of an EIS (EPA). The land under consideration for screening (with the exception of a very small portion of privately owned land) is under federal control. Some of this land is already withdrawn from public access; therefore, some barriers are removed because additional land acquisition under the Federal Land Policy and Management Act may be unnecessary. This objective calls for locations that facilitate expeditious interagency reviews and issuance of permits required for site characterization and repository development. Figure 46 shows location ratings based solely on this objective.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- "Applicable federal public health and safety criteria issued by the Nuclear Regulatory Commission (NRC) and the Environmental Protection Agency (EPA) shall be satisfied during the operational phase of the mined geologic disposal system. In particular, the limits specified in 40 CFR Part 191 (when adopted) shall be met." [Criterion 4.1.1]
- "Occupational radiological exposure to the repository personnel shall be maintained to within the limits specified in 10 CFR Part 20 and below these limits to as low as reasonably achievable levels. Applicable regulations of the Mining Safety and Health Administration (specifically, 30 CFR Part 57) and Occupational Safety and Health Administration shall be used to ensure the protection of repository personnel from mining and other occupational hazards." [Criterion 4.1.2]

NWTS-33(2)[4]

- "The consideration of air, water, and land use must include both surface use, subsurface use, and resource denial as currently regulated by local, state, and federal legislation." [Criterion 3.9(2)]

10 CFR 60 (Proposed)[5]

- No specific correlative requirements.

Relative Importance

This was one of the least important objectives in the screening, because much of the land in the screening area is already withdrawn federal land. The weighting poll resulted in an average assignment to this objective of 47% of the importance of the institutional branch of environmental objectives. Since this branch was assigned about 2%, this objective accounts for less than 1% of the overall importance in screening, making this objective the twenty-ninth most important of the 40 lower-level objectives (Figure 3).

Applicable Attribute

Land Use Categories

Only one attribute (land use categories) was used to rate alternative locations with respect to this objective. The land categories divide the screening area into four groups for permitting and temporary land withdrawal purposes: DOE, BLM, Air Force/BLM, and private land. Permitting and temporary land withdrawal issues could vary substantially among these categories. Because no attributes were used to evaluate locations for the other lower-level institutional objectives, this attribute served as the only measure of performance for the middle-level institutional branch of environmental objectives. However, its weight was that associated only with this lower-level objective.

4.5 Minimize Adverse Impacts on Significant Historic and Prehistoric Cultural Resources

(It serves as both middle- and lower-level objective.)

Description

This objective calls for locations where the characterization and development of a repository will not significantly and adversely affect any cultural resources. Cultural resources refer to any archeologic or historic sites or artifacts considered worthy of preservation. Preservation of cultural resources is an important objective of federal actions mandated by law. A significant piece of legislation governing the protection of cultural resources is the National Historic Preservation Act of 1966. The need to preserve cultural resources is also recognized in NEPA. To satisfy this objective, it is necessary to identify and evaluate the potential significance of cultural resources within the screening area and to develop procedures for mitigating adverse impacts should impacts be inevitable. Location screening can satisfy the first requirement by identifying known or suspected cultural resource sites and avoiding them, if possible. Mitigation procedures will be required if repository development occurs in a location where such resources might be disturbed. Figure 47 shows location ratings based solely on this objective.

Corresponding DOE and NRC Criteria

NWTS-33(1)[3]

- No specific correlative requirements.

NWTS-33(2)[4]

- "The evaluation of such impacts will include assessment of air, water, land, aesthetic, ecological, noise, resource, and *historical* factors appropriate to repository construction, operation, and isolation." (Emphasis Added) [Criterion 3.9(1)]

10 CFR 60 (Proposed)[6]

- No specific correlative requirements.

Relative Importance

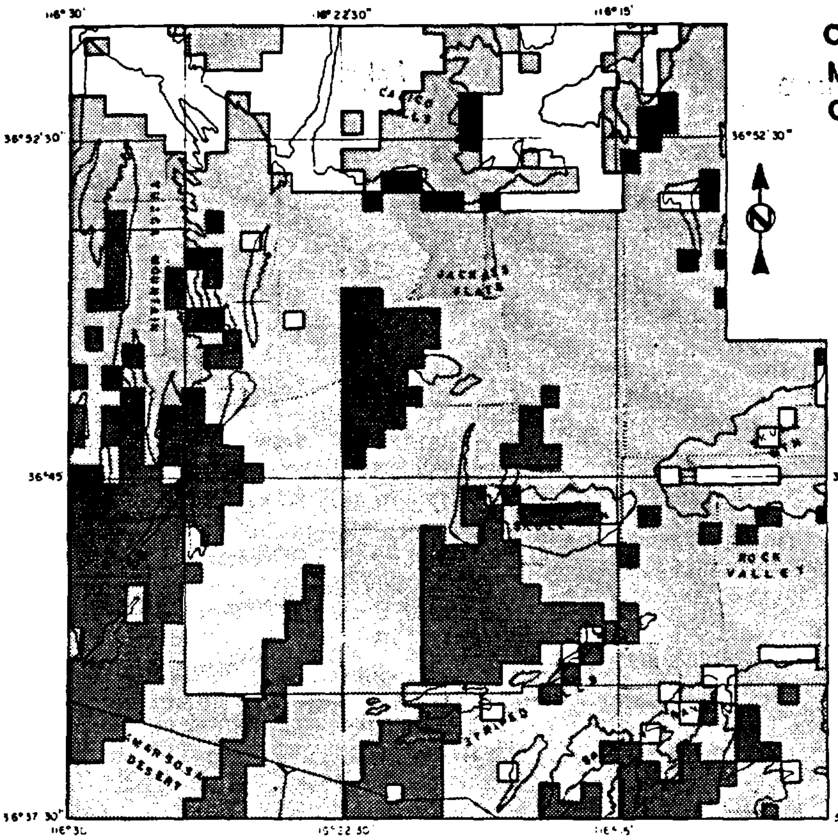
This objective was the least important of the middle-level environmental objectives. Though significant delays in repository construction may occur if significant cultural resources are present, it is possible to move the construction site to avoid disturbing those resources. Such resources could generally be salvaged by appropriate mitigation strategies such as collecting, cataloging, and preserving artifacts. Also, these resources generally tend to occur at small sites, thus allowing repository facilities to be built on other sites within a given location without undue expense and design modifications. The weighting poll resulted in an average assignment to this objective of 16% of the importance of environmental objectives. Since environment concerns were assigned 8%, this middle-level objective accounts for ~1.5% of the overall importance in screening, making this the least important of the 12 middle-level objectives (Figure 3).

Applicable Attributes

Potential Cultural Resources
Known Cultural Resources

Two attributes were used to rate the expected performance of alternative locations with respect to this objective. This objective has no component lower-level objectives, so these two attributes were used to directly evaluate this middle-level objective. The attribute that identifies where cultural resources have a greater likelihood of occurring was considered the more important. It incorporates elements of the natural environment (such as water, biotic resources, and topographic areas) that may have attracted prehistoric and historic peoples to conduct their routine activities. The potential cultural resource attribute was considered more important also because it was mapped for the entire area, providing a complete composite map for screening. The locations of known cultural resources were the other applicable attributes. Though it may seem more important because it identifies where resources are known to occur rather than inferred as likely to occur, it was assigned less importance because it is based on sporadic field surveys of cultural resources and represents a very small sample of the entire screening area.

OBJECTIVE 4.5.1
MINIMIZE IMPACTS ON CULTURAL RESOURCES



LEGEND FOR LOCATION RATINGS

☐ <55,000 ☐ 55,000-75,000 ■ >75,000

Based on Attributes 19&20 only.

	ATTRIBUTES	WEIGHT %
USED TO PRODUCE MAP	1 VOLCANIC POTENTIAL	
	2 FAULT DENSITY	
	3 FAULT TREND	
	4 AGE OF FAULTING	
	5 NATURAL SEISMIC POTENTIAL	
	6 WEAPONS SEISMIC POTENTIAL	
	7 BED ATTITUDE (ROCK DIP)	
	8 EROSION POTENTIAL	
	9 FLOOD POTENTIAL	
	10 TERRAIN RUGGEDNESS	
	11 BASE & PRECIOUS METAL RESOURCE POT.	
	12 GROUNDWATER RESOURCE POTENTIAL	
	13 GROUNDWATER FLUX	
	14 GROUNDWATER FLOW DIRECTION	
	15 THICKNESS OF UNSATURATED ZONE	
	16 SENSITIVE FLORAL SPECIES	
	17 SENSITIVE FAUNAL SPECIES	
	18 REVEGETATION POTENTIAL	
	19 KNOWN CULTURAL RESOURCES	30
	20 POTENTIAL CULTURAL RESOURCES	70
	21 AIR POLLUTION POTENTIAL	
	22 PERMITTING DIFFICULTIES	
	23 PRIVATE LAND USE	
USED TO PRODUCE HOST ROCK LIST	24 THERMAL CONDUCTIVITY	
	25 COMPRESSIVE STRENGTH (CONTAINMENT)	
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)	
	27 EXPANSION-CONTRACTION	
	28 MINERAL STABILITY	
	29 STRATIGRAPHIC SETTING	
	30 HYDRAULIC RETARDATION	
	31 HYDRAULIC TRANSMISSIVITY	

HOST ROCK RATINGS

AGE	ROCK TYPE	RATING
YOUNGER	Alluvium	NOT APPLICABLE
	Basalt	
	Non-welded Paintbrush Tuff	
	Topopah Spring Tuff	
	Calico Hills Tuff	
	Crater Flat Tuff	
OLDER	Granite	
	Argillite	
	Carbonate	

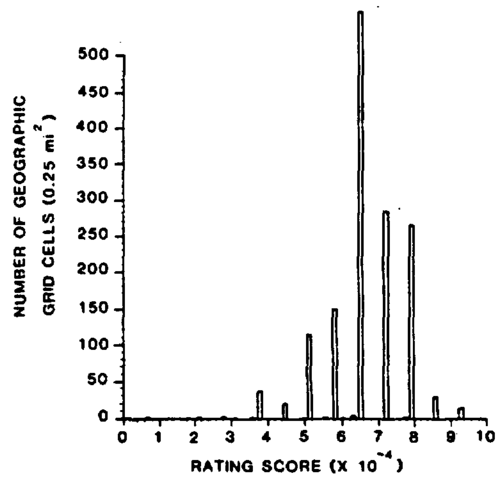


Figure 47. Location Ratings Based Solely on Cultural Resources. Map (upper left) shows high-, intermediate-, and low-location ratings based on geographical attributes affecting the distribution of historic and prehistoric cultural resources, weighted according to the attribute list (upper right); the sum of attribute weights is 100%. Histogram (lower left) shows the numerical distribution of rating values for all of the 1514 grid cells of the map. The maximum possible rating value is 100 000. Since the attributes do not address the effects of specific rock types on the occurrence of cultural resources, no host-rock ratings are available (lower right). Therefore, this objective was used only to help rate locations and could not be used to help discriminate among the potential host rocks. Because this middle-level objective has no component lower-level objectives, it serves for location rating purposes as a lower-level objective.

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APPENDIX

Weights Assigned by Individuals in Poll and the Mean and Standard Deviations of the Individual Weights

Participants in Poll

Set A Participants:

S. Sinnock, J. A. Fernandez, J. T. Neal, R. L. Link (Sandia National Laboratories)
R. C. Carlson, L. B. Ballou, W. C. Patrick (Lawrence Livermore National Laboratory)
B. M. Byers (US Geological Survey)

Set B Participants:

L. C. Pippin, J. L. Bowen (Desert Research Institute)
B. L. Yantis (University of Nevada, Las Vegas)
F. E. Bingham (Department of Energy, Nevada Operations Office)
T. P. O'Farrell and E. Collins (EG&G) (single response)
S. B. Bertram, J. A. Fernandez (Sandia National Laboratories)

Upper-Level Objectives

Participant Set A

Level 1 Objectives	Individual Respondent's (% of Overall Goal)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mean ± σ
1.0 Containment	41.5	22	21	52	26	30	25	30	30.94 ± 10.66
2.0 Isolation	11.0	32	21	31	43	40	55	40	34.13 ± 13.65
3.0 Construction & Operation	41.5	46	52	11	21	20	10	10	26.44 ± 17.37
4.0 Environment	6.0	0	6	6	10	10	10	20	8.5 ± 5.73

Middle-Level Objectives

Participant Set A

Level 2 Objectives	Individual Respondent's Weights (% of Upper Level Containment Objective)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mean ± 1σ
1.1 Processes	80	80	70	60	60	67	60	67	68.00 ± 8.33
1.2 Events	20	20	30	40	40	33	40	33	32.00 ± 8.33

Participant Set A

Level 2 Objectives	Individual Respondent's Weights (% of Upper Level Isolation Objective)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mean ± 1σ
2.1 Radionuclide Migration	60	80	70	50	50	67	73	67	64.63 ± 10.66
2.2 Changes to Pathways	40	20	30	50	50	33	27	33	35.38 ± 10.66

Participant Set A

Level 2 Objectives	Individual Respondent's Weights (% of Upper Level Construction Objective)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mean ± 1σ
3.1 Surface Facilities	35	20	30	20	15	33	30	33	27.00 ± 7.52
3.2 Subsurface Facilities	35	60	40	20	50	50	40	50	43.13 ± 12.23
3.3 Transportation	30	20	30	60	35	17	30	17	29.88 ± 13.95

Participant Set B

Level 2 Objectives	Individual Respondent's Weights (% of Upper Level Environmental Objective)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	Mean ± 1σ
4.1 Biotic Systems	15	25	20	10	20	33	28	21.57 ± 7.81
4.2 Abiotic Systems	15	35	30	20	20	7	23	21.43 ± 9.25
4.3 Socioeconomic	30	20	5	40	25	13	5	19.71 ± 13.06
4.4 Institutional Issues	35	10	25	20	25	20	16	21.57 ± 7.89
4.5 Cultural Resources	5	10	20	10	10	27	28	15.71 ± 9.21

Lower-Level Objectives

Participant Set A

Level 3 Objectives	Individual Respondent's Weights (% of Middle Level Containment-Process Objective)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mean ± 1σ
1.1.1 Chemical Processes	80	80	80	50	50	67	67	67	67.63 ± 12.43
1.1.2 Mechanical Processes	20	20	20	50	50	33	33	33	32.38 ± 12.43

Participant Set A

Level 3 Objectives	Individual Respondent's Weights (% of Middle Level Containment-Event Objective)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mean ± 1σ
1.2.1 Seismic	30	60	70	30	20	27	30	27	36.75 ± 17.94
1.2.2 Erosional	30	10	5	20	10	13	10	13	13.89 ± 7.77
1.2.3 Volcanic	30	20	20	30	30	20	10	7	20.88 ± 8.97
1.2.4 Human Intrusion	5	10	5	18	40	33	40	33	23.00 ± 15.21
1.2.5 Miscellaneous	5	0	0	2	0	7	10	20	5.50- ± 6.93

Participant Set A

Level 3 Objectives	Individual Respondent's Weights (% of Middle Level Isolation-Migration Objective)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mean ± 1σ
2.1.1 Groundwater Flow	30	40	30	70	25	30	50	40	39.38 ± 14.75
2.1.2 Nuclide Retardation	20	40	30	15	25	40	38	30	29.75 ± 9.36
2.1.3 Host Rock Thickness	50	20	30	10	25	20	7	20	22.75 ± 13.28
2.1.4 Volatile Pathways	0	0	10	5	25	10	5	10	8.13 ± 7.99

Participant Set A

Level 3 Objectives	Individual Respondent's Weights (% of Middle Level Isolation-Change Objective)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mean ± 1σ
2.2.1 Tectonic	30	40	50	40	25	27	20	20	31.50 ± 10.80
2.2.2 Climatic	10	20	20	20	15	20	33	27	20.63 ± 6.97
2.2.3 Geomorphic	30	40	20	20	10	13	13	13	19.88 ± 10.33
2.2.4 Human Induced	30	0	10	18	50	33	27	33	25.13 ± 15.50
2.2.5 Miscellaneous	0	0	0	2	0	7	7	7	2.88 ± 3.48

Participant Set A

Level 3 Objectives	Individual Respondent's Weights (% of Middle Level Surface Facility Objective)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mean ± 1σ
3.1.1 Seismic Hazards	10	30	30	30	16	24	16	14	21.25 ± 8.06
3.1.2 Monitoring Costs	0	0	20	5	16	5	16	28	11.25 ± 10.47
3.1.3 Foundation Conditons	30	60	20	15	16	28	16	19	25.50 ± 14.90
3.1.4 Wind Hazards	0	10	10	10	16	10	16	10	10.25 ± 5.18
3.1.5 Flood Hazards	40	0	10	15	16	19	16	24	17.50 ± 11.45
3.1.6 Construction Resources	20	0	10	25	16	14	16	5	13.25 ± 8.15

Participant Set A

Level 3 Objectives	Individual Respondent's Weights (% of Middle Level Subsurface Facility Objective)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mean ± 1σ
3.2.1 Seismic Hazards	30	10	10	20	10	13	10	20	15.38 ± 7.35
3.2.2 Flood Hazards	30	0	20	10	10	27	40	27	20.50 ± 13.07
3.2.3 Mining Conditions	0	40	20	20	50	33	20	33	27.00 ± 15.33
3.2.4 Host Rock Geometry	20	40	15	10	10	10	10	6	15.13 ± 10.89
3.2.5 Host Rock Homogeneity	20	10	15	10	10	10	10	7	11.50 ± 4.07
3.2.6 Waste Package Acceptance	0	0	20	30	10	7	10	7	10.50 ±10.11

Participant Set A

Level 3 Objectives	Individual Respondent's Weights (% of Middle Level Transportation Objective)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mean ± 1σ
3.3.1 Terrain	90	90	70	50	57	67	80	67	71.38 ± 14.50
3.3.2 Distance	10	10	30	50	43	33	20	33	28.63 ± 14.50

4.1 Minimize Effects on Biotic Systems

No poll necessary; 100% of weight for objective 4.1 is assigned to one subobjective (4.1.1), Sensitive Species.

Participant Set B

Level 3 Objectives	Individual Respondent's Weights (% of Middle Level Abiotic System Objective)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	Mean ± 1σ
4.2.1 Surface Features	40	10	25	20	30	17	10	21.71 ± 10.90
4.2.2 Water Quality	50	60	40	40	40	50	45	46.43 ± 7.48
4.2.3 Air Quality	10	30	35	40	30	33	45	31.86 ± 11.07

Participant Set B

Level 3 Objectives	Individual Respondent's Weights (% of Middle Level Socioeconomic Objective)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	Mean ± 1σ
4.3.1 Local Economics	60	55	10	30	30	50	50	40.71 ± 17.90
4.3.2 Lifestyles	40	5	80	35	60	33	45	42.57 ± 23.37
4.3.3 Private Land Use	0	40	10	35	10	17	5	16.71 ± 15.18

Participant Set B

Level 3 Objectives	Individual Respondent's Weights (% of Middle Level Institutional Objective)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	Mean ± 1σ
4.4.1 Permits	95	50	60	40	70	33	25	53.29 ± 24.03
4.4.2 Schedules	5	50	40	60	30	67	75	46.71 ± 24.03

4.5 Minimize Effects on Cultural Resources

No poll necessary; 100% of weight for objective 4.5 is assigned to one subobjective (4.5.1), Archaeological and Historical Sites.

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