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NATURAL RESOURCES REGULATORY REQUIREMENTS: BACKGROUND AND CONSIDERATION OF COMPLIANCE METHODOLOGIES

Prepared for

Nuclear Regulatory Commission
Contract NRC-02-88-005

Prepared by

Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

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ABSTRACT

There is a long and continuing interest in the possibility of inadvertent human intrusion into a geologic repository designed to contain high-level radioactive wastes. Nuclear Regulatory Commission (NRC) has expressed an interest in lessening the chances of inadvertent human intrusion at a repository site by avoiding areas which have known or perceived quantities of natural resources which might prove attractive to future explorationists. This document deals with the parts of 10 CFR Part 60 that are concerned with natural resources. Four Potentially Adverse Conditions (PAC) in 10 CFR 60.122(c)(1 through 24) include language which deals specifically with natural resources. These four are PAC (2) — Human Activity and Groundwater, PAC (17) — Presence of Naturally Occurring Materials, PAC (18) — Evidence of Subsurface Mining, and PAC (19) — Evidence of Drilling. Additionally, the NRC has included a description of natural resource related items to be included within the DOE Safety Analysis Report (SAR) which will be submitted to NRC in accordance with 10 CFR 60.21(c)(13).

The statutory and regulatory history of regulations dealing with natural resources is presented in Chapter 2 along with clarification of some specialized terms dealing with natural resources. Chapter 2 contains a discussion of both shared and unique aspects of the PAC. Chapter 3 discusses the geologic bases for consideration of natural resources at Yucca Mountain. Chapter 4 discusses compliance demonstration methodologies which might be used to satisfy the language of the regulation. Examples considering the Yucca Mountain proposed repository site are presented. Chapter 5 presents the conclusions of the study, including a restatement of the CNWRA interpretation of the intent of the NRC within the context of the language of the PAC — Presence of Naturally Occurring Materials. Three Appendices discuss the following: (i) A methodology for assessing groundwater resources as a potential source of human intrusion, (ii) Water resources in southern Nevada, and (iii) Groundwater classification: "Significant" and "special" sources and the individual and groundwater requirements of 40 CFR Part 191 at Yucca Mountain.

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EXECUTIVE SUMMARY

BACKGROUND

There is a long and continuing interest in the possibility of inadvertent human intrusion into a geologic repository designed to contain high-level radioactive wastes (HLW). The Nuclear Regulatory Commission (NRC) has expressed an interest in lessening the chances of inadvertent human intrusion at a repository site by avoiding areas which have known or perceived quantities of natural resources which might prove attractive to future explorationists. The Commission has specifically included language in 10 CFR Part 60 in the discussion of Potentially Adverse Conditions (PAC) in section 60.122(c)(1 through 24) which deal specifically with natural resources. CNWRA has identified four PAC in 10 CFR 60.122(c) which deal with natural resources as follows: (i) PAC (17) — Presence of Naturally Occurring Materials, (ii) PAC (18) — Evidence of Subsurface Mining, (iii) PAC (19) — Evidence of Drilling, and (iv) PAC (2) — Human Activity and Groundwater. Additionally, in 10 CFR 60.21(c)(13), NRC has provided a description of natural resource related items to be included within the Safety Analysis Report (SAR) of the Department of Energy (DOE) to NRC. Because the PACs are to be evaluated by comparing the effects of the conditions to the performance objectives, any discussion of natural resources should include a discussion of the applicable sections of 10 CFR 60.112 — the overall system performance objectives, 10 CFR 60.113 — the subsystem performance objectives, and 40 CFR Part 191, the Environmental Protection Agency (EPA) standard. Additionally, the effects of the PACs can be offset by an appropriate combination of the favorable conditions identified in 10 CFR 60.122(b). Lastly, the effects of PACs can be remedied by engineering measures employed by DOE.

This document accomplishes the following:

- Documents an investigation of the regulatory background of NRC regulations dealing with natural resources;
- Provides definition and clarification of ambiguous or unclear terms;
- Provides a discussion of the geologic bases for consideration of natural resources in the regional environment and particularly in the vicinity of Yucca Mountain, Nevada;
- Details the implicit and explicit regulatory requirements and discusses means to accomplish compliance with the regulations pertaining to natural resources; and
- Summarizes the natural resource-related requirements of 10 CFR Part 60 and presents a discussion relative to NRC intent.

PURPOSE OF THE REPORT

The purpose of this report is to provide NRC staff with an information and strategy base useful for documenting, formulating, and implementing a regulatory strategy for natural resources including a means of providing guidance on the intent of NRC regulations to DOE. Methods acceptable to NRC for DOE demonstration of compliance with the natural resource regulations contained in 10 CFR Part 60 are discussed. It is probable that this document will be used as a forum for debate within NRC to establish working methods for future consideration of natural resources related and other regulations.

REGULATORY BASES FOR ASSESSMENT OF NATURAL RESOURCES

Statutory Bases for Considering Natural Resources

The federal statutes which provide the legislative bases for assessment of natural resources are presented and discussed. Included are discussions of language pertinent to natural resources in the Atomic Energy Act of 1954, the Energy Reorganization Act of 1974, and the Nuclear Waste Policy Act (NWPA) of 1982.

Natural Resources and Licensing of a High-Level Waste Repository: A Regulatory History

This section reviews the regulatory history of the development of NRC regulations governing HLW repositories with respect to natural resource issues. NRC rules governing HLW repositories are the result of an evolutionary process and include requirements with respect to natural resources because of concern that the presence of such resources could result in inadvertent human disturbance of the repository and subsequent compromise of waste isolation. The natural resources at a repository site and the possibility of human intrusion attracted by those resources must therefore be evaluated when assessing the projected performance of the repository. It is demonstrated, by the record, that NRC intends for all reasonable precautions to be taken to discourage people from intruding into the repository and that selection of a site with little resource value is among those precautions. Identification of a site with "no foreseeably valuable resources" would reduce or eliminate the necessity to consider intrusion. It is clear from the final rule that the Commission intends to "permit consideration of intrusion . . . where circumstances warrant" (48 Fed. Reg. 28200, 1983) but that the Commission wants to avoid control of a license review by "highly speculative intrusion scenarios" (48 Fed. Reg. 28200, 1983). This approach was designed to assure prudent consideration of real concerns while refraining from excessive deliberation on scenarios with a negligible chance of occurrence.

Natural Resource Related Regulations Included in 10 CFR Part 60

This section describes the language in pertinent portions of 10 CFR Part 60 which relates to consideration of natural resources within the regulatory environment.

The SAR [10 CFR 60.21(c)] includes a discussion of the information and evaluation which NRC expects to be a part of the license application and, specifically, section 10 CFR 60.21(c)(13) is devoted to a consideration of natural resources. NRC requests that the SAR identify and evaluate natural resources of the geologic setting including both identified and undiscovered resources.

The language requires that the SAR document three specific types of investigation as follows:

- "Undiscovered deposits of resources characteristic of the area shall be estimated by reasonable inference based on geological and geophysical evidence";
- "The estimate of net value shall take into account current development, extraction, and marketing costs"; and
- "For natural resources without current markets, but which would be marketable given credible projected changes in economic or technological factors, the

resources shall be described by physical factors such as tonnage, or other amount, grade, or quality."

This language provides guidance on the acceptable means and methods to be used by DOE to satisfy the regulations dealing with natural resources in addition to the requirements contained in the language of 10 CFR 60.122(a)(2), 60.122(c), and the PACs described in 60.122(c)(2), 60.122(c)(17), 60.122(c)(18), and 60.122(c)(19).

The section dealing with 10 CFR 60.112, the overall system performance objectives, discusses the relationship between the language in 10 CFR Part 60 dealing with natural resources and the language of the EPA standard, 40 CFR Part 191. The Commission has specifically stated that inadvertent human intrusion is an unanticipated process or event and that DOE must consider "intrusion scenarios that have a sufficiently high likelihood and potentially adverse consequence to exceed the threshold for review. The scenarios must be 'sufficiently credible to warrant consideration'(48 Fed. Reg. 28200, 1983)." It is interpreted that future inadvertent human intrusion need not be considered in assessing the undisturbed performance of the repository with the exception that DOE must consider the effects of the exploitation of groundwater in DOE compliance demonstrations. The effects of inadvertent human intrusion should be included in DOE demonstration of the containment requirements of 40 CFR 191.13.

The performances of particular barriers after permanent closure are described by NRC in the subsystem performance objectives in 10 CFR 60.113. CNWRA has identified three separate requirements in the wording of 10 CFR 60.113 as follows: (i) Engineered Barrier System (EBS) — Performance After Permanent Closure [10 CFR 60.113(a)(1)(i)], (ii) EBS — Release of Radionuclides After Permanent Closure [10 CFR 60.113(a)(1)(ii)], and (iii) Ground Water Travel Time (GWTT)[10 CFR 60.113(a)(2)]. The EBS requirements, as stated, are to be considered in the context of anticipated processes and events, thus, inadvertent human intrusion for natural resources within the site in the context of 10 CFR 60.122(c)(17), which is an unanticipated process and event, will not be considered in the context of the engineered barrier subsystem performance objectives. Since GWTT is a pre-waste-emplacement based requirement, the PAC - Human Activity and Groundwater [10 CFR 60.122(c)(2)] which considers inadvertent human intrusion due to groundwater withdrawal outside the controlled area is plausible. Thus, the current or pre-waste-emplacement future exploitation of groundwater resources will have to be analyzed for effect upon the subsystem performance objective because the withdrawal of groundwater can impact GWTT, in particular.

A regulatory requirement dealing with Favorable Conditions is contained in the language of 10 CFR 60.122(a)(1) and 60.122(b). This language requires DOE to show that the geologic setting exhibits an appropriate combination of the favorable conditions so as to provide reasonable assurance that the performance objectives related to the isolation of the waste will be met. None of the listed favorable conditions can be directly identified as natural resource related. However, the Commission in 10 CFR 60.122(b) does identify as a favorable condition "a low population density within the geologic setting and a controlled area that is removed from population centers." Elsewhere the Commission has stated:

> "As to probability, it is difficult to relate the likelihood of releases to population factors; it is the view of the Commission that it is more realistic, as originally stated, to reduce the probability by avoiding sites with significant resource potential and by using records and monuments to caution future generations (48 Fed. Reg. 28198, 1983)."

CNWRA has identified each of the 24 PAC as a regulatory requirement which must be demonstrated to be complied with by DOE. NRC is considering revising the language of the regulation to cause combinations of adverse conditions to be weighed against combinations of favorable and other site conditions in the performance assessment of the proposed repository. The following four PAC have been identified as being directly related to a consideration of natural resources at a proposed repository site:

- (2) — Human Activity and Groundwater [10 CFR 60.122(c)(2)]
- (17) — Presence of Naturally Occurring Materials [10 CFR 60.122(c)(17)]
- (18) — Evidence of Subsurface Mining [10 CFR 60.122(c)(18)]
- (19) — Evidence of Drilling [10 CFR 60.122(c)(19)]

The regulatory text which is common to and makes up the bulk of the regulatory language of each PAC is found in 10 CFR 60.122(a)(2), 10 CFR 60.122(b), and 10 CFR 60.122(c).

The wording of the regulation in 10 CFR 60.122(a)(2) specifies that "If any of the PAC specified in paragraph (c) of this sections is present...." This language directs immediate attention to paragraph 10 CFR 60.122(c) "Potentially adverse conditions" which provides direction on the means to determine if a PAC is present. The two criteria presented for determining presence are: (i) PAC are deemed present if they are characteristic of the controlled area, and (ii) PAC are deemed present if they may affect isolation within the controlled area. If a condition satisfies either of the tests of "presence" then the remainder of 10 CFR 60.122(a)(2) must be satisfied. DOE must determine if a PAC: "...may compromise the ability of the geologic repository to meet the performance objectives relating to the isolation of the waste."

In order to show that a PAC <u>does not</u> compromise the integrity of the geologic repository DOE must demonstrate that the PAC:

- Is adequately investigated [10 CFR 60.122(a)(2)(i)], and

- Is adequately evaluated [10 CFR 60.122(a)(2)(ii)], and

<u>Either</u>

- Does not affect significantly the performance objectives relating to isolation of the waste [10 CFR 60.122(a)(2)(iii)(A)], or

- Causes an effect which is compensated by the presence of a combination of the favorable characteristics so that the performance objectives relating to the isolation of the waste are met [10 CFR 60.122(a)(2)(B) and 10 CFR 60.122(b)], or

- Can be remedied [10 CFR 60.122(a)(2)(iii)(C)].

CNWRA has identified eighteen (18) potential uncertainties common to each of the PAC found in 10 CFR 60.122(a)(2), 10 CFR 60.122(b), 10 CFR 60.122(c), and 10 CFR 60.122(c)(1) through 10 CFR 60.122(c)(24) (CNWRA, 1990a). In addition, the term "evidence of" found in PAC 10 CFR 60.122(c)(18) and 10 CFR 60.122(c)(19) was identified as potentially uncertain by CNWRA. The topics of potential uncertainties recommended for resolution by an NRC Task Team (NRC, 1991) are the following:

- "Geologic setting"
- "Taking into account the degree of resolution"
- "Not to affect significantly"
- "Adequately evaluated"
- "Not likely to underestimate the effect"
- "Adequately investigated"
- "Treatment of combinations of PAC"

GEOLOGIC BASES FOR THE CONSIDERATION OF NATURAL RESOURCES

This section details the geologic environment of the Great Basin, the Yucca Mountain region and the Yucca Mountain proposed geologic repository site. The stratigraphic and structural history of the Great Basin physiographic province is presented, with special reference to Yucca Mountain and vicinity. Mineral, petroleum, geothermal and groundwater resources of Nevada are considered, and current genetic models are discussed. Deposits which are believed unlikely to occur in a Great Basin-type setting and low unit-value industrial materials are not considered in the discussion. The Yucca Mountain environment is compared with these models. Based on such comparisons, favorable indications are needed at a number of logical steps before any exploration program would be likely to affect the proposed repository.

CONSIDERATION OF COMPLIANCE METHODOLOGIES TO SATISFY THE POTENTIALLY ADVERSE CONDITIONS RELATED TO NATURAL RESOURCES

The PAC — Presence of Naturally Occurring Materials [10 CFR 60.122(c)(17)] is discussed in detail. Methods to define the term "geologic setting" are presented. The size of the geologic setting is shown to be considered as "hundreds of square miles" (NRC, 1983, p.187). The geologic setting as a region is discussed with options presented for defining the boundaries of the region to be included within the geologic setting. DOE must logically and technically defend its selection of the attributes and region of the geologic setting in its License Application (LA). A discussion of the wording of the PAC — Presence of Naturally Occurring Materials includes in-depth treatment of various options which DOE might use to satisfy the requirements contained in 10 CFR 60.122(c)(17). PAC — Human Activity and Groundwater [10 CFR 60.122(c)(2)], PAC — Evidence of Subsurface Mining [10 CFR 60.122(c)(18)], and PAC — Evidence of Drilling [10 CFR 60.122(c)(19)] are each discussed regarding compliance methods.

CONCLUSIONS

The PAC - Human Activity and Groundwater [10 CFR 60.122(c)(2)] considers the evaluation of current and/or future effects of humans on the groundwater system. Currently, the concern related to natural resources is the withdrawal of groundwater. The effects of groundwater withdrawal (water is the only natural resource currently produced at the site) on the ability of the repository to meet the performance objectives, both currently and in the future, must be investigated and evaluated. This investigation should include any effects of current or planned (i.e., likely to occur within the pre-waste-emplacement timeframe) groundwater withdrawal on the GWTT subsystem performance objective (10 CFR 60.133(a)(2)] as well as the overall system performance objective (10 CFR 60.112).

The regulation contains language which describes eight considerations which must be a part of a DOE demonstration of compliance with the PAC — Presence of Naturally Occurring Materials [10 CFR

60.122(c)(17)]. Each of these considerations is tied into the economics of a natural resource at the proposed repository site. The Commission has stated that it is interested in natural resources because of the inadvertent human intrusion that the actual or perceived presence of natural resources might cause in the future of the repository. The current regulation effectively tells DOE what to include in their investigation and evaluation of natural resources. The language of the regulation does not directly state that the prime consideration of the Commission is the plausible effect of the presence or perception of presence of natural resources on future inadvertent human intrusion and the subsequent effect of such intrusion on the isolation of the waste (i.e., the overall and subsystem performance objectives).

The conclusion includes a discussion of an "explorationist" or "prospector's" approach to investigating and evaluating the natural resource potential of Yucca Mountain. The explorationist approach is the likely way the site would be investigated in the future after institutional controls have ceased to function. A reasonable explanation of the intent of the Commission in the framing of the PAC — Presence of Naturally Occurring Materials is that DOE should determine the potential for inadvertent human intrusion resulting from exploration for or exploitation of inferred or discovered naturally occurring materials which are currently resources or which may become resources due to credible projected changes in economic or technologic factors. The effects of plausible inadvertent human intrusion for natural resources upon the performance objectives of the geologic repository should be investigated and evaluated.

This explanation of CNWRA interpretation of NRC intent provides DOE with an explicit tie between naturally occurring materials and inadvertent human intrusion. The restated intent of 10 CFR 60.122(c)(17) guides DOE to determine the means to resolve the investigations/evaluations required to satisfy the regulation while placing no undue constraints upon DOE in the form of prescriptive methods or required analyses.

The two PACs dealing with Evidence of Subsurface Mining [10 CFR 60.122(c)(18)] and Evidence of Drilling [10 CFR 60.122(c)(19)] each can be handled relatively simply by DOE. DOE is required to determine if either condition exists at the site and then ascertain if such evidence of either drilling or subsurface mining for resources indicates whether the performance objectives are currently or will, in the future, be compromised because of the past mining or drilling. Additionally, the presence of recognizable drilling or mining, either pre-repository or repository-related, may enhance the perception of future explorationists that the site is desirable for prospecting resulting in an increased risk of inadvertent human intrusion which, if deemed plausible, should be factored into DOE's performance assessment.

1 INTRODUCTION

There is a long and continuing interest in the possibility of inadvertent human intrusion into a geologic repository designed to contain high-level radioactive wastes (HLW). United States Nuclear Regulatory Commission (NRC or Commission) has expressed an interest in lessening the chances of inadvertent human intrusion at a repository site by avoiding areas which have known or perceived quantities of natural resources which might prove attractive to future explorationists.

The problem of inadvertent human intrusion into a geologic repository is a recognized dilemma for each of the nations of the world which are planning to dispose of HLW in a mined geologic repository. The Nuclear Energy Agency Organization for Economic Co-operation and Development in a document entitled "Disposal of Radioactive Waste: Can Long-term Safety be Evaluated?" has identified the assessment of human intrusion through scenario development as one of the important aspects of determining the relative safety of a given repository (Nuclear Energy Agency, Organization for Economic Co-operation and Development, 1991). Governor Bob Miller, of Nevada, has identified the potential for future human intrusion of the proposed Yucca Mountain, Nevada repository site to acquire natural resources as one of the factors which he considers "should cause the site to be disqualified from further consideration" (Miller, 1989). Malone (1990) points out that there is a "dearth of information with respect to mineral deposits at Yucca Mountain." Malone (1990) goes on to point out that:

> "In view of the importance of preventing long-term future human intrusion into a nuclear waste repository (Human Interference Task Force and Gillis, 1985), intensive study at Yucca Mountain is needed on structural trends, geochronology of mineral emplacements, and geophysical characteristics of mineralized areas...
>
> ...Further exploration and study is needed to evaluate the probability of future human intrusion into a nuclear waste repository at Yucca Mountain as a result of extraction of naturally occurring resources (Malone, 1990)."

Robert M. Bernero, Director, Office of Nuclear Material Safety and Safeguards (NMSS) commented in the "NRC Staff Characterization Analysis of the Department of Energy's Site Characterization Plan [SCP], Yucca Mountain Site, Nevada" that:

> "There is a concern that the program of investigations for natural resources assessment [in the SCP] is too limited in view of recent publications, models, and discoveries suggesting the presence of mineral and/or hydrocarbon resources in the region near Yucca Mountain" (NRC, 1989).

Recognizing the importance of the consideration of natural resources at a proposed geologic repository site, the Commission has included language in 10 CFR Part 60 in the discussion of Potentially Adverse Conditions (PAC) in section 60.122(c)(1 through 24) which deals specifically with natural resources. Additionally, NRC has included a description of natural resource related items to be presented in Department of Energy (DOE) Safety Analysis Report (SAR) which will be submitted to NRC in accordance with 10 CFR 60.21(c)(13).

Because the PACs are to be evaluated by comparing the effects of the conditions to the performance objectives, any discussion of natural resources should include a discussion of the applicable sections of

10 CFR 60.112 — the overall system performance objectives, 10 CFR 60.113 — the subsystem performance objectives, and 40 CFR Part 191, the Environmental Protection Agency (EPA) standard. Additionally, the effects of a PAC can be offset by an appropriate combination of the favorable conditions identified in 10 CFR 60.122(b). Lastly, the effects of a PAC may be remedied by engineering measures employed by DOE.

This document accomplishes the following:

- Documents an investigation of the regulatory background of NRC regulations dealing with natural resources;

- Provides definition and clarification of ambiguous or unclear terms;

- Provides a discussion of the geologic bases for consideration of natural resources in the regional environment and particularly in the vicinity of Yucca Mountain, Nevada;

- Details the implicit and explicit regulatory requirements and discusses means to accomplish compliance with the regulations pertaining to natural resources; and

- Summarizes the natural resource-related requirements of 10 CFR Part 60 and presents a discussion relative to NRC intent.

The purpose of this report is to provide NRC staff with an information base useful for documenting, formulating, and implementing a regulatory strategy, including a means of providing guidance on the intent of NRC regulations to DOE. Approaches or methods for DOE demonstration of compliance with the natural resource regulations contained in 10 CFR Part 60 are identified. It is probable that this document will be used as a forum for debate within NRC to establish working methods for future consideration of natural resources related and other regulations.

2 REGULATORY BASES FOR ASSESSMENT OF NATURAL RESOURCES

2.1 STATUTORY BASES FOR CONSIDERING NATURAL RESOURCES

The responsibilities of the NRC to oversee the licensing of a geologic repository to contain HLW are founded in five sections of Federal statutes, as follows: (1) 42 USC 2232 — Atomic Energy Act of 1954, (2) 42 USC 2233 — Atomic Energy Act of 1954, (3) 42 USC 5842 — Energy Reorganization Act of 1974, (4) 42 USC 10132 — Nuclear Waste Policy Act (NWPA) of 1982, and (5) 42 USC 10141 — NWPA of 1982. The applicable wording and its importance to the consideration of natural resources are presented below.

2.1.1 Atomic Energy Act of 1954

The statutory language from the Atomic Energy Act of 1954, Section 182 (42 USC 2232) states that:

> "Each application for license. . .shall specifically state such information as the Commission, by rule or regulation, may determine to be necessary. . ."

This language applies to the rules and regulations formulated by NRC to govern the disposal of HLW in a geologic repository. The language requires that the applicant include within its license application (LA) all the information which the Commission requests and requires to fulfill its statutory responsibilities. The applicable regulation to the disposal of HLW in a geologic repository is 10 CFR Part 60.

The Atomic Energy Act of 1954, Section 183 (42 USC 2233) further states that:

> "Each license shall be in such form and contain such terms and conditions as the Commission may, by rule or regulation, prescribe to effectuate the provisions of this Act:. . ."

This language also applies to the rules and regulations formulated by NRC to govern the disposal of HLW in a geologic repository. The language requires that the applicant presents an application in proper form and containing responses to Commission prescribed rules or regulations, in this case, 10 CFR Part 60.

2.1.2 Energy Reorganization Act of 1974

The licensing and regulatory responsibilities of NRC regarding HLW storage were specified in Section 202 of the Energy Reorganization Act of 1974 (42 USC 5842):

> ". . .NRC shall. . . have licensing and related regulatory authority pursuant to chapters 6,7,8, and 10 of the Atomic Energy Act of 1954, as amended, as to the following facilities of the Administration:. . .

(3) Facilities used primarily for the receipt and storage of HLWs resulting from activities licensed under such Act.

(4) Retrievable surface storage facilities and other facilities authorized for the express purpose of subsequent long-term storage of HLW generated by the Administration, which are not used for, or are part of, research and development activities."

This language specifically assigns NRC the responsibility of regulating the disposal of HLW in the "long-term." The language specifically provides the Commission with appropriate licensing and regulatory authority for the disposal of HLW in the "long-term" and gives the Commission jurisdiction over the facilities used for receipt and storage of HLWs licensed under the Energy Reorganization Act of 1974.

2.1.3 Nuclear Waste Policy Act of 1982

The NWPA of 1982 [42 U. S. C. 10101 et seq., Public Law 97-425 (Jan. 7, 1983)] amplified the existing statutory authority and specifically provided for criteria to be promulgated by DOE for site selection and NRC for site approval and the licensing of geologic HLW repositories. The proposed approval, which NRC issued prior to passage of the NWPA, was under the authority of the Atomic Energy Act of 1954 and the Energy Reorganization Act of 1974. The NWPA established a consolidated HLW management framework requiring DOE to establish and utilize site selection guidelines after consultation with a specified list of interested agencies and parties, and the concurrence of NRC. Specific statutory language in the NWPA of 1982 (42 USC 10132):

"Part A — Repositories for Disposal of HLWs and Spent Nuclear Fuels 10132. Recommendation of candidate sites for characterization

(a) Guidelines. . .

. . .the Secretary [of Energy], following consultation with the Council on Environmental Quality, the Administrator of the Environmental Protection Agency, the Director of the Geological Survey, and interested Governors, and the concurrence of the Commission [NRC] shall issue general guidelines for the recommendation of sites for repositories. Such guidelines shall be primary criteria for the selection of sites in various geologic media. Such guidelines shall specify factors that qualify or disqualify any site from development as a repository, including <u>factors pertaining to the location of valuable natural resources</u>, hydrology, geophysics, seismic activity, and atomic energy defense activities, <u>proximity to water supplies</u>, proximity to populations, effect upon the rights of users of water, and proximity to components of the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, or National Forest Lands." [emphasis added]

This statute does not specify whether the interest in natural resources was due to concern about human intrusion of a repository as a result of the presence of attractive resources or whether the government did not wish to interfere with use of natural resources by placing a repository nearby. The legislative history merely states that "The Secretary is required to specify in the guidelines factors which would qualify or disqualify a site from development as a repository, including proximity to natural resources or populations, hydrogeophysics, seismic activity and nuclear defense activities." (House Comm. on Interior and Insular Affairs, H. Rep. No. 97-491, Part 1, reprinted in 1982 U.S. Code Cong. and Admin. News 3792, 3816). This language was provided by the legislature to the Secretary of Energy in order to guide the DOE recommendation of candidate sites for characterization. The specific language of the statute illustrates the concern of the legislators with the environment, particularly the natural resources including minerals, water, and aesthetic/ecologic concerns. Congress specifically directed DOE to establish qualifying and disqualifying conditions dealing with natural resources, water, and areas of national environmental interest. By inference, the Commission is, as the license grantor, to be considerate of the same conditions in their evaluation of the DOE LA.

Additional language in the NWPA of 1982, 42 USC 10141 specifically addressed NRC:

> "(b)(1)(A) . . .the commission, pursuant to authority under other provisions of law, shall, by rule, promulgate technical requirements and criteria that it will apply, under the Atomic Energy Act. . .and the Energy Reorganization Act. . .in approving or disapproving. . .
>
> (B) Such criteria shall provide for the use of a system of multiple barriers in the design of the repository
>
> (C) Such requirements and criteria shall not be inconsistent with any comparable sections promulgated by the Administrator under subsection (a)."

This language from the NWPA of 1982 specifically amplified the authority of the Commission to promulgate technical requirements and criteria for the licensing of a geologic repository for HLW. Previously discussed existing statutory authority is referred to in the language of 42 USC 10141. Credence is given to the philosophy of multiple barriers at a geologic repository with the wording of (B). The presence of natural resources is of regulatory interest in the context of the performance of the geologic component of this multiple-barrier disposal system.

2.1.4 Nuclear Waste Policy Act as Amended

In 1987, the NWPA was amended by Congress to narrow site characterization activities to the Yucca Mountain, Nevada proposed geologic repository site. No substantive changes were made relative to natural resources assessment.

2.2 NATURAL RESOURCES AND LICENSING OF A HLW REPOSITORY: A REGULATORY HISTORY

This section details the regulatory history and the documented intent associated with the development of NRC regulations governing HLW repositories with respect to natural resource issues. NRC is concerned that the presence or potential occurrence of natural resources might result in disturbance of a repository, and that such disturbance might affect waste isolation. Therefore, it is necessary to consider such disturbances in assessing the performance of a repository. This concern with possible human intrusion resulting from the presence of natural resources became clear early in the development of the regulations and continues to be of importance today. The following discussion presents specific references to the identification and evaluation of natural resources in the rules as promulgated and prior to adoption throughout the rulemaking process.

2.2.1 Proposed Licensing Procedures

In November, 1978, NRC published a proposed General Statement of Policy outlining procedures for licensing geologic HLW repositories. This General Statement was followed by a proposed rule [44 Fed. Reg. 70408 (1979)] which contained the procedural requirements for licensing. The technical criteria for the LA, however, were still under development and this document [44 Fed. Reg. 70408 (1979)] contains no mention of natural resources or human intrusion. There is only a general statement in section 60.21(c)(1) that "the assessment shall contain an analysis of the geology, hydrology, geochemistry . . . of the site. . ." and a requirement in section 60.21(c)(8) that the application describe "controls that the applicant will apply to restrict access. . ." [44 Fed. Reg. 70417 (1979)].

2.2.2 First Public Draft of Technical Criteria

In the first public draft of 10 CFR Part 60 technical criteria {the advance notice of proposed rulemaking [45 Fed. Reg. 31393 (1980)]}, portions of section 60.122 emphasized the importance of assessing the natural resources of any site under consideration for a HLW repository [45 Fed. Reg. 31401 (1980)]:

"§60.122 Siting requirements

(a) General requirements. . .

(a)(8) The Department shall perform a resource assessment for the region within 100 km of the site using available information. The Department shall include estimates of both the known and undiscovered deposits of all resources that

(i) have been or are being exploited or

(ii) have not been exploited but are exploitable under present technology and market conditions. The Department shall estimate undiscovered deposits by reasonable inference based on geologic and geophysical information. The Department shall estimate both gross and net value of resource deposits. The estimate of net value shall take into account development, extraction, and marketing costs."

It is clear from the discussion in the preamble to this advance notice of proposed rulemaking that the significance of natural resources with respect to a HLW repository derived from concerns regarding possible human intrusion [45 Fed. Reg. 31395 (1980)]:

". . .since engineering against human intrusion is impossible practically, [it is important] to avoid targets, i.e., sites, which may invite such intrusion. Mineral resources, water resources, interesting geologic or hydrologic features are sure to attract the developer or explorer. Shallow repositories would more easily be intruded upon than deep ones. Therefore, what is needed are site suitability criteria which would lead toward uninteresting sites of little resource value. . ."

This interest in possible human activity also was reflected in section 60.122's enunciation of conditions that, because of their potential adverse effects on waste isolation, would require further analysis:

"(b) Potentially adverse conditions. . .

(b)(1) Potentially adverse human activities

(b)(1)(i) There is or has been conventional for *in situ* subsurface mining for resources. . .

(b)(1)(iii) There are resources which are economically exploitable using existing technology under present market conditions.

(b)(1)(iv) Based on a resource assessment, there are resources that have either higher gross or net value than the average for other areas of similar size in the region in which the geologic repository is located. . .

(b)(1)(vii) There is indication that present or reasonably anticipatable human activities can significantly affect the hydrogeologic framework. Human activities include ground water withdrawals, extensive irrigation, subsurface injection of fluids, underground pumped storage facilities, or underground military activities."

It is important to note that draft 60.122(b)(1)(vii) was directed toward changes in "the hydrogeologic framework" which could result from a variety of human activities. In addition to the activities listed, activities related to natural resource extraction could also change "the hydrogeologic framework."

This document [45 Fed. Reg. 31393 (1980)] raised the possibility that the waste itself could be considered a resource which might prove attractive to potential intruders: an "intruder may know of the location and contents of the repository itself and may regard the HLW as a resource of some value." The uncertainty of how to regard such an intrusion is apparent in the questions posed in the preamble to the advanced notice of proposed rulemaking [45 Fed. Reg. 31398 (1980)]:

"How should such an intrusion be regarded as an event to be considered in the design of the repository? That is, should attempts be made to protect future generations from the deliberate intruder? To the general population? In the latter instance, where the event is one of inadvertent (accidental) intrusion other questions occur. Did the intrusion occur beyond the time that it is reasonable to expect the knowledge of the existence of the repository to be known? What is a reasonable period of time? What steps in repository design and enforcement can be taken to mitigate the consequences of an accidental intrusion? Is one kind of intrusion more likely than the other? Are the consequences of inadvertent intrusions different from those for deliberate intrusion?"

This section concludes that the "human intrusion issue. . . is far from being resolved." The subsequent proposed and final rule, as well as responses to related public comments further addressed this issue, are discussed in the following sections.

2.2.3 Final Procedural Rule

A final rule outlining the procedural requirements for licensing a HLW repository was published in 1981 [46 Fed. Reg. 13971 (1981)] and established an explicit requirement for an accounting of natural resources at a proposed site:

> "§60.21 Content of application...
>
> (c) The Safety Analysis Report shall include:
>
> (c)(13) An identification of the natural resources at the site, the exploitation of which could affect the ability of the site to isolate radioactive wastes." [emphasis added]

Thus, the procedural rule specifically required identification of natural resources and an assessment of the potential impacts of exploration. However, no definition of the word "site" was provided in this rule.

2.2.4 Proposed Technical Criteria

In 1981, NRC published proposed amendments [46 Fed. Reg. 35280 (1981)] to 10 CFR Part 60. This action proposed adding technical criteria to the existing rule and took into account the draft technical criteria presented in the 1980 advanced notice of proposed rulemaking and the comments received on that document. The introduction to this proposal includes extensive comments on the possibility of human intrusion into a repository [46 Fed. Reg. 35282 (1981)]:

> "Human Intrusion
>
> Some concern has been raised on the issue of human intrusion into a geologic repository. Human intrusion could conceivably occur either inadvertently or deliberately. Inadvertent intrusion is the accidental breaching of the repository in the course of some activity unrelated to the existence of the repository, e.g., exploration for or development of resources. For inadvertent intrusion to occur, the institutional controls, site markers, public records, and societal memory of the repository's existence must have been ineffective or have ceased to exist. Deliberate or intentional intrusion, on the other hand, assumes a conscious decision to breach the repository; for example, in order to recover the HLW itself, or exploit a mineral associated with the site.
>
> Historical evidence indicates that there is substantial continuity of information transfer over time. There are numerous examples of knowledge, including complex information, being preserved for thousands of years. This has occurred even in the absence of printing and modern information transfer and storage systems.

Furthermore, this information transfer has survived disruptive events, such as wars, natural disasters, and dramatic changes in the social and political fabric of societies. The combination of the historical record of information transfer, provisions for a well-marked and extensively documented site location, and the scale and technology of the operation needed to drill deeply enough to penetrate a geologic repository argue strongly that inadvertent intrusion as described above is highly improbable, at least for the first several hundred years during which time the wastes are most hazardous. Selecting a site for a repository which is unattractive with respect to both resource value and scientific interest further adds to the improbability of inadvertent human intrusion. It is also logical to assume that any future generation possessing the technical capability to locate and explore for resources at the depth of a repository would also possess the capability to assess the nature of the material discovered, to mitigate consequences of the breach and to reestablish administrative control over the area if needed. Finally, it is inconsistent to assume the scientific and technical capability to identify and explore an anomalous heat source several hundred meters beneath the Earth's surface and not assume that those exploring would have some idea of either what might be the cause of the anomaly or what steps to take to mitigate any untoward consequence of that exploration.

The above arguments do not apply to the case of deliberate intrusion. The repository itself could be attractive and invite intrusion simply because of the resource potential of the wastes themselves. Intrusion to recover the wastes demands (1) knowledge of the existence and nature of the repository, and (2) effort of the same magnitude as that undertaken to emplace the wastes. Hence intrusion of this sort can only be the result of a conscious, collective societal decision to recover the wastes.

Intrusion for the purpose of sabotage or terrorism has also been mentioned as a possibility. However, due to the nature of geologic disposal, there seems to be very little possibility that terrorists or saboteurs could breach a repository. Breach of the repository would require extensive use of machinery for drilling and excavating over a considerable period of time. It is highly improbable that a terrorist group could accomplish this covertly.

In light of the above, the Commission adopted the position that common sense dictates that everything that is reasonable be done to discourage people from intruding into the repository. Thus, the proposed technical criteria are written to direct site selection towards selection of sites of little resource value and for which there does not appear to be any attraction for future societies. Further, the proposed criteria would require reliable documentation of the existence and location of the repository and the nature of the wastes emplaced therein, including marking the site with the most permanent markers practical. However, once the site is selected, marked, and documented, it does no use to argue over whether these measures will be adequate in the future, or to speculate on the virtual infinity of human intrusion scenarios and whether they will or will not result in violation of the Environmental Protection Agency (EPA) standard. Of course, the Commission recognizes that there are alternative approaches to the Human Intrusion question. Accordingly, comment on this and alternative approaches is welcome."

The intent of this preamble, as stated in the Final rulemaking, was that all reasonable precautions should be taken to discourage people from intruding into the repository [48 Fed. Reg. 28199 (1983)]. Among these precautions is directing site selection toward areas with little resource value. This discussion, coupled with the land control, documentation, and the marking requirements suggest that inadvertent intrusion is improbable (especially during the first few hundred years) because of the continuity of information transfer over time. It was observed that any future persons capable of locating resources at repository depths would probably also be capable of recognizing HLW and of mitigating any hazard. Deliberate intrusion is recognized as a possibility to access the HLW itself as a resource, to exploit some associated resource value. With respect to deliberate intrusion to recover the waste itself as a resource, the Commission concluded that it is appropriate to leave the decision of possible release of radioactivity up to those undertaking the resource recovery operation. This discussion concludes that it is sensible to select a site which has little resource value and which would have little interest for future generations; however, speculation "on the virtual infinity of human intrusion scenarios" would serve no use [48 Fed. Reg. 28199 (1983)].

The preamble also relates the absence of any population-related siting requirements in the proposed rule to consideration of natural resources:

> "The Commission has not included any siting requirements which directly deal with population density or proximity to population centers. Rather, the issue has been addressed indirectly through consideration of resources in the geologic setting. The Commission believes this to be a more realistic approach given the long period of time involved with geologic disposal."

A portion of the licensing procedures section 60.21 [promulgated at 46 Fed. Reg. 13971 (1981)] would be expanded by this proposal [46 Fed. Reg. 35280 (1981)] to read:

> "§60.21 Content of application. . .
>
> (c) The Safety Analysis Report shall include. . .
>
> (13) An identification and evaluation of the natural resources at the site, including estimates as to undiscovered deposits, the exploitation of which could affect the ability of the site to isolate radioactive wastes. Undiscovered deposits of resources characteristic of the area shall be estimated by reasonable inference based on geological and geophysical evidence. This evaluation of resources, including undiscovered deposits, shall be conducted for the disturbed zone and for areas of similar size that are representative of and are within the geologic setting. For natural resources with current markets the resources shall be assessed, with estimates provided of both gross and net value. The estimate of net value shall take into account current development, extraction and marketing costs. For natural resources without current markets, but which would be marketable given credible projected changes in economic or technological factors, the resources shall be described by physical factors such as tonnage or other amount, grade, and quality." [emphasis added]

For the first time, the extent of the natural resource assessment required for licensing was presented in some detail. Also, the concept of comparing resources of areas outside the "disturbed zone" but representative of and within the geologic setting to the resource of the "disturbed zone" was introduced. In this version of 60.21(c)(13), the words "site" and "geologic setting" have the same meaning [46 Fed. Reg. 35286 (1981)]:

"§60.2 Definitions:

Geolögic setting or site is the spatially distributed geologic, hydrologic, and geochemical systems that provide isolation of the radioactive waste. . .

Site means the geologic setting."

In Subpart E — Technical Criteria of this proposal [46 Fed. Reg. 35280 (1981)], section 60.122 was a listing of "Favorable conditions" and sections 60.123 and 60.124 were created for "Potentially adverse conditions (PAC)" and "Assessment of potentially adverse conditions" respectively. The provisions require certain assessments to be made with respect to the impact of natural resources upon waste isolation. However, these proposed rules also indicate that there may exist offsetting conditions such that an "adverse condition" is adequately mitigated or can be "remedied."

"§60.123 Potentially adverse conditions. . .

(a) Adverse conditions in the geologic setting. . .

(3) Potential for human activity to affect significantly the geologic repository through changes in the hydrogeology. This activity includes, but is not limited to planned groundwater withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage facilities, or underground military activity. . .

(b) Adverse conditions in the disturbed zone. For the purpose of determining the presence of the following conditions within the disturbed zone, investigations should extend to the greater of either its calculated extent or a horizontal distance of 2 km from the limits of the underground facility, and from the surface to a depth of 500 meters below the limits of the repository excavation.

(1) Evidence of subsurface mining for resources.

(2) Evidence of drilling for any purpose.

(3) 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. . ."

§60.124 Assessment of potentially adverse conditions.

"In order to show that a potentially adverse condition or combination of conditions cited in §60.123 does not impair significantly the ability of the geologic repository to isolate the radioactive waste, the following must be demonstrated:

(a) The potentially adverse human activity or natural condition has been adequately characterized, including the extent to which the condition may be present and still be undetected taking into account the degree of resolution achieved by the investigations; and

(b) The effect of the potentially adverse human activity or natural condition on the geologic setting has been adequately evaluated using conservative analyses and assumptions, and the evaluation used is sensitive to the adverse human activity or natural condition; and

(c) (1) The potentially adverse human activity or natural condition is shown by analysis in paragraph (b) of this section not to affect significantly the ability of the geologic setting to isolate waste, or

(2) The effect of the potentially adverse human activity or natural condition is compensated by the presence of a combination of the favorable characteristics cited in §60.122, or

(3) The potentially adverse human activity or natural condition can be remedied."

In proposing the foregoing PAC, the Commission was not suggesting the establishment of absolute criteria for the disqualification of any specific site. Rather, as stated in the preamble, the proposal set out factors which would be considered in the evaluation [46 Fed. Reg. 35284 (1981)]:

"Thus, the Commission has judged that these should not be made absolute requirements. Presence of all the favorable characteristics does not lead to the conclusion that the site is suitable to host a repository. Neither is the presumption of unsuitability because of the presence of an unfavorable characteristic incontrovertible. Rather, the Commission's approach requires a sufficient combination of conditions at the selected site to provide reasonable assurance that the performance objectives will be achieved."

2.2.5 Final Rule

In June of 1983, NRC published a final rule, promulgating 10 CFR Part 60, including technical criteria and amended licensing procedures for a HLW repository [48 Fed. Reg. 28194 (1983)]. This final rule responds to comments on the earlier proposed technical criteria [46 Fed. Reg. 35280 (1981)]. It is noted in the preamble to this publication that, in general, the commenters accepted the proposed approach. However, some modifications were required [48 Fed. Reg. 28199 (1983)]:

"After careful consideration of the public comments received on questions relating to human intrusion, the Commission is of the view that while the passive control measures it is requiring will reduce significantly the likelihood of inadvertent intrusion into a geologic repository, occasional penetration of the geologic repository over the period of isolation cannot be ruled out, and some provision should be made in the final rule for consideration of intrusion should these measures fail. . . The rule now incorporates a definition of "unanticipated processes and events" which are reviewable in a licensing proceeding; such processes and events expressly include intrusion scenarios that have a sufficiently high likelihood and potentially adverse consequence to exceed the threshold for review. The scenarios must be "sufficiently credible to warrant consideration." . . .the Commission requires an assumption that the value to future generations of potential resources can be assessed adequately at this time. Consistent with its previously stated views, it thinks that the selection of a site with no foreseeably valuable resources could so reduce the likelihood of intrusion as to reduce, or eliminate, any further need for it to be considered. . .The definition of "unanticipated processes and events" also implicitly bounds the consequences of intrusion scenarios."

The objective of these changes was to accommodate evaluation of "events that are reasonably of concern." Furthermore, the intention was to exclude "speculative scenarios that are inherently implausible." NRC wanted to avoid consideration of "fanciful events which the Commission has an abiding conviction will never occur. . ." The Commission states that "it will grant a license if it is satisfied that the risk to the health and safety of future generations is not unreasonable" [48 Fed. Reg. 28199 (1983)]. In the final rule, the possibility that the waste itself might attract human intrusion falls under the definition of "unanticipated processes and events" and therefore would have to be reviewed during licensing only if the scenario of concern is "sufficiently credible to warrant consideration."

These changes from the proposed rule are expressed in section 60.2 as:

§60.2 Definitions. . .

"Unanticipated processes and events". . .
Unanticipated processes and events may be either natural processes or events or processes and events initiated by human activities other than those activities licensed under this part. Processes and events initiated by human activities may only be found to be sufficiently credible to warrant consideration if it is assumed that:

(1) The monuments provided for by this part are sufficiently permanent to serve their intended purpose;

(2) the value to future generations of potential resources within the site can be assessed adequately under the applicable provisions of this part;

(3) an understanding of the nature of radioactivity, and an appreciation of its hazards, have been retained in some functioning institutions;

(4) institutions are able to assess risk and to take remedial action at a level of social organization and technological competence equivalent to, or superior to, that which was applied in initiating the processes or events concerned; and

(5) relevant records are preserved, and remain accessible, for several hundred years after permanent closure.

All of the above requirements must therefore be considered in assessment of intrusion scenarios.

Revised definitions were also provided in the final rule [48 Fed. Reg. 28194 (1983)] for the words "geologic setting" and "site," and in response to specific comments a definition of a "controlled area" was added:

"§60.2 Definitions. . .

"Controlled area" means a surface location. . . extending horizontally no more than 10 kilometers in any direction from the outer boundary of the underground facility, and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be restricted following permanent closure. . .

"Geologic setting" means the geologic, hydrologic, and geochemical systems of the region in which a geologic repository operations area is or may be located. . .

"Site" means the location of the controlled area."

In the proposed rule [46 Fed. Reg. 35280 (1981)], "geologic setting" would have been limited to systems that "provide isolation" of the waste. The Commission intended the adopted definition of "geologic setting" to cover a wider "region of interest" [48 Fed. Reg. 28202 (1983)]. The final rule calls for isolation to be provided within a "controlled area" rather than within the "geologic setting" [48 Fed. Reg. 28202 (1983)]. Therefore, the definition of "site" was changed to refer to the location of the "controlled area."

Section 60.21(c)(13) was issued in this document [48 Fed. Reg. 28194 (1983)] with two changes from the proposed rule [46 Fed. Reg. 35280 (1981)]. In sentence 1, "at the site" was altered to "of the geologic setting" and in sentence 3, "disturbed zone" was replaced by "site." These changes were made to reflect the revised definitions; no change in philosophy was intended [48 Fed. Reg. 28201 (1983)]:

"§60.21 Content of application. . .

(c) Safety Analysis Report shall include. . .

(c)(13) An identification and evaluation of the natural resources <u>of the geologic setting</u>, including estimates as to undiscovered deposits, the exploitation of which could affect the ability of the geologic repository to isolate radioactive wastes. Undiscovered deposits of resources characteristic of the area shall be estimated by reasonable inference based on geological and geophysical evidence. This evaluation of resources, including undiscovered deposits, shall be conducted for the <u>site</u> and for areas of similar size that are representative of and are within the geologic setting. For natural resources with current markets the resources shall be assessed, with estimates provided of both gross and net value. The estimate of net value shall take into account current development, extraction and marketing costs. For natural resources without current markets, but which would be marketable given credible projected changes in economic or technological factors, the resources shall be described by physical factors such as tonnage or other amount, grade, and quality." [emphasis added]

The Commission stated in the preamble to the final rule that changes to the proposed rule regarding Siting Criteria were made in order to clarify the Commission's purpose [48 Fed. Reg. 28201 (1983)]. The concepts of favorable and adverse conditions were retained; it was emphasized that there may exist a combination of adverse and favorable conditions which would be acceptable for a repository site. Significantly, as addressed above, changes were made to reflect the updated definitions of "geologic setting," "site," and "disturbed zone." In addition to merging sections 60.122, 60.123, and 60.124 into section 60.122, the final rule changed the siting criteria so that "the presence of any of the enumerated conditions is to be regarded as potentially adverse if it applies to the controlled area and, in addition, such a condition outside the controlled area is to be regarded as potentially adverse if it may affect isolation within the controlled area." Portions of the rule relevant to this discussion include:

"§60.122 Siting Criteria. . .

(a)(2) If any of the potentially adverse conditions specified in paragraph (c) of this section is present, it may compromise the ability of the geologic repository to meet the performance objectives relating to isolation of the waste. In order to show that a potentially adverse condition does not so compromise the performance of the geologic repository the following must be demonstrated:

(a)(2)(i) The potentially adverse human activity or natural condition has been adequately investigated, including the extent to which the condition may be present and still be undetected taking into account the degree of resolution achieved by the investigations; and

(a)(2)(ii) The effect of the potentially adverse human activity or natural condition on the site has been adequately evaluated using analyses which are sensitive to the potentially adverse human activity or natural condition and assumptions which are not likely to underestimate its effect; and

(a)(2)(iii)(A) The potentially adverse human activity or natural condition is shown by analysis pursuant to paragraph (a)(2)(ii) of this section not to affect significantly the ability of the geologic repository to meet the performance objectives relating to isolation of the waste, or

(a)(2)(iii)(B) The effect of the potentially adverse human activity or natural condition is compensated by the presence of a combination of the favorable characteristics so that the performance objectives relating to isolation of the waste are met, or

(a)(2)(iii)(C) The potentially adverse human activity or natural condition can be remedied.

(b) Favorable conditions

(b)(1) The nature and rates of tectonic, hydrogeologic, geochemical, and geomorphic processes (or any of such processes) operating within the geologic setting during the Quaternary Period, when projected, would not affect or would favorably affect the ability of the geologic repository to isolate the waste.

(b)(2) For disposal in the saturated zone, hydrogeologic conditions that provide—

(b)(2)(i) A host rock with low horizontal and vertical permeability;

(b)(2)(ii) Downward or dominantly horizontal hydraulic gradient in the host rock and immediately surrounding hydrogeologic units; and

(b)(2)(iii) Low vertical permeability and low hydraulic potential between the host rock and surrounding hydrogeologic units; or

(b)(2)(iv) Pre-waste-emplacement groundwater travel time (GWTT) along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment that substantially exceeds 1,000 years.

(b)(3) Geochemical conditions that—

(b)(3)(i) Promote precipitation or sorption of radionuclides;

(b)(3)(ii) Inhibit the formation of particulates, colloids, and inorganic and organic complexes that increase the mobility of radionuclides; or

(b)(3)(iii) Inhibit the transport of radionuclides by particulates, colloids, and complexes.

(b)(4) Mineral assemblages that, when subjected to anticipated thermal loading, will remain unaltered or alter to mineral assemblages having equal or increased capacity to inhibit radionuclide migration.

(b)(5) Conditions that permit the emplacement of waste at a minimum depth of 300 meters from the ground surface. (The ground surface shall be deemed to be the elevation of the lowest point on the surface above the disturbed zone.)

(b)(6) A low population density within the geologic setting and a controlled area that is remote from population centers.

(c) Potentially adverse conditions. The following conditions are potentially adverse conditions if they are characteristic of the controlled area or may affect isolation within the controlled area. . .

(c)(2) Potential for foreseeable human activity to adversely affect the groundwater flow system, such as groundwater withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activity or construction of large scale surface water impoundments. . .

(c)(17) The presence of naturally occurring materials, whether identified or undiscovered, within the site, in such form that:

(c)(17)(i) Economic extraction is currently feasible or potentially feasible during the foreseeable future; or

(c)(17)(ii) Such materials have greater gross value or net value than the average for other areas of similar size that are representative of and located within the geologic setting.

(c)(18) Evidence of subsurface mining for resources within the site.

(c)(19) Evidence of drilling for any purpose within the site. . ."

The final version of these provisions reconciled the references to resources in section 60.122 to the requirements for the content of the Safety Analysis Report (SAR) (60.21). The rule, as adopted, provides that section 60.122 applies to the site, rather than the disturbed zone "since it is the site that provides isolation of the waste" [48 Fed. Reg. 28212 (1983)].

2.2.6 Staff Analysis of Public Comments on Proposed Rule 10 CFR Part 60, NUREG-0804 and Supplementary Information Section of 1983 Final Rule

The Commission received 93 comment letters in response to the July 1981 publication of the proposed technical criteria as shown in Section 2.2.6 [46 Fed. Reg. 35280 (1981)], 89 of which arrived in time to be considered for the final criteria. The Commission had requested public comment on six issues:

(1) A single overall performance standard versus minimum performance standards for each of the major elements of the geologic repository;

(2) The need for, and appropriate duration of, a waste retrievability period;

(3) The level of detail to be used in the criteria, particularly with respect to design and construction requirements;

(4) The desirability of population-related siting criteria;

(5) The application of an ALARA (as low as reasonably achievable) principle to the performance requirements dealing with containment and control of releases; and

(6) alternative approaches on dealing with possibilities of human intrusion into the geologic repository.

Of these six issues, numbers 4 and 6 include natural resource-related considerations.

Issue 4 — The proposed rule did not contain any direct population requirements for siting a repository; however, Section 112(a) of the NWPA does require DOE to include population consideration in the guidelines for site recommendation [42 USC 10132(a)]. The Commission believed that it would be more realistic to avoid sites with "significant resource potential" and thereby indirectly address the population issue in a manner more appropriate for the long time period necessary for waste isolation. Some comments on the proposed rule endorsed this approach and some said that population requirements were important. After analyzing the comments, the Commission maintained its original view with regard to resources but noted that future human activities are "an important source of uncertainty." Consequently, a "low population density within the geologic setting and a controlled area that is remote from population centers" was included as a favorable condition in the final rule [48 Fed. Reg. 28198 (1983)].

Issue 6 — In the proposed rule, the Commission observed that site selection should be directed toward areas with little resource value in order to discourage people from intruding into a repository. Comments on the proposed rule generally agreed with that reasoning. The proposed rule did not explicitly require that intrusion scenarios be considered. In order to clarify its position, the Commission decided to add to the rule a definition of "unanticipated processes and events" which "expressly include(s) intrusion scenarios." To make sure that the processes and events are "sufficiently credible to warrant consideration" the Commission required (among others) that the "value to future generations of potential resources can be adequately assessed at this time." The Commission thought that choice of a site with "no foreseeably valuable resources" would reduce or eliminate the necessity to consider intrusion [48 Fed. Reg. 28199 (1983)].

2.2.7 Proposed Amendments to Rule

In 1986, NRC issued a list of proposed amendments to 10 CFR Part 60 [51 Fed. Reg. 22288 (1986)] which were intended to conform existing NRC regulations to environmental standards published by the EPA [50 Fed. Reg. 38066 (1985)]. The Commission found that the EPA sometimes used terms differently from existing 10 CFR Part 60 wording. Most of the proposed changes in this document reflect attempts to reconcile wording differences.

EPA Assurance Requirement 40 CFR 191.14(e) states:

> "Places where there has been mining for resources, or where there is reasonable expectation of exploration for scarce or easily accessible resources, or where there is a significant concentration of any material that is not widely available from other sources, should be avoided in selecting disposal sites. Resources to be considered shall include minerals, petroleum or natural gas, valuable geologic formations, and ground waters that are either irreplaceable because there is not reasonable alternative source of drinking water available for substantial populations or that are vital to the preservation of unique and sensitive ecosystems. Such places shall not be used for disposal of the wastes covered by this Part (40 CFR Part 191) unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future."

In response to the adoption of this standard, NRC proposed to make the following revisions:

> "Part 60 contains provisions that, in large part, are equivalent to this assurance requirement. See 60.122(c)(17), (18), and (19). The existing regulation does not, however, address "a significant concentration of any material that is not widely available from other sources." The Commission believes that there is merit in having the presence of such concentrated materials evaluated in the context of the licensing proceeding. It is, after all, quite possible that the economic value of materials could

change in the future in a way which might attract future exploration or development detrimental to repository performance. By adding an additional "potentially adverse condition" to those already set out in the regulation, DOE would be required to identify the presence of the materials in question and evaluate the effect thereof on repository performance, as specified in 60.122(a)(2)(ii). It should be noted that the presence of potentially adverse conditions does not preclude the selection and use of a site for a geologic repository, provided that the conditions have been evaluated and demonstrated not to compromise performance."

NRC proposal to add an additional "potentially adverse condition" took the form:

"§60.122 Siting Criteria. . .

(c) Potentially adverse conditions. . .

(c)(18) The presence of significant concentrations of any naturally occurring material that is not reasonably available from other sources."

This rulemaking has never been completed or withdrawn, in part due to the litigation and remand of EPA's rule (40 CFR Part 191). It is anticipated that EPA's standard will be reproposed and finalized prior to the completion of this rulemaking action.

2.2.8 Update to Final Rule

In 1989, NRC published a final rule updating Part 60 [54 Fed. Reg. 27864 (1989)] to adopt "procedures for implementation of the National Environmental Policy Act." These changes involved a requirement for inclusion of an environmental impact statement in the application and some changes for filing and distribution of an application. This rulemaking did not affect the provisions involving natural resources.

2.2.9 Conclusions

NRC rules governing HLW repositories have evolved to include requirements with respect to natural resources in response to concerns that the presence of such resources could result in disturbance of the repository and compromise of waste isolation. The natural resources at a repository site and the possibility of human intrusion attracted by those resources must therefore be evaluated when assessing the projected performance of the repository. It is evident from the development of the rule that NRC intends for all reasonable precautions to be taken to discourage people from intruding into the repository and that selection of a site with little resource value is among those precautions. Identification of a site with "no foreseeably valuable resources" would reduce or eliminate the potential for intrusion [48 Fed. Reg. 28199 (1983)]. The rules described above make it clear that the Commission intended to "permit consideration of intrusion. . . where circumstances warrant" but that the Commission wanted to avoid control of a license review by "highly speculative intrusion scenarios" [48 Fed. Reg. 28200 (1983)]. This approach was designed to assure prudent consideration of plausible concerns while refraining from excessive deliberation on scenarios with a negligible chance of occurrence and impact on performance.

2.3 NATURAL RESOURCE RELATED REGULATIONS MANDATED IN 10 CFR PART 60

In NRC regulation, 10 CFR Part 60, five regulatory citations are identified which are directly related to consideration of natural resources (assumed to be synonymous with "naturally occurring materials") or the consequences of past searches or exploitation of natural resources (e.g. drilling and subsurface mining). These five pertinent regulatory requirements are SAR [10 CFR 60.21(c)(13)]; Potentially Adverse Condition (PAC) — Human Activity and Groundwater [10 CFR 60.122(c)(2)]; PAC — Presence of Naturally Occurring Materials [10 CFR 60.122(c)(17)]; PAC — Evidence of Subsurface Mining, 10 CFR 60.122(c)(18); and PAC — Evidence of Drilling [10 CFR 60.122(c)(19)]. Additionally, the regulatory requirement dealing with consideration of the Favorable Conditions (FC), 10 CFR 60.122(b), must take into account the adverse conditions present in order for the Commission to be able to adjudge that "the favorable conditions present are sufficient to provide reasonable assurance that the performance objectives relating to isolation of the waste will be met" [a part of 10 CFR 60.122(a)(1)]. Also, the evaluation of natural resources relative to PAC, and FC is to be determined by using the performance objectives stated in 10 CFR 60.113 for the evaluation of subsystems performance and in 10 CFR 60.112 for the evaluation of overall system performance. 10 CFR 60.112, in turn, identifies its operative standards as those that
". . . may have been established by the Environmental Protection Agency with respect to both anticipated processes and events and unanticipated processes and events." These EPA standards are identified by NRC as those contained in 40 CFR Part 191 which is remanded at the present time. Each of the pertinent sections of 10 CFR Part 60 are discussed below in the order of appearance in 10 CFR Part 60.

2.3.1 Safety Analysis Report

The effects of the exploration and exploitation of natural resources on a HLW repository site have long been a consideration of the siting criteria for a HLW repository. 10 CFR Part 60 discusses natural resources in two separate places. One is in the description of the contents of the SAR found in 10 CFR 60.21(c)(13). The Commission describes the type of information that is to be included in the SAR along with guidance on the methods, and means to accomplish the desired levels of evaluation which the Commission expects to receive from DOE in order to make a Commission decision on the acceptability of the site based on the concept of "reasonable assurance."

10 CFR 60.21(c)(13) begins with the following statement: "An identification and evaluation of the natural resources of the geologic setting, including estimates as to undiscovered deposits, the exploitation of which could affect the ability of the geologic repository to isolate radioactive wastes." This section calls for an evaluation of both the discovered and undiscovered resources whose exploitation could affect the ability of the geologic repository to isolate waste. It is clear that resources which are remote from the site need not be identified or considered if their exploitation would not cause the performance of a site to be affected. This wording encompasses the need to evaluate natural resources within both the geologic setting and the controlled area, as well as resources adjacent to the controlled area but still within the geologic setting, where exploitation of the resources, though not affecting the controlled area directly, might change conditions within the controlled area in a manner which could compromise the performance objectives. It appears, based on the wording in 10 CFR 60.21(c)(13), that the license applicant is not required to investigate and evaluate all resources within the entire geologic setting but should concentrate on resources contained within and nearby the controlled area and for which exploitation could affect the ability of a geologic repository to isolate radioactive waste.

Unfortunately, some apparently contradictory statements regarding the identification and evaluation of natural resources may be found in Staff Analysis of Public Comments on Proposed Rule 10 CFR 60 "Disposal of High-Level Radioactive Wastes in Geologic Repositories (NRC, 1983). These contradictory statements are as follows:

- "Moreover, natural resources, whether identified or undiscovered must be evaluated throughout the entire geologic setting" (NRC, 1983, p.214).
- "We (the staff) consider the estimation of undiscovered deposits to be a reasonable approach to site investigations for a geologic repository. Because of the large area that could be relied on to provide isolation (the controlled area could approach approximately 150 square miles) and realizing that the geologic setting itself could cover hundreds of square miles, it would be unreasonable to require identification of resources in the sense of the above definition of identified resources [" 'identified resources'. . .are specific bodies of mineral-bearing material whose location, quality, and quantity are known from geological evidence supported by engineering measurements. . ."]" (NRC, 1983, pp.217 and 218).
- "However, given NRC's approach to selection of sites of little resource value in order to reduce the likelihood of future human intrusion, the resource potential of this large area must be considered in the licensing process. Therefore, we have retained the requirement to estimate undiscovered deposits in the final rule" (NRC, 1983, p.218.).

The first statement simply states that both identified and undiscovered deposits are to be evaluated throughout the entire geologic setting. The key words are "evaluated" and "entire." "Entire" is specific, whatever total area is defined as the geologic setting must be completely considered. "Evaluated" is a relative term and it appears that the information given in the second and third statements elaborate on what level of evaluation is necessary. NRC staff appears to allow for a less stringent investigation of identified resources in the geologic setting than that implied in the provided definition of the term "identified resources" which is designated to include location, quality, quantity, and engineering measurements. At the same time, the staff acknowledges that some evaluation of undiscovered deposits is also to be included in the discussion of the geologic setting.

On the basis of the three statements above, the geologic setting is to be evaluated by DOE for both identified and undiscovered mineral or other resources but, as noted in the second statement, not to the extent that individual deposits of known resources within the entire geologic setting are to be catalogued, described, and evaluated in terms of location, quantity, quality and engineering measurement. Rather, DOE is expected to investigate the types of occurrences of known natural resources within the geologic setting and infer the types of resources which might exist within or near to a proposed repository site ("near" being defined as a distance at which exploration for or exploitation of the resource could affect waste isolation). A series of resource models, characteristic of the geologic setting could be developed by such an investigation, and these models evaluated for likelihood of occurrence at the repository site. Certainly, any discovered resources at a repository site, within or near the controlled area, would be expected to be located, quantities determined, qualities described, and extent quantified by engineering measurement. The site should be investigated thoroughly using geologic and geophysical methods to ascertain, as stringently as current industry practice allows, the presence or absence of natural resources. In addition, appropriate natural resource occurrence models should be applied to evaluate the likelihood of undiscovered deposits within or near the site. The assessment of the existence of natural resources at a site would be primarily deterministic, while it is anticipated that the assignment of likelihood of occurrence of natural resources at a given site would be primarily probabilistic. It is possible that the development of natural resource occurrence models for a given site would enhance the search for natural resources at a site by identifying all the anticipated resources which could exist in a particular environment. The search for and evaluation of the likely occurrence of possible resources should be a part of the site investigation planning process to ensure that no possible resource occurrences are overlooked in the site investigations.

Additional information contained in the SAR requires DOE accomplish three unique facets of investigation and evaluation relative to natural resources which are not discussed elsewhere in 10 CFR Part 60. These are:

- "Undiscovered deposits of resources characteristic of the area shall be estimated by reasonable inference based on geological and geophysical evidence."
- "The estimate of net value shall take into account current development, extraction, and marketing costs."
- "For natural resources without current markets, but which would be marketable given credible projected changes in economic or technological factors, the resources shall be described by physical factors such as tonnage, or other amount, grade, and quality."

Each of these directions provides guidance to DOE on acceptable means of accomplishing the requirements of 10 CFR 60.122(c)(17) as well as serving the needs of 10 CFR 60.21(c)(13), in particular. The SAR section relating to natural resources describes the expected DOE deliverable to the Commission where the conclusions and pertinent supporting information of DOE demonstrating their appropriate consideration of natural resources in the siting and design of a proposed HLW repository will be reported.

The remainder of 10 CFR 60.21(c)(13) contains wording very similar to the wording of 10 CFR 60.122(c)(17) which is the "potentially adverse condition" dealing with "naturally occurring materials" [assumed to be the "natural resources" discussed in 10 CFR 60.21(c)(13)]. No additional guidance to DOE on the expected contents of the information contained in the SAR is provided in this duplicative text. It should be noted that 10 CFR 60.21 does not explicitly state the association between natural resources and performance objectives which is in 10 CFR 60.122.

2.3.2 Overall System Performance Objectives (10 CFR 60.112)

2.3.2.1 Role of Natural Resources in the Performance Evaluation Process

Natural resources are a primary factor in mankind's survival. However, their existence or the perception of their existence within a nuclear repository environment may at some time become paradoxically a cause of grave environmental concern. Indeed, it is not difficult to imagine that the growing scarcity of natural resources worldwide may become a predominant economic factor in the centuries ahead, important enough to spur potential exploration and subsequent drilling and/or mining activities at Yucca mountain and its vicinity.

The search for natural resources relies on geophysical exploration techniques which are not unique but involve a number of well established methods, among others, seismic, gravity, magnetic, electrical and electromagnetic, radiometric, well logging (borehole geophysical methods) (see Raney and

Wetzel, 1990). Drilling is normally employed to provide subsurface geological, geochemical and geophysical information through the recovery of cores, cutting, and drilling fluids that cannot be obtained through the application of competing exploration methods. A natural consequence of drilling and underground excavation within and nearby the controlled area will be the creation of boreholes, and underground mined workings (e.g. adits and drifts).

The adverse impact of these man-induced pathways on the overall system performance objective will have to be assessed by means of near field and far field performance assessment analyses. These in turn will require the identification of scenarios; assignment of probabilities to their occurrences, parameterization of the scenario [i.e., type (e.g., boreholes, open pit mining), size (diameter, depth of penetration), location, and time of intrusion]; definition of appropriate conceptual and mathematical models of the site and the various processes witnessed at and near the site, and finally, the identification and implementation of computer code(s) used for addressing the resulting range of consequences (Cranwell et al., 1990, Dormuth and Quick, 1980).

Out of the steps outlined in the previous paragraph, definition of human intrusion scenarios and coincident assignment of probabilities and frequencies of occurrence are most dependent upon a knowledge of the natural resources of a site. The remaining steps in performance assessment then can proceed without much consideration about the value of the natural resources. The possible connection between the economic value of the natural resources and the scenario definition, and its probability of occurrence is discussed later in Section 4.3.

2.3.2.2 Role of Inadvertent Human Intrusion in Overall System Performance Assessment

The overall system performance objective is contained in System Performance After Permanent Closure, 10 CFR 60.112. The regulatory requirements dealing with the PAC and the evaluation of favorable conditions invoke the determination of compliance with the performance objectives. Thus, the overall system performance objective regulatory requirement is included as an integral part of the discussion of natural resources related regulatory requirements. The reason that the natural resources related regulatory requirements must be considered is because of: (i) the potential for inadvertent human intrusion to acquire natural resources within the controlled area, thus adversely affecting the overall system performance objectives exists, and/or (ii) the advent of inadvertent change in conditions adversely affecting the post closure overall system performance objectives within the controlled area due to human activity physically located outside the controlled area which affects conditions governing system performance within the controlled area. The performance assessment scenarios developed for a given repository site, thus, must consider the occurrence and consequence of human intrusion at or near to the site to explore for and/or extract natural resources at the site or near to it. The numerical criteria for radioactive release which the site must accommodate are included in EPA regulations, primarily, 40 CFR Part 191. Some guidance on the number of drillholes to be considered is given by the EPA in Appendix B of 40 CFR Part 191 but the EPA guidance is not binding on NRC licensees. NRC anticipates providing guidance to DOE on acceptable means to evaluate the number and consequence of drillholes or other exploratory/exploitative acts which could threaten the ability of the geologic repository to meet the overall system performance objectives.

It is stated in 10 CFR Part 60 Final Rule action that inadvertent intrusion into the repository is to be treated as an unanticipated process and event. The Commission said, "The rule now incorporates the definition of 'unanticipated processes and events' which are reviewable in a licensing proceeding; such processes and events expressly include intrusion scenarios that have a sufficiently high likelihood and potentially adverse consequence to exceed the threshold for review. The scenarios must be 'sufficiently credible to warrant consideration'" [48 Fed. Reg. 28199 (1983)].

Abundance of natural resources, i.e., minerals, precious metals, gas or oil, geothermal and groundwater, at a site may be a sufficient cause to reach a determination that a site is unsuitable for a HLW repository. Therefore, it is reasonable to assume that type, nature, and abundance of natural resources will be considered during evaluation of site suitability. However, natural resources of various types in varying amounts (presumably small, as otherwise the site might not have been selected for further investigations) may be present at potential sites. In spite of the 'small' amounts, the presence of or the perception of the presence of natural resources, on site or in its vicinity, may, in the future, cause inadvertent human intrusions. These inadvertent human intrusions may impact the long-term performance of the repository system. It is in this context that regulatory performance requirements are to be considered vis a vis the natural resources.

It should be noted that natural resources are of primary concern in regard to consideration of inadvertent human intrusion for performance assessments. Inadvertent intrusion implies that the knowledge about the presence of the repository will be lost to future generations at some point in time within the period of concern [10,000 years — given in 40 CFR 191.13(a)]. The inherent assumption in such considerations is that if the future generations choose to explore the site knowing that a nuclear waste repository is present, then they would also be knowledgeable about taking mitigative measures. For example, future generations may consider the spent nuclear fuel itself in the repository to be a valuable resource and may take steps to extract it but at the same time taking measures to protect the environment. Such planned (advertent) human intrusions may be considered to not affect repository performance adversely.

Regulations regarding performance of the repository are stated below. Overall post-closure performance requirements for the total repository system (i.e., site and the engineered subsystems) are stated in 10 CFR 60.112 as follows:

> "The geologic setting shall be selected and the engineered barrier system and the drifts, boreholes and their seals shall be designed to assure that releases of radioactive materials to the accessible environment following permanent closure conform to such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency with respect to both anticipated processes and events and unanticipated processes and events"

The generally applicable environmental standards referred to in the above requirements were promulgated by the EPA in 1985 as 40 CFR Part 191: "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes". There are three primary performance requirements in the EPA standard, as delineated in the following:

- <u>Containment Requirements</u> are stated in 40 CFR 191.13 (a): "Disposal system for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation based upon performance assessments that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from <u>all significant processes and events</u> [emphasis added] that may affect the disposal system shall: (1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A); (2)

Have a likelihood of less than one chance in 1000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A)."

- Individual Protection Requirements are stated in 40 CFR 191.15: "Disposal system for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation that for 1,000 years after disposal undisturbed performance of the disposal system shall not cause the annual dose equivalent from the disposal system to any member of the public in the accessible environment to exceed 25 millirem to the whole body or 75 millirem to any critical organ. All potential pathways (associated with undisturbed performance) from the disposal system to people shall be considered, including the assumption that individuals consume 2 liters per day of drinking water from any significant source of ground water outside of the controlled area." [emphasis added]

- Ground Water Protection Requirements are stated in 40 CFR 191.16: "(a) Disposal system for spent nuclear fuel of high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation that for 1,000 years after disposal, undisturbed performance of the disposal system shall not cause the radionuclide concentrations averaged over any portion of a special source of ground water to exceed: (1) 5 picocuries per liter of radium-226 and radium-228; (2) 15 picocuries per liter of alpha-emitting radionuclides (including radium-226 and radium-228 but excluding radon) or (3) the combined concentrations of radionuclides that emit either beta or gamma radiation that would produce an annual dose equivalent to the total body or any internal organ greater than 4 millirem per year if an individual consumed 2 liters per day of drinking water from such a source of ground water. (b) If any of the average annual radionuclide concentrations existing in a special source of ground water before construction of the disposal system already exceeded the limits in 191.16(a), the disposal system shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not increase the existing average annual radionuclide concentrations in water withdrawn from that special source of ground water by more than the limits established in 191.16(a)." [emphasis added]

The EPA standards are currently in remand due to a defect in 40 CFR 191.16 as determined by a federal court. New standards are expected to be promulgated in the near future and are expected to contain the same regulatory philosophy as contained in the text reproduced above.

In 10 CFR 60.2, "processes and events initiated by human activities" are included in the definition of unanticipated processes and events. This is interpreted to mean that inadvertent human intrusion (even when the probability of such intrusion is judged to be high) need not be considered in assessing the undisturbed performance of the repository. Therefore, human intrusion (and, hence, presence of natural resources) does not play any role in analyses related to 40 CFR 191.15 and 191.16 except that these relate to ground water. The exploitation of groundwater has to be considered in DOE compliance demonstration. Similarly, the subsystem performance requirements of 10 CFR 60.113 also apply for anticipated processes and events only and, therefore, are not affected by considerations of inadvertent human intrusion in 10 CFR 60.122(c)(17) which, by definition, is an unanticipated process and event. CNWRA suggests that human activity which affects groundwater prior to the time of waste emplacement should be considered in 10 CFR 60.122(c)(2) and such human activities must be factored into an evaluation of the GWTT subsystem performance requirement of 10 CFR 60.113(a)(2). The effects of inadvertent human intrusion as investigated in 10 CFR 60.122(c)(17) should be included only in demonstrating the containment requirements of 40 CFR 191.13.

2.3.3 Performance of Particular Barriers After Permanent Closure

The subsystem requirements of Part 60 (10 CFR 60.113) contain segments devoted to performance of the engineered barriers system, to the geologic setting, to an optional rule change and to the ability to approve alternative criteria available to the Commission. The regulation can be subdivided into three distinct regulatory requirements as follows:

- EBS Performance After Permanent Closure which is comprised of 10 CFR 60.113(a)(1)(i)(A)

- EBS Release of Radionuclides After Permanent Closure which is comprised of 10 CFR 60.113(a)(1)(i)(B)

- Ground Water Travel Time which is comprised of 10 CFR 60.113(a)(2).

In 10 CFR 60.113(b), the Commission reserves the option of approving or specifying different subsystem regulations, and in 10 CFR 60.113(c) the Commission is given the option of adding requirements to satisfy the overall system performance objective as it relates to unanticipated processes and events. The natural resource related regulatory requirements are each intended to evaluate some facet of potential or past exploration or exploitation of natural resources and the effect of these activities on the performance objectives. Since inadvertent human intrusion within the repository controlled area is an "unanticipated process and event" of post-closure timeframe, it does not fall under consideration in 10 CFR 60.113 (unless the Commission writes a new requirement to deal specifically with inadvertent human intrusion). It is likely that PAC (2) - Human Activity and Groundwater, which has not been defined as only a post-closure consideration, would have to be evaluated in order to determine the pre-waste-emplacement groundwater travel time (GWTT) at the proposed repository site. Because the waste emplacement timeframe is in the 80 or so year range with the pre-waste-emplacement timeframe being some portion of that, it is possible that changes in local groundwater use might affect the groundwater travel time. Any projected effect on GWTT prior to waste emplacement would be considered within PAC (2) since it would affect waste isolation. Thus, 10 CFR 60.113, in its entirety, (including both engineered barriers and the geologic setting) would have to be evaluated in the context of PACs (2), (18) and (19) since the subsystem performance objectives must be affected in the pre-waste-emplacement through closure of the repository stages. The post-closure consideration of natural resources which could compromise performance would be a part of the investigations/evaluations of 10 CFR 60.122(c)(17) - Presence of Naturally Occurring Materials.

2.3.4 Favorable Conditions

The FC regulatory text found in 10 CFR 60.122(a)(1) and 10 CFR 60.122(b) does not contain any direct mention of natural resources. However, some have expressed the sentiment that FC (4) ties a consideration of natural resources into the consideration of the favorable conditions at a site. FC (4) reads as follows: "Mineral assemblages that, when subjected to anticipated thermal loading, will remain unaltered or alter to mineral assemblages having equal or increased capacity to inhibit radionuclide migration." The argument has been made that since natural resources at a site include a determination of economic mineral deposits (both discovered and undiscovered) then natural resources considerations should be a part of this FC because the term "mineral assemblage" could include an aggregate of economic minerals (i.e. resources). CNWRA viewpoint is that because the FC, as stated, relates to the change in mineral assemblages due to thermal loading such that radionuclide migration is inhibited, and not to the likelihood that the presence of a given mineral will increase the potential for human intrusion at a site, then, natural resources are not a consideration of the favorable nature of the mineral assemblages. Certainly, any information on the presence of minerals in commercial quantities at a site or any information which indicates that commercial quantities of certain minerals are likely to be present at a site should be integrated with other information acquired to determine whether the presence of such minerals are likely to cause the geology at the site to be a better isolating agent in the presence of anticipated thermal loads. The entire text which lists the FCs is found in 10 CFR 60.122(b).

FC (6) which reads as follows: "A low population density within the geologic setting and a controlled area that is remote from population centers" can be tied to natural resources directly and indirectly. In a direct tie, the Commission notes that "considerations related to future human activities, particularly uses of groundwater, are an important source of uncertainty in assessing future performance of a geologic repository" [48 Fed. Reg. 28198 (1983)]. In an indirect manner, the Commission ties low population density to lack of resources in the following statement:

> "As to probability, it is difficult to relate the likelihood of releases to population factors; it is the view of the Commission that it is more realistic, as originally stated, to reduce the probability by avoiding sites with significant resource potential and by using records and monuments to caution future generations. Consequences of unanticipated releases would be greater if they should occur in densely populated areas" [48 Fed. Reg. 28198 (1983)].

It appears that natural resources, including groundwater, are more apt to engender potentially adverse intrusions into a given repository if there is a high-population density rather than a low population density. Furthermore, the consequence for the effect of likely human intrusion should be greater in a high population scenario than a low population scenario and such differences in potential impact must be considered in the overall performance assessment of the repository.

2.3.5 Potentially Adverse Conditions

The 24 PACs in 10 CFR 60.122(c) are each considered as a regulatory requirement. The regulatory text requires that each of the 24 PAC be shown to be characteristic of the controlled area or capable of affecting isolation within the controlled area (i.e., repository performance), if located outside the controlled area, or the particular potentially adverse condition need not be considered further in the context of the wording in 10 CFR 60.122(a)(2). If the potentially adverse condition is found to be either characteristic of the controlled area or likely to affect isolation within the controlled area, it is deemed present and further investigation/evaluation of the condition relative to the text in 10 CFR 60.122(a)(2) must occur. Each of the 24 PAC relates to the same regulatory text from 10 CFR 60.122(a)(2). This shared regulatory text specifies that each of the PAC, if present, must be adequately investigated [10 CFR 60.122(a)(2)(i)] and must be adequately evaluated [10 CFR 60.122(a)(2)(ii)], and that each potentially adverse condition must be proven to either (i) not to affect the performance objectives significantly [10

CFR 60.122(a)(2)(iii)(A)], or (ii) to be compensated by a combination of the favorable conditions at a site so that performance objectives will not be compromised [10 CFR 60.122(b) and 10 CFR 60.122(a)(2)(iii)(B)], or (iii) to be capable of remedy by engineering means [10 CFR 60.122(a)(2)(iii)(C)].

The current language of the regulation which requires each PAC to be individually evaluated against a combination of the favorable conditions when determining the performance of the repository is being reconsidered by NRC. An NRC option to be considered is a modification of the regulatory language so that combinations of the PACs are evaluated against combinations of the FC and other site conditions as a part of the overall system performance assessment.

2.3.5.1 Potentially Adverse Condition: Human Activity and Groundwater

The text contained in 10 CFR 60.122(c)(2) — Potentially Adverse Condition: Human Activity and Groundwater is considered to deal partially with natural resources because the exploration for or exploitation of natural resources (including groundwater) could affect the groundwater flow system within the controlled area and vicinity. The Commission chose to give some examples of the types of human activity which might affect the groundwater flow system and included groundwater withdrawal and subsurface injection of fluids as possible considerations. Both of these considerations, conceivably, could result from the effect of human activity to find or utilize natural resources at or near the site. As with each adverse condition, the effects of human intrusion for natural resources is to be weighed in the context of the performance objectives in 10 CFR 60.112 (Overall System Performance) and 10 CFR 60.113 (Subsystem Performance).

2.3.5.2 Potentially Adverse Condition: Presence of Naturally Occurring Materials

The text contained in 10 CFR 60.122(c)(17) — PAC — Presence of Naturally Occurring Materials is essentially duplicated and elaborated on in 10 CFR 60.21(c)(13) which was discussed earlier in this report (Section 2.3.1). This requirement in the regulations is referred to as "Natural Resources" as a matter of convenience, although the term is not mentioned within the cited regulatory text. (It is, however, "natural resources" which are called out in 10 CFR 60.21(c)(13). Significant numbers of references to "natural resources" are present in Staff Analysis of Public Comments ... (NRC, 1983) relative to this identified regulatory text so the intended link between "naturally occurring materials" and "natural resources" is well documented by the Commission (See [48 Fed. Reg. 28199 (1983)] and NRC, 1983, p. 50, for example). The Commission has established that it is the presence of "naturally occurring materials" in economically exploitable quantities and/or the perception of same which might cause a selected repository site to be intruded by future generations. This potential future human intrusion at a repository site must be defined based on an understanding of current conditions at a given site and a prediction of expected future conditions of economics and associated human activity, in particular. The likelihood and magnitude of probable human intrusion at a given site must be integrated into performance assessment activities of site evaluation so that realistic scenarios of human intrusion and the anticipated likelihood and extent of such human intrusion can be included in both subsystem performance assessment and overall system performance assessment.

2.3.5.3 Potentially Adverse Condition: Evidence of Subsurface Mining

The text contained in 10 CFR 60.122(c)(18) — Potentially Adverse Condition: Evidence of Subsurface Mining reads as follows: "Evidence of subsurface mining for resources within the site." It has been recognized that it is not the "evidence" of a particular potentially adverse condition which is important but rather the implications for future conditions which is inferred from the "evidence" which is of concern (CNWRA, 1989). The implication of prior subsurface mining for resources at a given repository site is that the particular site was at one time viewed as more desirable for resource exploration or production than other comparable sites within the region which had never been explored or mined. Thus, the reasoning is that the site would have a higher than average desirability for future generations to accomplish similar exploration or mining. The Commission would like to avoid such sites which cannot be mitigated by the various means discussed earlier in Section 2.3.5 of this report. Additionally, extant subsurface workings might cause the site to be unable to meet the desired performance objectives and would result in dismissal of the site as a potential repository host once such subsurface conditions resulting from past subsurface mining for resources are adequately evaluated in the performance assessment exercises.

2.3.5.4 Potentially Adverse Condition: Evidence of Drilling

The text contained in 10 CFR 60.122(c)(19) — Potentially Adverse Condition: Evidence of Drilling reads as follows: "Evidence of drilling for any purpose within the site." As noted above in the discussion of subsurface mining for resources, it is not the "evidence" of a particular potentially adverse condition which is important but rather the implications for future conditions which is inferred from the "evidence" which is of concern. The implications of prior drilling for any purpose at a given repository site is that the particular site was at one time viewed as more desirable for resource exploration or production through drilling than other comparable sites within the region that had never been drilled for any purpose. Thus, the reasoning is that the drilled site would have a higher than average desirability for future generations to accomplish similar drilling. The Commission would like to avoid such sites which cannot be mitigated by the various means discussed earlier in Section 2.3.5. Additionally, past drilling at a given site might cause the site to be unable to meet the desired performance objectives irrespective of future activities at the site and such existing drillholes would result in dismissal of the site as a potential repository host once such conditions resulting from past drilling for resources were adequately evaluated in the performance assessment exercises.

2.4 DEFINITIONS OF SELECTED PHRASES FROM 10 CFR PART 60 CONCERNING NATURAL RESOURCES

2.4.1 Introduction

This section provides (i) definitions for selected terms and phrases from 10 CFR Part 60 that are involved in the identification and evaluation of natural resources and (ii) identification and discussion of uncertainties identified in: Identification and Evaluation of Regulatory and Institutional Uncertainties in 10 CFR Part 60," CNWRA 90-003 (CNWRA, 1990a). The definitions are provided to increase the clarity of use of the terms and phrases as NRC has interpreted them to apply to regulatory considerations associated with natural resources. The uncertainties were identified and reported on to NRC by the CNWRA. In Section 2.4.2 of this report, the relevant provisions of 10 CFR Part 60 are reproduced and the selected terms and phrases are underlined and numbered from [1] to [11]. The numbers key to the proposed definitions also in Section 2.4.2. The regulatory uncertainties are identified and discussed in Section 2.4.3.

2.4.2 Natural Resource Terms From 10 CFR Part 60 Which Require Definition

The following are the relevant portions of 10 CFR Part 60 which were found to contain terms requiring interpretive guidance to DOE. Each of the terms which will be defined is identified by [X] and is underlined in the text of the regulation reproduced below.

10 CFR 60.21(c)(13) states the following must be included in the Safety Analysis Report:

"An identification and evaluation of the natural resources of the geologic setting, including estimates as to [1] undiscovered deposits, the exploitation of which [2] could affect the ability of the geologic repository to isolate radioactive wastes. Undiscovered deposits of resources characteristic of the area shall be estimated by [3] reasonable inference based on geological and geophysical evidence. This evaluation of resources, including undiscovered deposits, shall be conducted for the site and for [4] areas of similar size that are representative of and are within the geologic setting. For natural resources [5] with current markets the resources shall be assessed, with estimates provided of both gross and net value. The estimate of net value shall take into account current development, extraction and marketing costs. For natural resources [6] without current markets, but which would be marketable given [7] credible projected changes in economic or technological factors, the resources shall be described by physical factors such as tonnage or other amount, grade, and quality." [emphasis added to terms and phrases for which definitions are provided in Section 2.4.3]

10 CFR 60.122(c)(17), one of the PAC states:

"The presence of naturally occurring materials, whether identified or undiscovered, [8] within the site, in such form that:

(i) [9] Economic extraction is currently feasible or [10] potentially feasible during the foreseeable future; or (ii) Such materials have greater gross value or net value than the average for other areas of similar size that are representative of and located within the geologic setting." [emphasis added to phrases for which definitions are provided in Section 2.4.3]

The 10 CFR 60.2 definition of unanticipated processes and events states:

"Unanticipated processes and events means those processes and events affecting the geologic setting that are judged not to be reasonably likely to occur during the period the intended performance objective must be achieved, but which are nevertheless sufficiently credible to warrant consideration. Unanticipated processes and events may be either natural processes or processes and events initiated by human activities other than those activities licensed under this part. Processes and events initiated by human activities may only be found to be sufficiently credible to warrant consideration if it is assumed that: (1) The monuments provided for by this part are sufficiently permanent to serve their intended purpose; (2) the value to future generations of potential resources within the site can be [11] assessed adequately under the applicable provisions of this part; (3) an understanding of the nature of radioactivity, and an appreciation of its hazards, have been retained in some functioning institutions; (4) institutions are able to assess risk and to take remedial action at a level of social organization and technological competence equivalent to, or superior to, that which was applied in initiating the processes or events concerned; and (5) relevant records are preserved, and remain accessible, for several hundred years after permanent closure."

2.4.2.1 Undiscovered Deposits

"Undiscovered deposits" [1] — means those occurrences of a useful mineral or ore, in sufficient extent and degree of concentration to invite exploitation that are estimated to exist, from broad geologic knowledge and theory, outside of known accumulations.

Undiscovered deposits refers to those unspecified bodies of mineral-bearing material that are postulated to exist separately from identified deposits. In contrast, "identified deposits" are known to exist at a specific location, based on tangible, or inferred physical evidence such as samples obtained from a borehole or mine working, or geophysical evaluation although the extent and nature of the deposits may not be definable. Generally, water is not considered as a "deposit" although coal and oil may be considered as a "deposit" if they are defined in context.

NRC staff has provided the following definition (NRC, 1983, p.217):

"Undiscovered deposits are unspecified bodies of mineral-bearing material surmised to exist on the basis of broad geologic knowledge and theory."

"Undiscovered deposits of resources" in 10 CFR 60.21(c)(13) is believed to have the same meaning as "undiscovered resources."

This definition is taken from page 3A of a 1976 publication by the U.S. Bureau of Mines and U.S. Geological Survey (U. S. Geological Survey, 1976). Since that time, minor revisions of the definition have appeared in publications of the U.S. Geological Survey. In 1989, the Department of Interior (DOI) released its estimates of national oil and gas resources (U.S. DOI, 1989, p. 5), with this definition:

"Undiscovered resources — Resources estimated to exist, on the basis of broad geologic knowledge and theory, outside of known fields and accumulations."

The 1989 definition was provided within an oil and gas context. Nevertheless, with the deletion of "fields and" the definition becomes applicable to both solid and liquid resources and useful for 10 CFR Part 60. The 1989 definition, as modified, is preferred because: (i) the wording is succinct and fits the needs of Part 60; (ii) the 1989 definition is contained in an antecedent document, Geological Survey Working Paper 88-373, which received extensive peer review and comment; and (iii) the 1989 definition is more modern than the 1976 definition and reflects the thinking since that time.

2.4.2.2 Could Affect the Ability of the Geologic Repository to Isolate

"Could affect the ability of the geologic repository to isolate" [2] — means that an adverse condition could cause adverse change in the ability of the geologic repository to isolate waste without necessarily causing a violation the performance objectives [60.122(a)(2)].

This phrase, as well as the "undiscovered deposits" in definition [1], form part of the first sentence of 10 CFR 60.21(c)(13), which discusses the contents of the Safety Analysis Report. Section 10 CFR Part 60.21(c)(13) is devoted to natural resources. Natural resources are of concern in repository siting, because if present they could invite human intrusion through exploration or exploitation. "The Commission observed, in the preamble of the proposed rule, that everything that is reasonable should be done to discourage people from intruding into the geologic repository. Those measures which it considered to be reasonable included directing site selection toward sites having little resource value and marking and documentation of the site" [48 Fed. Reg. 28199 (1983)].

Natural resources within the site are of first concern. These are dealt with in 60.21(c)(13), 60.122(c)(17), and 60.122(c)(18). However, resources can also be present outside the site in a location where exploitation could adversely affect the groundwater flow system. The identification and evaluation of such resources is necessary to fulfill the requirements in 60.122(c)(2) on evaluation of the "potential for foreseeable human activity to adversely affect the groundwater flow system. . .".

The opening sentence of 10 CFR 60.21(c)(13) requires identification of all natural resources in and near the site. Certain natural resources could, perhaps, be exploited without adverse effect on repository performance. Examples may include timber, water power and surficial deposits of sand, gravel and caliche. These could, perhaps, be demonstrated to be of such a nature that exploitation is possible without affecting repository performance. All other resources are subject to the evaluation specified in 10 CFR Part 60. The Commission was apparently interested in causing all potential adverse effects of natural resource exploitation to be evaluated for possible effect on the performance objectives. Those effects that did not appear to compromise the objectives could be dismissed after due consideration.

2.4.2.3 Reasonable Inference

"Reasonable inference" [3] — means logical and rational deduction. The development of a reasonable inference about estimates of undiscovered resources, would be expected: (i) to draw on all applicable data; (ii) to apply broad geological and geophysical knowledge and theory; and (iii) to use a defensible assessment methodology that is developed or adapted to meet the requirements of 10 CFR Part 60.

The methodology for assessment of undiscovered resources is a subject of active interest, especially by government agencies involved in resource management and land use planning. Examples that demonstrate the use of reasonable inference in assessing undiscovered resources are: (i) the DOI's national assessment of undiscovered oil and gas resources (DOI, 1989); (ii) DOE's assessment of uranium resources (DOE, 1980); and (iii) the assessment of Alaskan mineral resources by the U.S. Geological Survey (Singer, 1980). DOE may well draw on similar experience to develop a defensible methodology appropriate to a LA.

2.4.2.4 Areas of Similar Size that are Representative of

"Areas of similar size that are representative of" [4] — means (i) that each area within the geologic setting selected for comparison of resources contains about the same amount of area as the site (controlled area); and (ii) that the group of comparison areas is similar, geologically, to the controlled area and is a part of the geologic setting so that estimates of natural resources in the controlled area can be prepared by evaluation of the natural resources of the comparison areas. Although not directly stated, the comparison should include a commodity-by-commodity accounting in each of the areas being compared (i.e., separate discussions of gold, zeolites, silver, potable water, and other mineral commodities which are a part of the geologic setting).

Similar size — The comparison areas, located within the geologic setting, are selected to be similar in size to the site. DOE must determine what amount of area is apt to be taken up by a typical repository site. The EPA rule, 40 CFR Part 191, explicitly states:

> "Controlled area means: (1) A surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system; and (2) the subsurface underlying such a surface location" (50 Fed. Reg. 38084, 1985).

While the language concerning the controlled area in 10 CFR Part 60 is as follows:

> "'Controlled area' means a surface location, to be marked by suitable monuments, extending horizontally no more than 10 kilometers in any direction from the outer boundary of the underground facility, and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be restricted following permanent closure."

As a starting point, it is worth noting the equivalence between the site and the controlled area, for the purposes of resource evaluation:

> "According to the final rule, the comparative evaluation will relate to the controlled area. . ." (NRC, 1983, p. 214)

By definition (10 CFR 60.2 Definitions), "site" means the location of the controlled area. and the controlled area extends no more than 10 kilometers from the perimeter of the underground facility. The actual configuration of a real site would, of course, be needed to properly determine the size of the site; however, some examples may provide order of magnitude figures for the present discussion.

Consider a circular underground facility with a radius of 1 kilometer, in one case, and a radius of 2 kilometers, in a second case, surrounded by a controlled area that extends outward for a distance of 5 kilometers, in one case, and 10 kilometers, in a second case. The resultant areas are shown in Table 2-1 for the four cases.

This exercise suggests that each "similar size" area will occupy more than a hundred square kilometers, equivalent to scores of square miles. The size of the controlled area given the 10 CFR Part

Table 2-1. Examples of Controlled Area Size

	Size	Controlled Area (km^2/mi^2)	
		5 km	10 km
Underground Facility	1 km	113/41	137/38
	2 km	154/55	452/163

60 dimensions can be several times greater than the 100 square kilometer restriction placed on the controlled area by the EPA standard (40 CFR Part 191).

Representative of — "Representative of. . ." means that the group of comparison areas is similar (not exactly the same) geologically, to the controlled area within the geologic setting. NRC staff which was involved in the drafting of 10 CFR Part 60 desired this "similarity" in geology so that estimates of the natural resources of the controlled area could be prepared by evaluation of the natural resources of the comparison areas with subsequent extrapolation to the controlled area.

Explanation of comparison areas — Section 60.21(c)(13) calls for the evaluation of resources "for the site and for areas of similar size that are representative of and are within the geologic setting". Section 60.122(c)(17)(ii) calls for a comparison between the value of resources within the site and the average of the values for the other areas. In this discussion, the areas that are selected for comparison with the site are called "comparison areas".

The current site under consideration at Yucca Mountain, Nevada is in a portion of the Great Basin which has been heavily explored and exploited for mineral resources in the historical past. However, the proposed site, itself, on Yucca Mountain has been off-limits to mineral exploration and exploitation for almost 50 years as a result of the establishment of the Nuclear Test Site (NTS). Thus, if DOE were to compare the relatively little explored proposed Yucca Mountain site to other areas in the geologic setting, the candidate site, comparatively speaking, would be considered to be relatively resource poor (i.e., it would look "good" on the basis of lack of known resources). It is suggested that DOE should not literally interpret the language of 10 CFR 60.21(c)(13) and 10 CFR 60.122(c)(17)(ii) but, rather, should factor the lack of recent exploration of the proposed site into their consideration of the likelihood of occurrence of natural resources at the site which might lead to inadvertent human intrusion into a geologic repository at Yucca Mountain. Generally, DOE must give special consideration to evaluating the likelihood of natural resource presence at any proposed site which is or has been on restricted access land which is located in mining districts but which may not, itself, have been subjected to the same rigorous commercial-based inspections for resources as other nearby nonrestricted areas.

2.4.2.5 With Current Markets

"With current markets" [5] — means that similar natural resources to those that might be found at a proposed site are saleable or determined as strategic under market conditions at the time of the resource evaluation. The normal economics of industry apply here. Discussions of the investigation and evaluation of natural resources will be a part of several documents that are produced by DOE at various times during the life history of a repository. Examples are the LA itself; the updating of the LA at the time of docketing; and the filing of an application for license amendment, as for application for permanent closure. At these times the resource evaluation presented by DOE may be subject to adjudication. Any DOE evaluation which is submitted during the complete souse of licensing through closure should reflect economic conditions and market conditions for resources which are based on then-current market or strategic conditions.

2.4.2.6 Without Current Markets

"Without current markets" [6] — means that resources similar to those that may be perceived to occur at the proposed site are not saleable or strategic, because there is no commercial market or government-stated strategic need, at the time of the evaluation, for those kinds of resources. Uranium is an example of a resource that currently lacks a current market for social and military reasons. Technology for recovering and producing uranium is established. However, the current demand for uranium is so low that uranium cannot be economically produced. Hence, uranium is at the present "without a current market."

Sections 10 CFR 60.21(c)(13) and 10 CFR 60.122(c)(17 and 18) emphasize current, commercial considerations in industry. There is, however, a requirement in the regulation for the development of substantive, credible scenarios within which a material with no present use, or marketability, might become useful, and marketable, if potential but uncertain technological or economic changes took place in the foreseeable future.

2.4.2.7 Credible Projected Changes

"Credible projected changes" [7] — means believable future changes that are identified by reference to recognized trends in industry or government strategic needs at the time of the resource assessment. An illustration of a "credible projected change" in an economic factor is the change in market conditions for uranium ore that resulted from the government announcement in early 1948, by the U. S. Atomic Energy Commission, that, for strategic reasons, it would commence the purchase of uranium ore on April 11, 1948 (AEC, 1948). At the time of the announcement, there was no prior U.S. market for uranium ore.

An illustration of a "credible projected change" in a technological factor is the development and testing of heap leaching for the improved recovery of gold from ores. Certain low grade gold deposits in Nevada which could not be produced, due to the poor economics of gold recovery, later became commercial, due to the credible, projected change in recovery economics resulting from the development and testing of the heap leaching method. Potentially, "in situ" leaching of gold might be a required consideration at a site such as Yucca Mountain, Nevada. Typically, a beneficial technological change results in an economic benefit, such as a reduction of production cost. On the other hand, a technological change might result in improvement of the quality of the product so that it would become marketable.

To be credible, there must be confidence in the likelihood of the projected changes. The projected changes would be among many other economic and technological projections for a future operation to extract a resource. The projected changes should contain no higher level of uncertainty than the other projections for the future extractive operation.

2.4.2.8 Within the Site

"Within the site" [8] — is a specific statement found in the language of 10 CFR 60.122(c)(17) which should not be followed literally. NRC staff recognizes that naturally occurring materials outside the site must be investigated and evaluated if it is possible that their exploration/exploitation might have a detrimental effect upon the performance objectives. The naturally occurring materials found "within the site" are of prime significance; however, off-site resources must also be considered.

2.4.2.9 Economic Extraction is Currently Feasible

"Economic extraction is currently feasible" [9] — means that an operation to extract and sell or stockpile the resources would be profitable under market conditions or acceptable government practice (subsidies) at the time of the resource assessment. It is expected that the normal standards of industry, for the economic analysis of a potential extractive operation, apply here. Generally, economic extraction means that all production costs — including the costs of land, discovery, development, extraction, marketing and reclamation — are less than the revenue received from the sales (i.e., a profit is realized).

2.4.2.10 Economic Extraction is. . .Potentially Feasible During the Foreseeable Future

"Economic extraction is. . .potentially feasible during the foreseeable future" [10] — means that an operation to extract and sell the resources would be profitable under improved economic conditions over the next several decades are plausible for the exploitation operation.

"Foreseeable future" — the following can be said about the concept of the "foreseeable future" with respect to the future economic extraction of natural resources: (i) predictions of the future are based largely on the record of the past; (ii) predictions of future economic extraction depend on predictions of both the market price for the resource and the production cost; (iii) the historical record shows marked variability, over short time periods, in market prices of resources; (iv) typical long-term forecasts in the minerals industry extend over a few decades; and hence, (v) the "foreseeable future" for the economic extraction of mineral resources, which are not now marketable, is apt to be measured in decades, rather than centuries or longer.

It may be interpreted that these economic predictions were intended to encompass the 10,000 year regulatory life of the HLW repository. It is suggested here that such an interpretation of the "foreseeable future" is too energetic and can not be readily defended. The types of "resources" which will be investigated in a study of naturally occurring materials at a given repository site are those which are known to have value at present and those materials which, for whatever reason, can be construed as having a future imputed value. Currently, society places economic value and the predictability of future value no more than a few decades into the future. Home mortgages are generally issued for no more than 30 years in the United States. Historically, contracts for mineral exploration ventures are planned and capitalized no more than 50 years into the future and, generally, range only 20 to 30 years into the future. The reaction of costs to expected changes in the base value of currency is such that funds are discounted to essentially no value within a future span of twenty or so years. These and other examples demonstrate that learned systems and individuals operating within the economic environment of resources and commodities are capable of, and are willing to, predict no more than a few decades into the future. The regulations of the EPA in 40 CFR Part 191 suggest that institutional controls at a waste site be assumed to be active for no more than 100 years after disposal (interpreted to mean 100 years after closure of the site) which is a similar time span to the 50 year span which is thought to represent reasonable prognostication for economic matters.

DOE attempts to foresee more than 50 years or so (as defensible) into the future are problematic when examining the likelihood of materials or substances without current markets becoming viable resources in the future. NRC [48 Fed. Reg. 28199 (1983)] states that "that the value to future generations of valuable resources can be assessed adequately at this time." Based on the apparent ability of current society to predict the future, it appears that the value of resources to only a few future generations may be adequately assessed (i.e., those generations contained within a 50 year time span from the present) in the context of the regulation and today's society. [48 Fed, Reg. 28199 (1983)] emphasizes that any scenario must be "sufficiently credible to warrant consideration." Further, "highly speculative intrusion scenarios should not be allowed to become the driving force in license reviews. . ."[48 Fed. Reg. 28200 (1983)].

This concept of "foreseeable future" is limited to the present context of natural resource considerations [i.e., the provisions of 10 CFR 60.122(c)(17)], which identify certain kinds of resources that could constitute a potentially adverse condition. This concept is not appropriate for application to other provisions of 10 CFR Part 60 that deal with long-term future time. For example, a time frame of 10,000 years may be needed for performance assessment of a repository. Scenarios for inadvertent human intrusion may also involve a lengthy time frame.

2.4.2.11 Assessed Adequately

"Assessed adequately" [11] — in context, means that the value of the resources to future generations is fully represented in the evaluation of resources prescribed in 10 CFR Part 60 for the LA. No additional assessment, beyond the requirements of 10 CFR Part 60, is needed to cover any imputed value of natural resources to future generations.

2.4.3 Natural Resource Terms Which Were Identified as Regulatory Uncertainties

NRC is particularly concerned with perceived ambiguity, or lack of clarity in its regulation because such uncertainty will impede the licensing process. CNWRA has identified within the regulation fifteen (15) potential uncertainties common to each of the PAC found in 10 CFR 60.122(c)(1) through (24). Of the natural resource related regulatory requirements only PAC — Evidence of Subsurface Mining [10 CFR 60.122(c)(18)] and PAC — Evidence of Drilling [10 CFR 60.122(c)(19)] have an additional potential regulatory uncertainty identified. The reader is directed to CNWRA (1990a) for more detailed information on each perceived uncertainty including the parent regulatory text, type of uncertainty, text of uncertainty, and rationale for inclusion or exclusion of the uncertainty.

The discussion herein encapsulates the CNWRA uncertainty report (CNWRA, 1990a) into a compact format. Table 2-2 shows the various regulatory uncertainties identified within the wording of the PAC and the classification of each as either an included or excluded potential uncertainty. Included uncertainties require additional NRC consideration while excluded potential uncertainties were deemed not to require additional NRC clarification. Eight of the regulatory uncertainties were classified as included uncertainties and these eight are paraphrased as follows: (i) adequately investigated, (ii) adequately evaluated, (iii) not to affect significantly, (iv) taking into account the degree of resolution, (v) not likely to underestimate the effect, (vi) geologic setting, (vii) inconsistency in treatment of

Table 2-2. Uncertainties in potentially adverse conditions related to natural resources as identified in CNWRA 90-003

10 CFR Part 60 Uncertainty Identifier[N]	Uncertainty Type	Included/Excluded	Uncertainty Topic
10 CFR 60.122(a)(2)(i) /UN0001*	Regulatory	Included	Taking into account the degree of resolution
10 CFR 60.122(a)(2)(ii) /UN0002*	Regulatory	Included	Not to affect significantly
10 CFR 60.122(a)(2)(ii) /UN0003*	Regulatory	Included	Adequately evaluated
10 CFR 60.122(a)(2)(II) /UN0004*	Regulatory	Included	Not likely to underestimate its effect
10 CFR 60.122(a)(2)(i) /UN0005*	Regulatory	Included	Adequately investigated
10 CFR 60.122(a)(2)(iii)(B) /UN0006*	Regulatory	Excluded	Effect compensated by a combination
10 CFR 60.122(a)(2)(iii)(B) /UN0007*	Regulatory	Excluded	Favorable characteristic versus favorable conditions
10 CFR 60.122(a)(2)(iii)(C) /UN0008*	Regulatory	Excluded	Can be remedied
10 CFR 60.122(c) /UN0009*	Regulatory	Excluded	Characteristic
10 CFR 60.122(c) /UN0010*	Regulatory	Excluded	May affect isolation
10 CFR 60.122(c) /UN0011*	Regulatory	Excluded	Controlled area

* Common Uncertainties Identified In Potentially Adverse Conditions (1) through (24)

combinations of PAC, and (viii) inconsistency in inclusion of terms such as "adequately investigated/evaluated and performance objectives" in DOE demonstration requirements in 60.122(a)(2)(iii)(A), ... (B), and ... (C). Each of these is discussed individually in Sections 2.4.3.1 through 2.4.3.19 later.

Table 2-2. Uncertainties in potentially adverse conditions related to natural resources as identified in CNWRA-90-003 (Cont'd)

10 CFR Part 60 Uncertainty Identifier	Uncertainty Type	Included/ Excluded	Uncertainty Topic
10 CFR 60.122(a)(1) /UN0012*	Regulatory	Included	Geologic setting
10 CFR 60.122(b)(1) /UN0013*	Regulatory	Excluded	Quaternary period
10 CFR 60.122(b) /UN0014*	Technical	Included	Fastest path of likely radionuclide travel
10 CFR 60.122(b)(7) /UN0015*	Technical	Included	Disturbed zone
10 CFR 60.122(b)(7) /UN0016*	Regulatory	Excluded	Substantially exceeds 1000 years
10 CFR 60.122(a)(2)(1) /UN0017*	Regulatory	Included	Treatment of combinations of potentially adverse conditions
10 CFR 60.122(a)(2)(iii)(C) /UN0018*	Regulatory	Included	Omission of adequate investigation/evaluation of effect, favorable, and remedy
10 CFR 60.122(c)(18) /UN0019⁺⁺	Regulatory	Excluded	Evidence of

* Common Uncertainties Identified In Potentially Adverse Conditions (1) through (24)(xx=02 through 24)

++ This Potential Uncertainty is common to 10 CFR 60.122(c)(18) — Mining for Resources and 10 CFR 60.122(c)(19) — Drilling

Seven of these uncertainties have been considered by a working group of NRC staff to determine an uncertainty resolution methodology. A draft NRC report entitled "Task Team HLW Repository Regulation Uncertainty-Reduction Recommendations" (NRC, 1991) has been developed. Table 2-3 shows the recommended uncertainty reduction method for each of the included uncertainties in the PACs.

Table 2-3. NRC recommended resolution approaches for uncertainty topics

Uncertainty Topic	CNWRA Identification	Recommended Resolution Approach
Geologic setting	10 CFR 60.122(a)(1)/UN0012	Further analysis
Taking into account the degree of resolution	10 CFR 60.122(a)(2)(i) /UN0001	Guidance
Not to affect significantly	10 CFR 60.122(a)(2)(iii)(A) /UN0002	Guidance
Adequately evaluated	10 CFR 60.122(a)(2)(ii) /UN0003	Guidance
Not likely to underestimate the effect	10 CFR 60.122(a)(2)(ii) /UN0004	Guidance
Adequately investigated	10 CFR 60.122(a)(2)(i) /UN0005	Guidance
Treatment of combinations of potentially adverse conditions	10 CFR 60.122(a)(1)/UN0017	Guidance
Omission of adequate investigation/evaluation of effect, favorables, and remedy	10 CFR 60.122(a)(2)(iii)(C) /UN0018	Not considered by NRC Evaluation Team

2.4.3.1 Taking into Account the Degree of Resolution

The CNWRA recommended that the intended meaning of the phrase "taking into account the degree of resolution of the investigations" found in 10 CFR 60.122(a)(2)(i) be clarified so that DOE has clear guidance on NRC requirement to adequately investigate aspects of a potentially adverse condition necessary to support the LA. It was thought by the CNWRA that in 10 CFR 60.122(a)(2)(i) "take into account" could imply that some weighting should be applied to the possibility of undetected PAC and the probability of their occurrence and possible effect on the performance expectations. It might also be interpreted to mean that a safety margin (allowance for inherent uncertainty) or high statistical confidence be applied to the evaluation of a potentially adverse condition during the investigation process.

The "degree of resolution" may be interpreted as the precision (scale of numerical assessment) with which the potentially adverse condition is evaluated, or the relative importance of differing types of evaluations. Alternatively, "taking into account the degree of resolution" could mean that the investigations recognize the uncertainties inherent in any geologic studies such as the resolution of exploratory geophysical methods in detecting faults. Another interpretation might be that the accuracy of measurement of the potentially adverse condition be used to assess the relative importance of the measured values and that this relative importance be used in the overall assessment of the condition. It has been suggested that the perceived uncertainty in the regulation was intended to provide flexibility in implementation. There would seem to be limited value in such regulatory flexibility in this instance when one considers the potential for LA evaluation delays in which the alleged cause of unacceptable DOE investigations/analyses may be ambiguous NRC requirements. NRC should, at some point, define the LA evaluation criteria. It would appear to be advantageous to all parties if, at least, the generic high-order decision criteria were developed prior to the start of or, at the latest, early in the conduct of the site characterization activities to which they apply. NRC is contemplating guidance which should clarify the meaning of the existing language "taking into account the degree of resolution achieved by the investigations" and define the criteria by which the adequacy of the "taking into account" will be judged.

2.4.3.2 Not to Affect Significantly

The meaning of the phrase "not to affect significantly" in 60.122(a)(2)(iii)(A) should be clarified in order for DOE to demonstrate that the potentially adverse activity or condition does or does not exceed the level of effect considered important to the ability of a geologic repository to meet the performance objectives. It is not possible to ascertain from the current language if the Commission intends for "significant effects" to be those that imperil the performance objectives or whether the effects are those which are perceived as larger than normal adverse effects on the performance objective but not large enough to cause the performance objectives to be compromised. NRC needs to clarify the meaning of the existing language for DOE by identifying whether a significant effect is one which causes the performance objectives to be breached or is to be measured by some other criteria to determine "significance." NRC is contemplating guidance which should clarify the meaning of the existing language "not to affect significantly."

2.4.3.3 Adequately Evaluated

The criteria for "adequate evaluation" are not given in 10 CFR 60.122(a)(2)(ii). Since the precise nature of the different PAC varies considerably, these criteria should include the factors specific to each potentially adverse condition which will be viewed as critical in NRC evaluation of the adequacy of the individual characterization evaluations presented by DOE in the license submittal. It has been suggested that the perceived uncertainty in the regulation is intended to provide flexibility of implementation. There would seem to be limited value in such regulatory flexibility in this instance when one considers the potential for LA evaluation delays in which the alleged cause of unacceptable DOE investigations/analyses may be ambiguous NRC requirements. NRC should, at some point, define the LA evaluation criteria. It would appear to be advantageous to all parties if, at least, the generic high-order decision criteria were developed prior to the start of or, at the latest, early in the conduct of the site characterization activities to which they apply. NRC is planning guidance which should clarify the meaning of the existing language "adequately evaluated" and define the criteria by which the adequacy of an evaluation will be judged.

2.4.3.4 Not Likely to Underestimate its Effect

The meaning of the term "not likely to underestimate its effect" in 10 CFR 60.122(a)(2(ii) is unclear. The criteria for acceptability of a given estimated value, in order for the value to be judged acceptable within the definition "not likely to underestimate its effect" should be provided to DOE to allow for an appropriate DOE assessment. For example, would a marginal estimation (i.e., one that barely crossed a preferred threshold) be considered as adequate as an estimation that provided a major margin of safety (such as 2 or 3 times a threshold value)? Additionally, DOE can not tell from the regulation whether the threshold it has chosen for consideration is an acceptable threshold for NRC regulator. In the Staff Analysis of Public Comments... (NRC, 1983, p. 393) the following is found: "The wording 'conservative analyses and assumptions' has been replaced with 'assumptions which are not likely to underestimate its effect.' The staff considered this change to alleviate the concern expressed in the comment." The comment which elicited NRC response is as follows: "This paragraph should be changed to read '...evaluated using realistic analyses and assumptions...' The use of 'conservative analyses and assumptions' (originally proposed by NRC) in analyzing potential events can result in a lack of balance in the evaluation of a site and the rejection of, what is in fact, a good site."

NRC is planning guidance which should clarify the meaning of the existing language "not likely to underestimate its effect" and define the criteria by which the adequacy of "not likely to underestimate its effect" will be judged.

2.4.3.5 Adequately Investigated

The criteria for "adequate investigation" are not given in 10 CFR 60.122(a)(2)(i). Since the precise nature of the different PAC varies considerably, these criteria should include the factors specific to each potentially adverse condition which will be viewed as critical in NRC evaluation of the adequacy of the individual characterization investigations presented by DOE in the license submittal. It has been suggested that the perceived uncertainty in the regulation is intended to provide flexibility of implementation. There would seem to be limited value in such regulatory flexibility in this instance when one considers the potential for LA evaluation delays in which the alleged cause of unacceptable DOE investigations/analyses may be ambiguous NRC requirements. NRC should, at some point, define the LA evaluation criteria. It would appear to be advantageous to all parties if, at least, the generic high-order decision criteria were developed prior to the start of or, at the latest, early in the conduct of the site characterization activities to which they apply. NRC is planning guidance which should clarify the meaning of the existing language "adequately investigated" and define the criteria by which the adequacy of an investigation will be judged.

2.4.3.6 Effect Compensated by a Combination

The term "effect compensated by a combination" was determined to be self-explanatory within the normal usage of words contained in the statement. No additional NRC guidance on this term is planned.

2.4.3.7 Favorable Characteristic Versus Favorable Conditions

Although the favorable "conditions" listed in 10 CFR 60.122(b)(1) through 10 CFR 60.122(b)(8) are referred to as favorable "characteristics" in 10 CFR 60.122(a)(2)(iii)(B) no distinction was intended between the two terms. The favorable conditions of 10 CFR 60.122(b) are the favorable characteristics called out in 10 CFR 60.122(a)(2)(iii)(B). No additional NRC guidance on this term is planned.

2.4.3.8 Can be Remedied

Although investigated by the CNWRA as a potential uncertainty, the language "can be remedied" was determined to be straight-forward and routinely definable in the normal use of the word "remedy." A remedy is either something that corrects or counteracts. Thus the effects of a potentially adverse condition could be alleviated by either changing the conditions itself or by counteracting only the resulting effects of the given condition through engineering means. No additional NRC guidance on this term is planned.

2.4.3.9 Characteristic

The word "characteristic" was determined to be routinely defined as "something that identifies a person, thing, or a class" (i.e., a group of individual elements common to the identifiable whole). No additional NRC guidance on this term is planned.

2.4.3.10 May Affect Isolation

The term "may affect isolation" was determined to be self-explanatory and no additional NRC guidance on this term is planned.

2.4.3.11 Controlled Area

The term "controlled area" is defined in 10 CFR 60.2 as "a surface location, to be marked by suitable monuments, extending horizontally no more than 10 kilometers in any direction from the outer boundary of the underground facility, and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be restricted following permanent closure." No additional NRC guidance on this term is planned.

2.4.3.12 Geologic Setting

"Geologic setting" is defined in 10 CFR 60.2 as " the geologic, hydrologic, and geochemical systems of the region in which a geologic repository operations area is or may be located. The definition of the term "geologic setting" as used throughout 10 CFR 60.122 and defined is determined by NRC staff to be ambiguous. There are 18 occurrences of the term in 10 CFR Part 60. DOE at a Tectonics Technical Exchange on October 31, 1989, questioned the meaning of "geologic setting" relative to the area which was supposed to be considered as a part of the "geologic setting." DOE did not know how the setting was to be bounded and whether "geologic setting" would apply to different sized regions for the different types of geologic processes which might be found at a site. A rulemaking is under consideration which will include clarification of the definition of the term. Approaches to utilizing the term "geologic setting" relative to natural resource considerations is discussed in Section 4.1 of this document. NRC is planning further analysis to resolve the question of the ambiguity in the definition of the term "geologic setting."

2.4.3.13 Quaternary Period

The length of time to be included in the "Quaternary period" is not included in 10 CFR 60.122(b)(1) and elsewhere in the regulation where the term is used. In the Staff Analysis of Public Comments ... (NRC, 1983, p.373), NRC provides a definition of the Quaternary period, as follows:

> "Although there is still debate in the geological community concerning the precise age of the Quaternary Period, the staff believes that for regulatory purposes an age of 2 million years is appropriate. This is because most geologists would assign an age of approximately 2 million years to the lower limit of the Quaternary Period (Pliocene/ Pleistocene boundary) based upon results of investigations on deep sea cores and on

the Calabria, Italy section. The staff considers that it is not necessary to quantify the term 'Quaternary' [further]."

No additional NRC guidance on this term is planned.

2.4.3.14 Fastest Path of Likely Radionuclide Travel

Relative to GWTT NRC has stated "...it is not certain that the fastest path of likely radionuclide travel can be delineated with reasonable assurance in heterogeneous geologic materials present at real repository sites." (NRC, 1988, Enclosure 2) The uncertainty referred to in NRC statement concerns the technical feasibility of establishing the fastest path of likely radionuclide travel in rock present at a given site. NRC is presently involved in clarifying ambiguity in the GWTT portion of the regulation. The term "fastest path of likely radionuclide travel" is a part of GWTT [10 CFR 60.113(a)(2)] and the favorable ground water travel time condition [10 CFR 60.122(b)(7)]. NRC plans to provide guidance to DOE on the radionuclide travel topic in the near future as a part of the clarification of the GWTT rule [10 CFR 60.113(a)(2)].

2.4.3.15 Disturbed Zone

The meaning and subsequent application of the term "disturbed zone" is unclear. There is no certainty in the means to establish the boundary of the disturbed zone in order to evaluate the effect of the disturbed zone on performance. Also, the boundary of the disturbed zone must be understood before the disturbed zone can be defined, unfortunately, in order to study and evaluate the disturbed zone the boundary of the disturbed zone must first be defined. A circular argument is evident. NRC is presently involved in clarifying ambiguity in the GWTT portion of the regulation. The term "disturbed zone" is a part of GWTT [10 CFR 60.113(a)(2)] and the favorable ground water travel time condition [10 CFR 60.122(b)(7)]. NRC plans to provide guidance to DOE on the disturbed zone topic in the near future as a part of the clarification of the GWTT rule [10 CFR 60.113(a)(2)].

2.4.3.16 Substantially Exceeds 1000 Years

This term was originally identified by the CNWRA as an uncertainty in the regulation but upon further consideration the term was considered not ambiguous. "Substantially exceeds" simply means that DOE is to provide a significantly large number of years above 1000 in its defense of its use of a GWTT greater than 1000 years as a favorable condition to "offset" any of the PAC which might be found at a site. The burden of proof is placed on DOE to show that the particular number of years above 1000 provides reasonable assurance that the performance objectives will be met even in the presence of one or more adverse conditions.

2.4.3.17 Treatment of Combinations of Potentially Adverse Conditions

There is an inconsistency in the treatment of combinations of PAC between 10 CFR 60.21(c)(1)(ii)(C) and 10 CFR 60.122. The former allows combinations of adverse conditions to be used in scenario development while the later suggests that only one adverse condition be compared to a combination of favorable conditions. If only one adverse condition at a time is considered, the synergistic effects of adverse conditions would not be required evaluated during the site selection and performance evaluation process.

10 CFR 60.122 is written in the singular and does not refer to combinations of PAC, implying that only a single adverse condition is to be evaluated against a multitude of favorable conditions. Moreover, 10 CFR 60.122(a)(1) specifically suggests that combinations of favorable conditions can offset any single potentially adverse. If NRC intent is to allow combining adverse conditions, then the regulatory basis and the conditions and constraints for combinations of adverse conditions in response to 60.112 should be placed into the public record. NRC is considering means to provide clarification of the relationship between 10 CFR 60.112 and 10 CFR 60.122. The current language of the regulation which requires each PAC to be individually evaluated against a combination of the favorable conditions when determining the performance of the repository is being reconsidered by NRC. An NRC option to be considered is a modification of the regulatory language so that combinations of the PACs are evaluated against combinations of the FC and other site conditions as a part of the overall system performance assessment.

2.4.3.18 Omission of Adequate Investigation/Evaluation of Effect, Favorable, and Remedy

Although the language of the regulation in 10 CFR 60.122(a(2)(iii)(A), 10 CFR 60.122(a)(2)(iii)(B), and 10 CFR 60.122(a)(2)(iii)(C) does not specifically state that an adequate investigation and evaluation of each topic is required, NRC believes that the tone of the regulation requiring adequate investigation and evaluation is a direction which must be accomplished in all aspects of studies of the PAC. No additional NRC guidance on this relationship is planned.

2.4.3.19 Evidence of

The regulatory intent of the meaning of "evidence of" was identified by the CNWRA as an uncertainty because it is not the "evidence of" a particular condition which is important rather it is the implications which such evidence provide regarding the future conditions expected during the lifetime of the repository which are important. NRC believes that it is the intent of the regulation that the condition itself is potentially adverse not the "evidence" of the condition's existence. NRC view is that the language of 10 CFR 60.122(a)(2) provides an adequate basis for placing the PAC in their proper context and that further elaboration on the meaning of "evidence of" is unjustified and unnecessary. No additional NRC guidance on this term is planned.

3 GEOLOGIC BASES FOR THE CONSIDERATION OF NATURAL RESOURCES AT THE PROPOSED HIGH-LEVEL RADIOACTIVE WASTE REPOSITORY AT YUCCA MOUNTAIN, NEVADA

3.1 INTRODUCTION

Resource evaluation, in part, requires an understanding of the geologic processes and conditions that are believed necessary to produce economic concentrations of a given resource (Reed et al., 1989; Harris and Pan, 1991). Geologic models for the formation and concentration of different resources (mineral, petroleum, etc.) are generally developed for localities where resource potential has been demonstrated, either through historic production or a mature exploration program. Developing these models involves interpreting the available geologic information, such as field mapping and borehole logs, and geochemical, structural, geophysical and remote sensing data. These data are then used to identify aspects of the setting related to the formation of a deposit such as physicochemical conditions (pressure, temperature, etc.), structures, host rock lithologies, source and trap rocks, and associated regional trends. Interrelationships among these features are evaluated in order to assemble genetic models for deposit formation. Comparisons between similar types of deposits aid in generalizing the model to various geologic settings, and in discriminating essential features.

Technical, economic, social and political factors all help determine the economic viability of a given deposit. For example, many types of mineral deposits such as disseminated gold/silver and industrial minerals rely on low production costs to return a profit at current prices and technologies. Therefore, the existence of an anomalous concentration of a resource may not by itself be a true indication of the likelihood of its exploitation. Limited reserves and/or high production costs due to thick overburden, lack of water, lack of an accessible market, or a need for sophisticated (or nonexistent) technology may all contribute to a deposit not being placed into production. Future production of these subeconomic concentrations may require that either prices rise beyond historical levels, or new technologies are developed that drastically reduce production costs, both of which are very difficult to predict over long time periods.

Therefore, to evaluate the resource potential of a given area, it is necessary to understand both the geologic environment, and economic limitations on production. In practice, geologic information that is readily available at the surface of the area is compared to the genetic models of deposit formation. Then the likelihood of similar processes and/or conditions having occurred in the area is evaluated, either through mathematical analysis (Pan and Harris, 1990) or subjective interpretation. Subsurface exploration is unlikely unless surface or geophysical indications are favorable. Economic requirements for exploitation of the resource (reserves, overburden, etc.) can also be evaluated in a general sense, and the resource potential estimated. This is, of course, an ideal case, and there are many uncertainties in both the models applied and the geologic knowledge of the area. In order to determine the potential for both discovered (identified) and undiscovered resources, however, it is clear that knowledge of the geology and a conceptual model of the types of deposits that might occur in the area of interest are necessary.

The geologic history of the area of the proposed HLW Repository at Yucca Mountain (Figures 3-1 and 3-2) is perhaps best understood in terms of the regional geology of the Great Basin subprovince of the Basin and Range physiographic province (Figure 3-3), which incorporates most of the state of Nevada and parts of each of the adjoining states. A discussion of the geology of the southern Great Basin

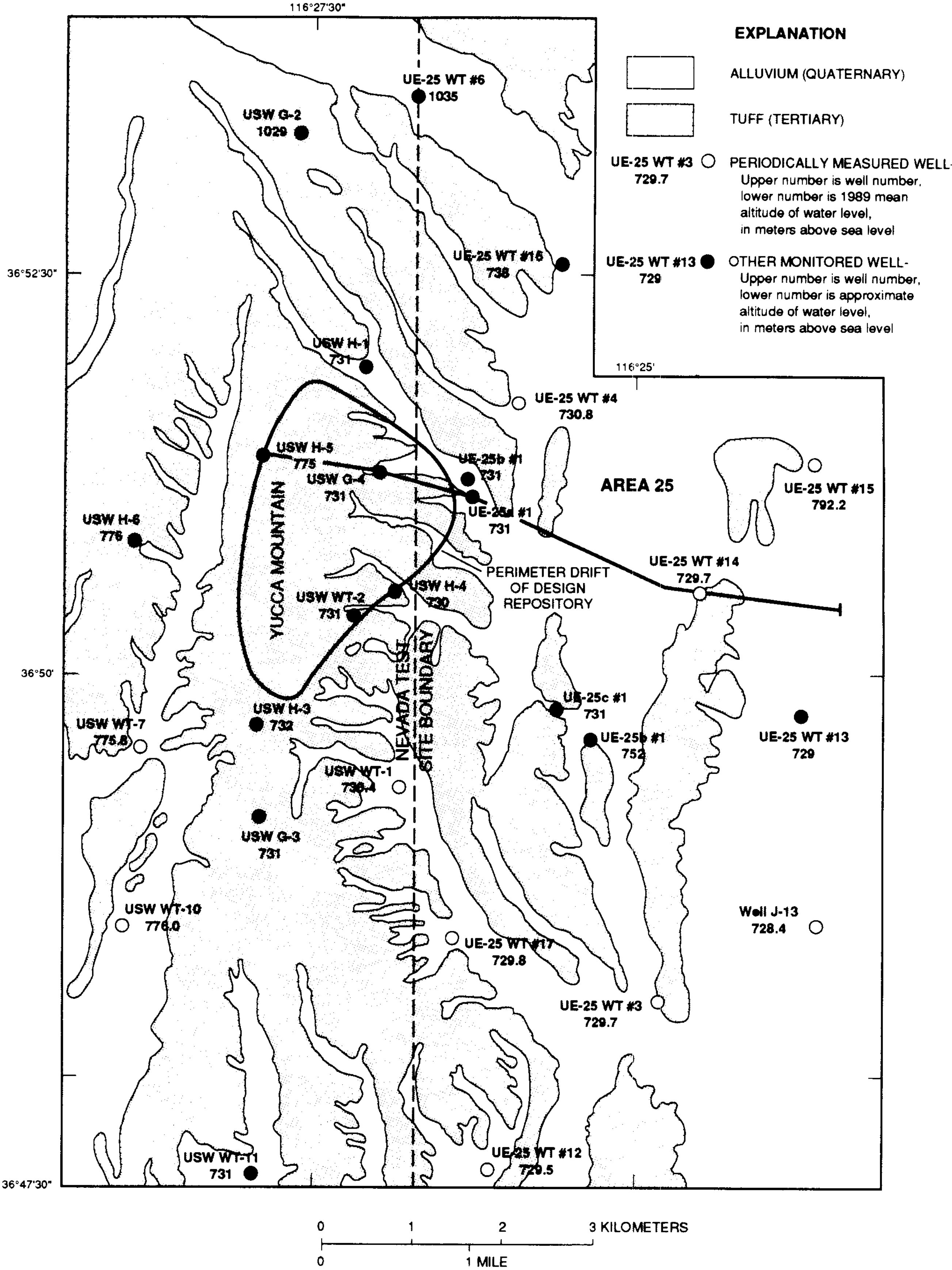


Figure 3-1. Location map for Yucca Mountain, Nevada. The heavy line across Yucca Mountain marks the location of the west-east cross section of Figure 3-2 (modified from O'Brien, 1991).

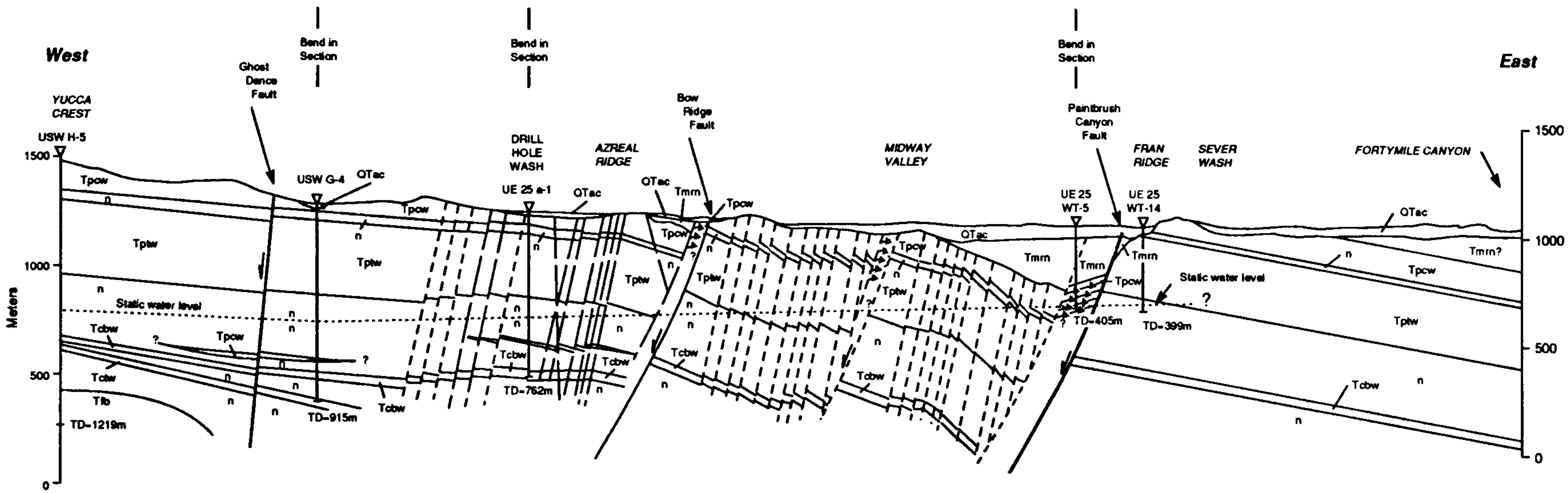


Figure 3-2. West-east cross-section, Yucca Mountain, Nevada. Abbreviations are: QTac-Alluvium; Tmrn-Rainier Mesa Mbr, Timber Mountain Tuff; Tpcw-Tiva Canyon Mbr, Paintbrush Tuff; n-nonwelded tuff; Tptw-Topopah Spring Mbr, Paintbrush Tuff; n-nonwelded tuff; Tcbw-Bullfrog Mbr, Crater Flat Tuff (modified from Scott and Bonk, 1984).

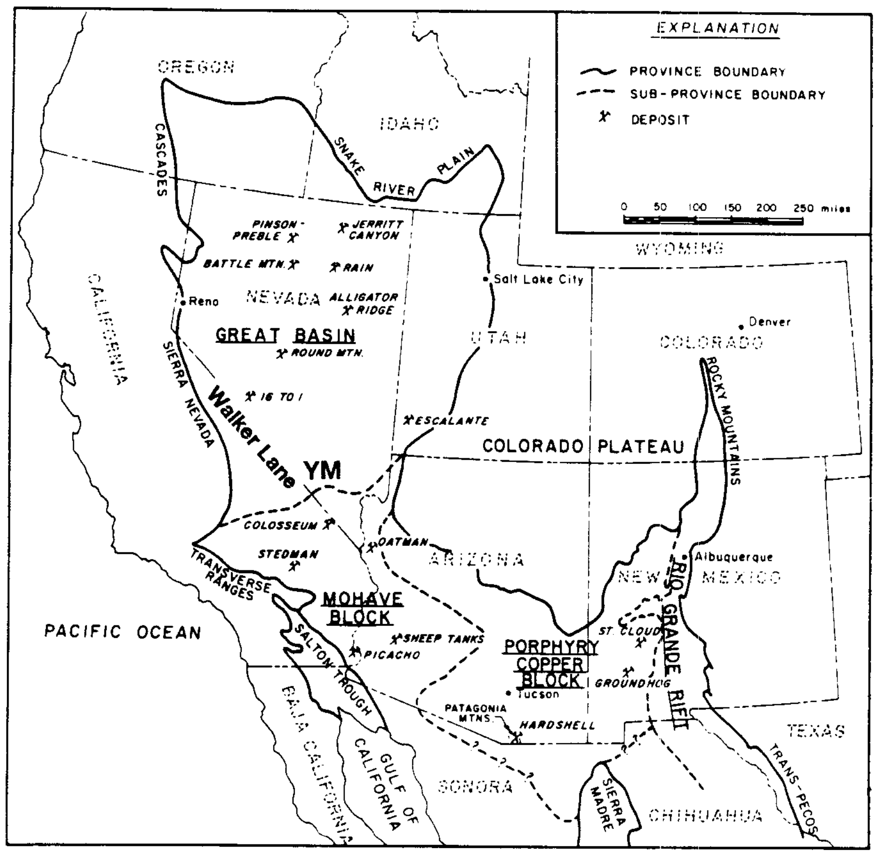


Figure 3-3. Geographic subprovinces of the Basin and Range geographic province, western United States. YM-Yucca Mountain (modified from Wilkins, 1984).

and the Yucca Mountain vicinity will be undertaken by considering the stratigraphic history (Figures 3-4 and 3-5), and then the tectonic activity of the region.

3.2 STRATIGRAPHIC HISTORY

Stratigraphic control is often apparent in the concentration and distribution of many types of mineral, petroleum, geothermal, and groundwater resource reserves. Organic-rich shales are postulated as source rocks for hydrocarbon and coal resources, and the leaching of large volumes of sediments and volcanics has been inferred as the source for valuable metal resources. Porous sedimentary and volcanic rocks serve as channels and aquifers for the migration of groundwaters, hydrocarbons, and mineralizing fluids, while relatively impermeable units can act as a cap rock to focus these fluids and provide economic concentrations of a given resource. In hydrothermal systems, a reactive host rock may act as a buffer on the physicochemical system during ore deposition, or provide critical elements through dissolution. Inherently brittle rocks may preferentially fracture during deformation, providing both favorable structures for the migration and localization of resource-bearing fluids, and potential ore depositional mechanisms through pressure decreases and associated secondary boiling. In order to use stratigraphy as an aid in resource evaluation, it is important to understand the distribution of the various types of stratigraphic units encountered in the geologic environment of interest. The following section considers the stratigraphic history of the Great Basin physiographic province, with particular emphasis on the Yucca Mountain vicinity.

3.2.1 Precambrian Stratigraphy

Precambrian outcrop is sparse in Nevada, being largely limited to Esmeralda, Nye, and Clark Counties in the southern part of the state and eastern White Pine and Elko Counties (see Figure 3-6 for county locations). From oldest to youngest, the Precambrian units in Nevada consist of: gneiss and schist, dated at 1.7 to 1.4 b.y. (Stewart, 1980); and partially metamorphosed quartzite, shale, and carbonate believed to be deposited at the western edge of the North American continent. In the Yucca Mountain area, Precambrian outcrop is limited to gneiss and schist in the Bullfrog Hills to the northwest, and the quartzite, sandstones, and shales of the Johnnie Formation and Sterling Quartzite in the Spring Mountains to the southeast (Stewart, 1980; McKague et al., 1989). These rocks are believed to underlie the proposed repository site at Yucca Mountain at depth, but have not been encountered at current drilling depths (McKague et al., 1989).

3.2.2 Paleozoic Stratigraphy

Paleozoic rocks in the Great Basin can be broadly divided into two assemblages (Stewart, 1980): an eastern carbonate assemblage which contains the Yucca Mountain exploratory block, and a western siliceous-volcanic assemblage which dominates western Nevada and parts of California (Figure 3-7). The eastern assemblage consists largely of a westward-thickening sequence of marine sediments deposited in the miogeoclinal basin between the craton to the east in eastern Utah and the siliceous-volcanogenic eugeoclinal sequence associated with a possible island-arc terrain to the west in California (Hintze, 1973; Stewart, 1980; DOE, 1988). Clastic sediments dominated the eastern assemblage during the early Cambrian period (Wood Canyon Formation), grading upwards into thick marine limestone and dolomite sequences with clastic intervals, such as the Cambrian Dunderburg Shale, and the Ordovician Ninemile Formation and Eureka Quartzite. Carbonate deposition dominated the eastern assemblage from middle Cambrian through late Devonian.

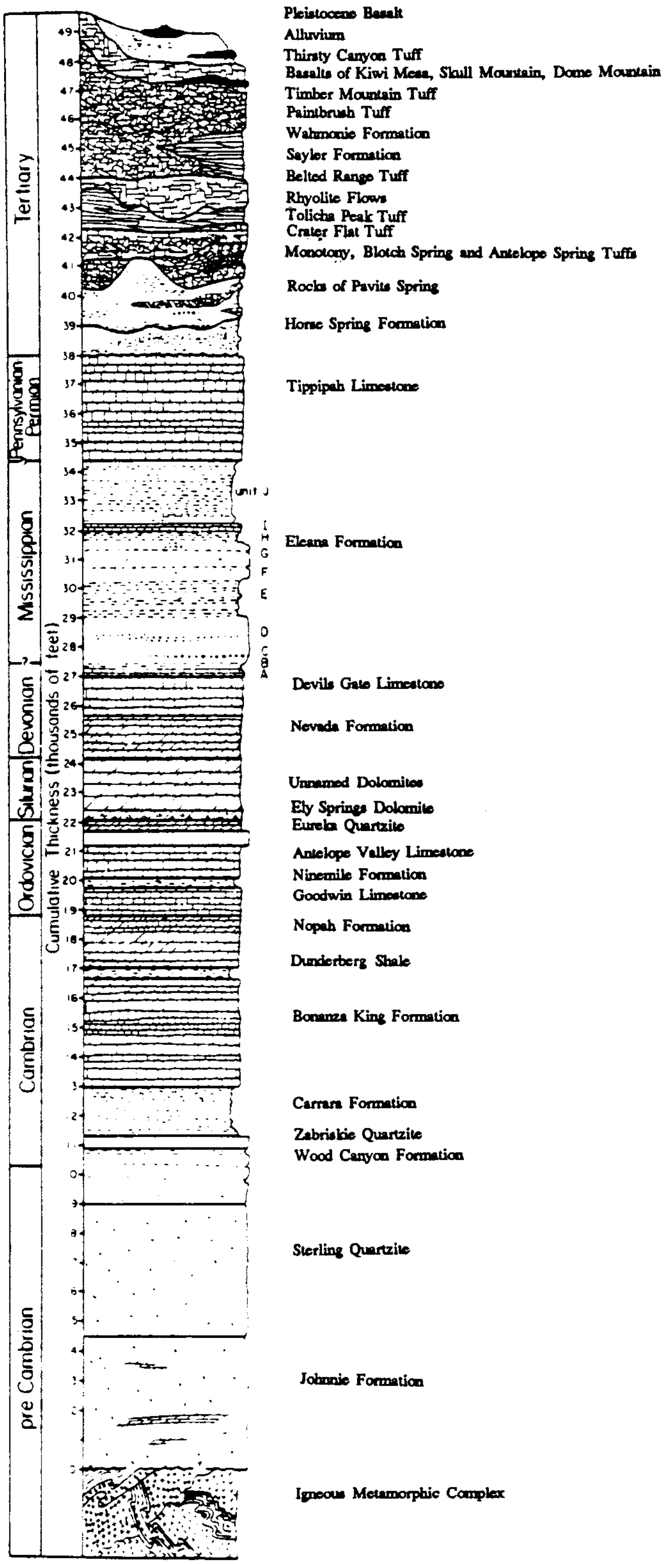


Figure 3-4. Generalized regional stratigraphy of southern Nevada (after Sinnock, 1982).

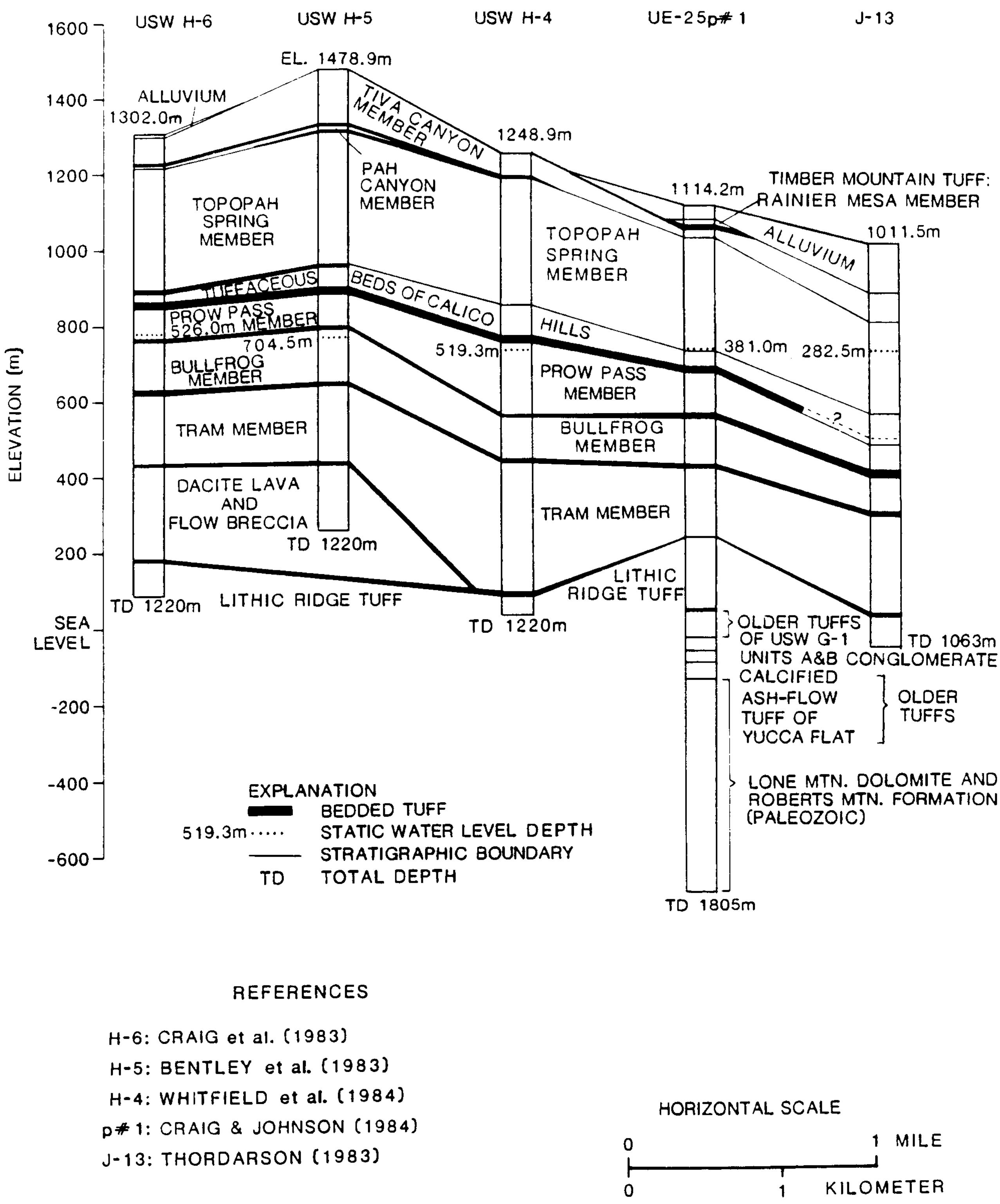


Figure 3-5. Tertiary stratigraphy in the vicinity of Yucca Mountain. Drill hole locations are shown in Figure 3-1. Only drill hole UE-25p#1 intercepts pre-Tertiary rocks (from DOE, 1988).

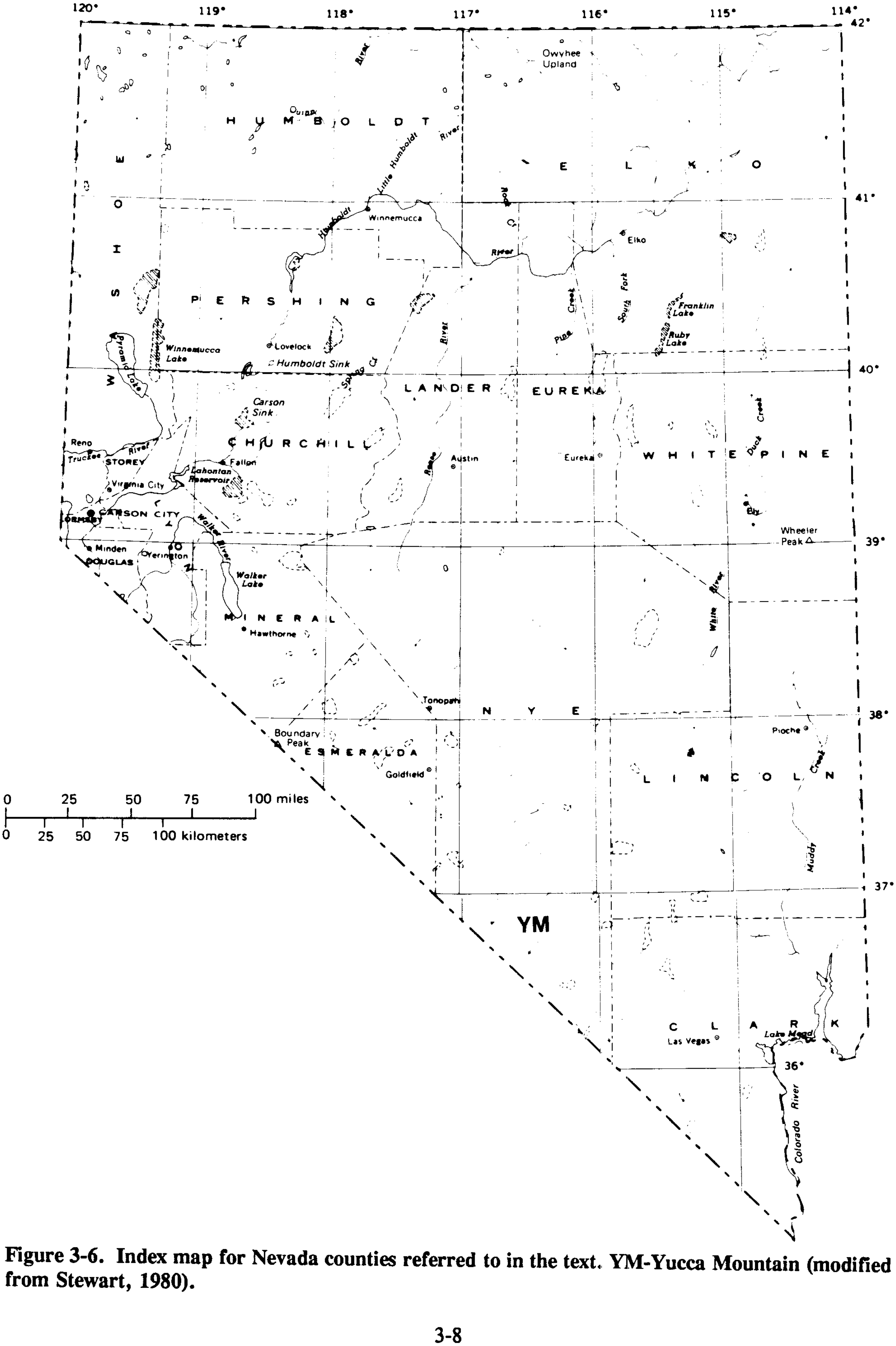


Figure 3-6. Index map for Nevada counties referred to in the text. YM-Yucca Mountain (modified from Stewart, 1980).

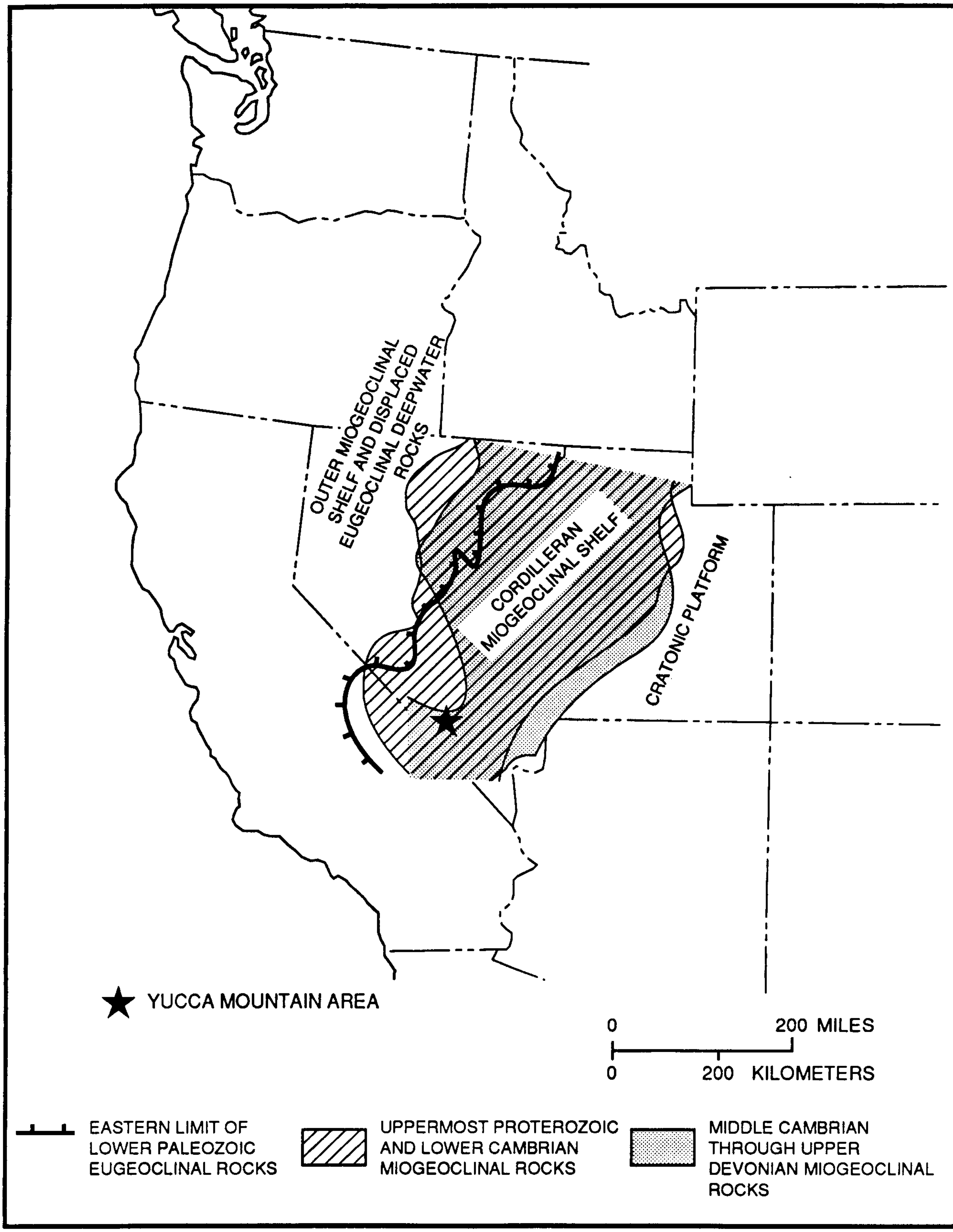


Figure 3-7. Precambrian through Middle Devonian paleogeography of the Great Basin (after DOE, 1988).

With the onset of eastward thrusting during the Devonian/Mississippian Antler Orogeny (see below), a highland belt was created to the west of the miogeoclinal basin that had dominated the depositional environment during most of the Paleozoic (Figure 3-8). Outcrop from the siliceous and volcanic highland provinces (Stewart, 1980) is preserved in the western part of the state. Clastic sediments and flysch deposits (Mississippian/Devonian Pilot Shale, Mississippian Diamond Peak and Eleana Formations, and the Mississippian Chainman Shale) resulting from the erosion of this highland were deposited to the east, forming a band of eastward-thickening clastic rocks that now crop out in the eastern half of the state. Thick carbonate sequences continued to be deposited further to the east between these highland-derived sediments and the craton. These depositional conditions continued through the close of the Permian.

3.2.2.1 Yucca Mountain Vicinity

In the southern Great Basin, the Paleozoic section (Figure 3-4) is fairly complete, extending from the Cambrian Wood Canyon Formation to the southeast near Lathrop Wells, upwards through the Permian Tippipah Limestone at Syncline Ridge to the northeast (Cornwall, 1972), for a total thickness of approximately 9000 m (McKague et al., 1989). Paleozoic rocks do not crop out in the exploratory block, but they are believed to underlie the Tertiary volcanics of Yucca Mountain (DOE, 1988; Mattson et al., 1989). To date, however, Paleozoic carbonate (Silurian Lone Mountain Dolomite and Roberts Mountain Formation) has only been encountered in drill hole UE-25p#1 (Figure 3-5) about 3 km to the southeast of the site at a depth of about 1200 m (Carr et al., 1986).

3.2.3 Mesozoic Stratigraphy

3.2.3.1 Sedimentary Rocks

As with the Paleozoic rocks, Mesozoic sedimentary rocks in north and north-central Nevada can be divided into an eastern and a western assemblage. These assemblages are separated by a Triassic Upland, inferred from the absence of Triassic rocks in the central part of the state. This depositional environment continued at least through the early Jurassic, although there is evidence to suggest that the Triassic Upland was removed prior to Jurassic time (Stewart, 1980). Eastern rock assemblages are predominantly shallow water marine carbonates and siltstones (Triassic Moenkopi Formation) grading upward into continental sandstones, conglomerates and clays (Jurassic Aztec Sandstone). The western assemblage consists of a sequence of carbonate, terrigenous detrital rocks, volcanogenic clastic rocks, and volcanic tuffs and flows. By late Jurassic time, sediment deposition had largely ceased. Although outcrop is mostly limited to Eureka and Clark Counties, minor deposition continued into the Cretaceous, with continental conglomerates and detritus derived from the thrusting associated with the Sevier Orogeny (see below). Some serpentinite is found in northwest Nye County and western Mineral County, and is believed to be associated with the Permian/Triassic Sonoma Orogeny (see discussion later).

3.2.3.2 Igneous Rocks

Mesozoic igneous activity in the Great Basin occurred at roughly the same time as the formation of the granitic terrain of the Sierra Nevada, and was largely confined to the western part of Nevada. More recent Ar/Ar age-dating in the Grant Range of southeastern Nevada indicates, however, that some intrusions, previously dated as Tertiary using K/Ar techniques (Armstrong, 1970), are actually Cretaceous in age (J. Fryxell, 1990 Personal Communication). This may reflect a Tertiary resetting of the

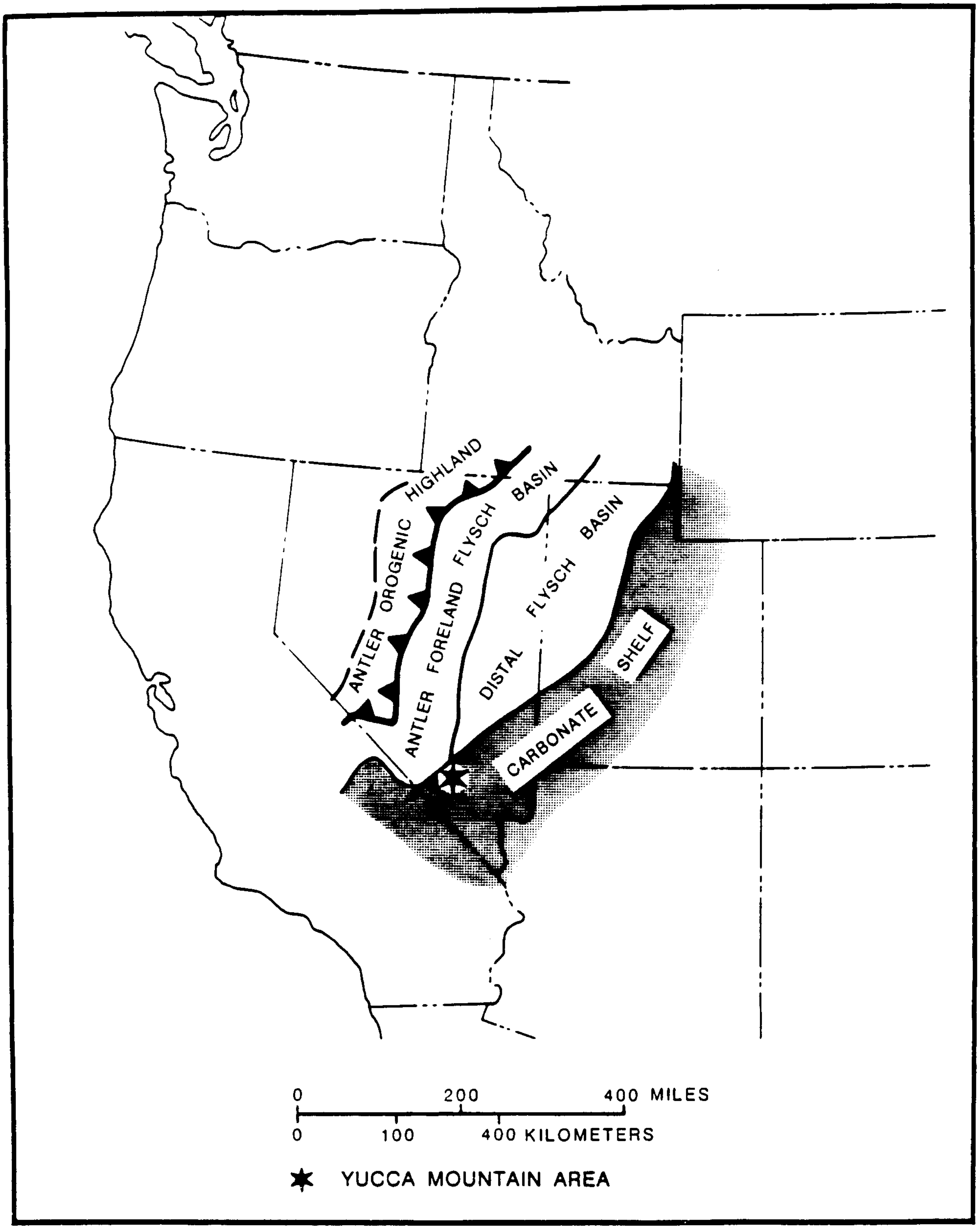


Figure 3-8. Late Devonian through Mississippian paleogeography of the Great Basin (after DOE, 1988).

radiometric "clock", and suggests a broader distribution of Mesozoic igneous activity. Most of the Mesozoic plutonic rocks in Nevada are equigranular calc-alkaline intrusions, and most have been dated as post-Triassic. Most of the Mesozoic granitic plutons in the Great Basin are Cretaceous in age, and there is a general trend towards more silicic compositions from Triassic through Cretaceous time. There are some dioritic Jurassic/Cretaceous plutons which are mostly limited to outcrops in Mineral and Esmeralda Counties. Mesozoic igneous activity is associated with many of the known mineral deposits of Nevada and California, and will be discussed in more detail below.

3.2.3.3 Yucca Mountain Vicinity

Mesozoic outcrop near Yucca Mountain is extremely sparse, and is limited to the Climax and Gold Meadows stocks at the north end of Yucca Flat. The stocks are granodiorite/quartz monzonite in composition (Barnes et al., 1963). Fission-track dating yields ages of 101 m.y. and 94 m.y. for the Climax and Gold Meadows stocks, respectively (Naeser and Maldonado, 1981). Megabreccias of uncertain Mesozoic/Tertiary age crop out at the south end of Yucca Mountain, and are composed almost entirely of dolomite and limestone fragments from the Cambrian Bonanza King Formation (Cornwall, 1972).

3.2.4 Cenozoic Stratigraphy

3.2.4.1 Sedimentary Rocks

In the Great Basin, Tertiary sedimentary rocks are widely distributed, and deposits from the entire period are found intercalated with volcanic rocks. In the lower Tertiary, the sediments consist of nonvolcanic, nonmarine conglomerate, limestone, shale and sandstone, and some volcanogenic sediments. Typical of these is the Sheep Pass Formation of Northern Nye County, which is limited to local basin fill, although total thicknesses ranges up to 1000 m or more. Younger sedimentary rocks consist of conglomerate, sandstone, siltstone, and limestone units. These rocks are largely volcanogenic in origin, and consist of fluvial and lacustrine reworking of contemporaneous tuffs and lavas. More than half of the surface area of Nevada is covered by unconsolidated sediments of Pliocene and younger age. These sediments largely consist of alluvial fan, playa and valley fill deposits with minor contributions from sand dunes, beaches, and landslides.

3.2.4.2 Igneous Rocks

Nearly one-fourth of the surface area of Nevada is covered by Cenozoic igneous rocks (Stewart, 1980). Major igneous activity began at about 43 m.y. and continued throughout the Tertiary period. Igneous rocks have been divided into four age categories based on changes in the character and distribution of the igneous activity (McKee, 1971; Stewart, 1980). The oldest rocks (43 to 34 m.y.) are dominated by andesitic and rhyolitic lavas. Between 34 and 17 m.y., the character of the volcanic activity changed to the eruption of tremendous volumes (up to 2000 km^3) of dominantly silicic tuffs (Monotony Tuff). At about 17 m.y. the current Basin and Range tectonism became established and there was a brief cessation of volcanic activity. Upon resuming, the nature of the volcanism changed to the eruption of basaltic lavas, bimodal basalt/rhyolite volcanism and caldera formation (Timber Mountain Tuff, Paintbrush Tuff). Widespread volcanism ended at about 6 m.y., and subsequent activity continuing into the Pleistocene was largely limited to cinder cones and lava flows (Lunar Crater). There is a general concentric age zonation of the igneous rock (Figure 3-9), with the oldest rocks found in the northeast

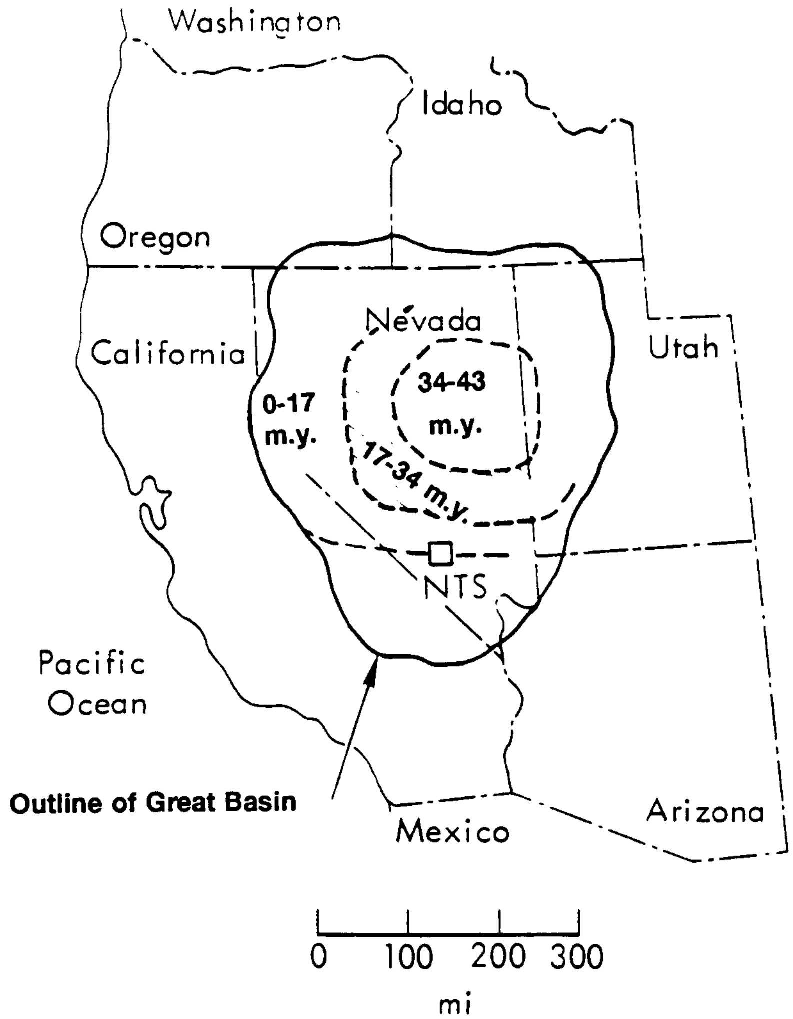


Figure 3-9. Zoned age relationships of Tertiary volcanism of the Great Basin. Numbers show approximate age of volcanics in millions of years. NTS-Nevada Test Site (modified from Hannon and McKague, 1975).

corner of the state, and becoming increasingly younger with distance from this center (Hannon and McKague, 1975). Calc-alkaline and silicic intrusions were emplaced throughout the Tertiary, and their geographic distribution is consistent with volcanic activity of similar age. Cenozoic igneous activity is associated with many of the known mineral resources of Nevada, and will be discussed below. Quaternary igneous activity is mostly restricted to small lava flows and cinder cones along a north-south trend in Nye County, from Lunar Crater at the south end of the Pancake Range to Death Valley. Scattered cones, andesites, and maar basalt flows occur along the California/Nevada border in Mineral, Esmeralda, and Lyon Counties, although some of this may be from eruptions at Mono Craters, California.

3.2.4.3 Yucca Mountain Vicinity

Near Yucca Mountain, the maximum thicknesses of all Tertiary units form a sequence with a composite thickness of over 12,000 m (Marvin et al., 1970; Hannon and McKague, 1975). The Titus Canyon Formation represents early-Tertiary sedimentation similar to the Sheep Pass Formation of northern-Nye County. The oldest series of Great Basin Cenozoic volcanics (43 to 34 m.y.) are not found in southern Nevada; the oldest volcanics in the vicinity of the Nevada Test Site are dated at 29 m.y. (part of the Horse Spring Formation, 37-24 m.y.), and all subsequent Cenozoic volcanic periods are represented. Yucca Mountain is primarily composed of Tertiary volcanics. The bulk of the igneous activity began with the eruption of rhyolite to dacite, welded to nonwelded tuffs at about 16 m.y. from calderas to the north (DOE, 1988), and culminated in the eruption of the Thirsty Canyon Tuff from the Black Mountain Caldera at about 7 m.y. This interval includes the Calico Hills, and Paintbrush Tuffs, units which will host and isolate the proposed repository, and the Timber Mountain Tuff which overlies them on the eastern flank of Yucca Mountain. Tertiary units at Yucca Mountain decrease in thickness from west to east. Drill core along the mountain crest (e.g., USW-G1) has penetrated to 1800 m without leaving the volcanics. About 3 km to the southeast of the exploratory block (UE-25p#1, Figure 3-1), Silurian carbonate has been reached at about 1200 m (Carr et al., 1986).

Subsequent volcanism consisted of basaltic lava flows and cinder from vents and cones that are consistent with the Death Valley/Pancake Range volcanic zone (Crowe et al., 1986; DOE, 1988). These rocks have been divided into three periods of activity, with flow volume decreasing through time (DOE, 1988). The oldest is 11 to 8.5 m.y., and involved bimodal basalt/rhyolite eruption. The second episode consisted of the eruption of basaltic lavas from 9 to 6.5 m.y. After a brief hiatus, the final episode began at 3.7 m.y., and continued through the late Pleistocene epoch.

3.3 STRUCTURAL HISTORY

Structural control of resource distribution is readily apparent at a variety of scales, from vein deposits along fractures, to springs on fault lines, to structural hydrocarbon traps. Fracturing associated with structural deformation provides enhanced permeability and conduits for the migration and focussing of hydrothermal fluids, hydrocarbons, and groundwaters. Folding of favorable units can provide anticlinal traps for hydrocarbons and hydrothermal fluids, while extension may result in fault block traps. Faulting frequently provides access for fluid circulation to a heat source at depth, and may lead to pressure fluctuations that can act as an ore depositional mechanism. Movement related to tectonic activity may superimpose units that are not in stratigraphic contact, creating a favorable environment for ore deposition or hydrocarbon maturation and migration. As with stratigraphic controls, an understanding of the temporal and spatial distribution of different types of deformation is necessary in order to use structural control as a tool in the resource evaluation of a given area. The following discussion considers the structural and tectonic history of the Great Basin and the Yucca Mountain vicinity.

3.3.1 Precambrian Structure

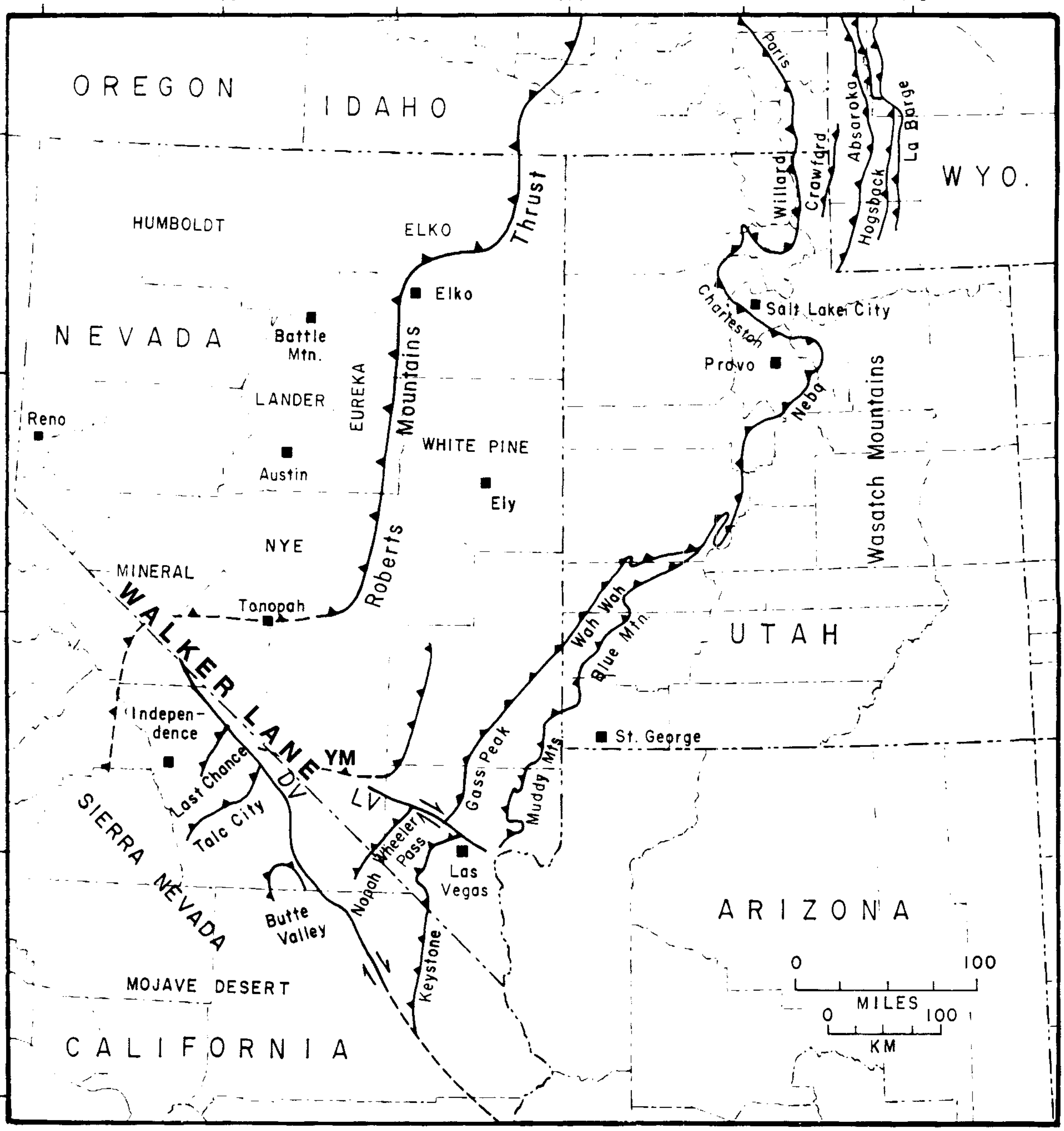
Precambrian structure is poorly understood in Nevada due to the lack of surface exposure. A deformational episode dated at approximately 1,750 m.y. (Stewart, 1980) is believed to be associated with the Hudsonian Orogeny (Hannon and McKague, 1975), and there are some slightly later intrusions (~ 1,500 m.y.). By the end of the Precambrian, the depositional environment that persisted through the Paleozoic era was well established.

3.3.2 Paleozoic Structure

During the early Paleozoic, the Great Basin lay to the west of the North American craton with an island-arc terrain developing to the west in California. The only evidence of orogenic activity prior to Late Devonian suggests a possible mild disturbance in the Ruby Mountains in Elko County during Ordovician time. Thrusting during the Late Devonian/Mississippian Antler Orogeny resulted in the eastward emplacement of western assemblage siliceous rocks over the shallow marine carbonates of the eastern assemblage. Displacement along the Roberts Mountain Thrust may have been as much as 145 km, and the resultant Antler highlands dominated sediment deposition for the rest of the Paleozoic (Figure 3-10). Compressional folding and faulting is associated with the overthrusting. The tectonic setting associated with the Antler Orogeny has been proposed as an eastward-migrating island arc during ocean closure (Poole, 1974; Dickinson, 1977; Stewart, 1980). During Late Permian/Triassic time, eastward overthrusting was renewed with the Sonoma Orogeny, emplacing oceanic siliceous and volcanic rocks to the east over shallow water sediments of the Antler highland belt. Displacement along the Golconda thrust, the major structural feature of the Sonoma Orogeny, may be as much as 70 km. The proposed tectonic setting is similar to that for the Antler Orogeny with an eastward migration of a magmatic island arc toward the continent resulting from ocean closure (Speed, 1977, 1979). The Yucca Mountain exploratory block lies in the footwall of both the Roberts Mountain and Golconda thrusts (Stewart, 1980), and compressional faulting and folding of the allocthons related to overthrusting is not preserved at the surface.

3.3.3 Mesozoic Structure

The tectonic setting of the early Mesozoic was dominated by continued overthrusting of the Sonoma Orogeny which began in the Late Permian (Figure 3-11). Post-Sonoma east-vergent imbricate thrusting and associated compressional folding in Nevada have been related to the Sevier Orogeny (Armstrong, 1968), which began in the middle Jurassic and may have continued through the end of the Mesozoic. In western Utah, this overthrusting is large-scale, with displacement on the order of 30 to 120 km. In Nevada, displacement is less (30-70 km), and includes the Eureka Fold and Thrust belt of central Nevada, the Keystone and Pahranagat thrust of southern Nevada, and the Mine Mountain and CP thrusts in southern Nye County, southeast of Yucca Mountain. Metamorphic core complexes have been identified in northern and eastern Nevada in the Ruby Mountains, Snake Range, and possibly the White Pine Range, and assigned a tentative Jurassic age (Stewart, 1980). Low-angle detachment faults in Nye, White Pine, and Lincoln Counties (Figure 3-11) involving the emplacement of younger over older rocks (mostly Paleozoic), are believed to be Middle to Late Mesozoic in age (Stewart, 1980). In the Yucca Mountain area, right-lateral strike-slip faulting of the Walker Lane/Las Vegas Valley Shear zone in western and southern Nevada may also have begun during the Jurassic (Speed, 1978). Total lateral displacement may be as much as 190 km, and field evidence suggests that activity continued into the Tertiary period as recently as 11 m.y. (Anderson et al., 1972; Hardyman et al., 1975). The tectonic setting of the Mesozoic Era is believed to be one of subduction to the west of the North American Continent. Subduction resulted in the welding of island arc terrains to the western edge of the craton, and is perhaps related to the Laramide Orogeny responsible for the uplift of the Cordillera to the east of the Basin and Range.



Thrust fault. *Dashed where inferred; sawteeth on upper plate. Depicts leading edge of fault system or major fault*

Strike-slip fault. *Dashed where inferred; arrows show relative horizontal movement. LV—Las Vegas Valley shear zone. DV—Death Valley-Furnace Creek fault zone*

Figure 3-10. Major regional-scale structural features of the Great Basin. YM-Yucca Mountain (modified from Stewart, 1980).

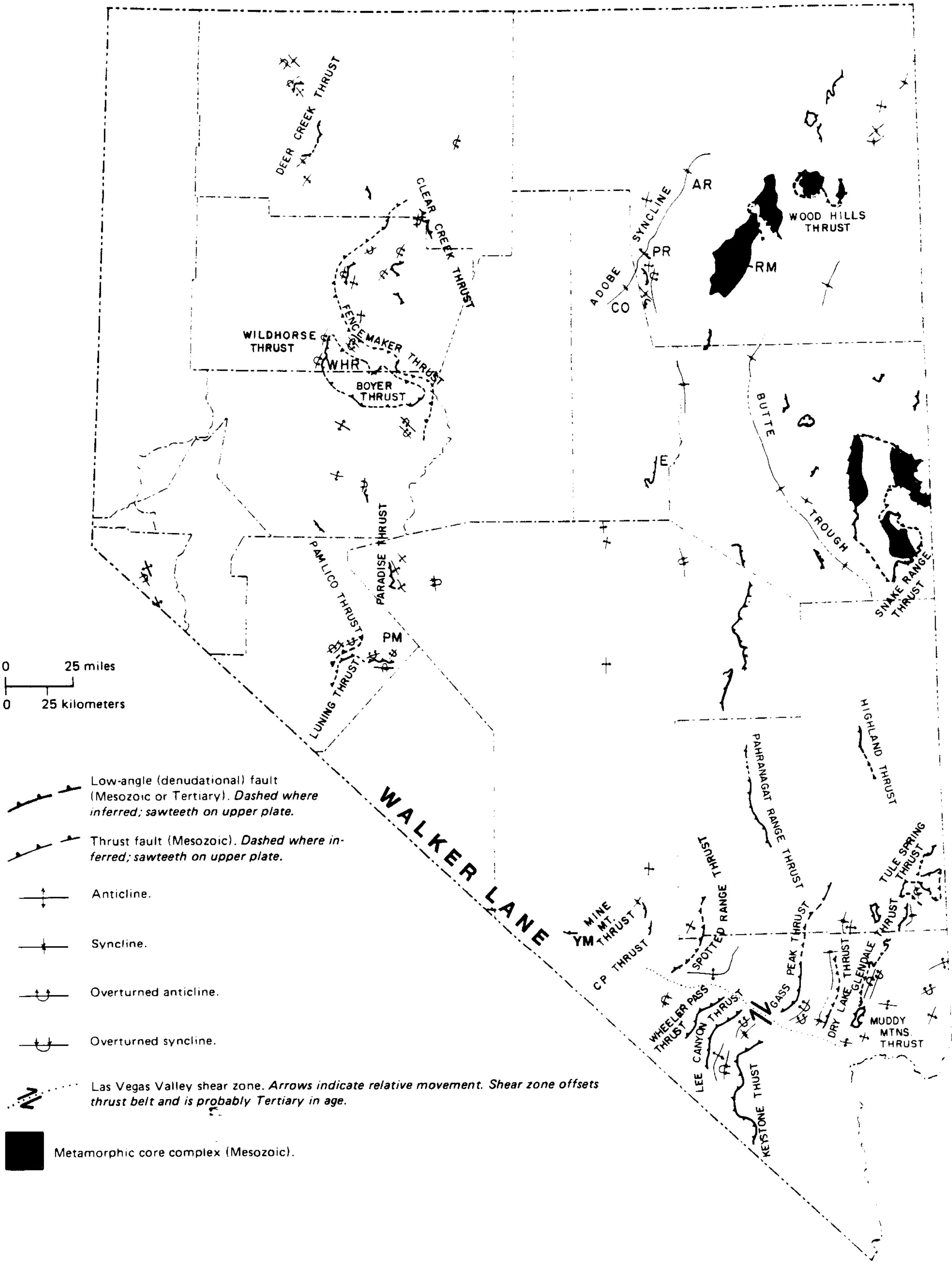


Figure 3-11. Mesozoic structures of the Sevier orogeny of Nevada. YM-Yucca Mountain; WHR-West Humboldt Range; PM-Pilot Mountain; CO-Cortez Range; PR-Pinon Range; AR-Adobe Range; E-Eureka; RM-Ruby Mountain; SR-Snake Range (modified from Stewart, 1980).

3.3.4 Cenozoic Structure

Two main structural features are associated with the Cenozoic Era (Figure 3-12). The first includes caldera-formation and extensional faulting associated with the eruption of the silicic tuffs (34 to 6 m.y.). This is largely confined to Nye, Esmeralda, and Lander Counties, although there are other scattered locations throughout the state. Caldera-formation is intimately associated with the Yucca Mountain area, where a cluster of calderas from Mount Helen (> 14 m.y.) through Timber Mountain (~11 m.y.), and ending with the Black Mountain Caldera (~7 m.y.), erupted the thick tuff sequence that is being considered for the repository (Hannon and McKague, 1975).

The second, and dominant, structural feature of the Great Basin is the normal faulting associated with Basin and Range extension, beginning at about 17 m.y. and continuing into historic time. The onset of extension is believed to be related to the migration of the East Pacific Rise to contact the North American Continent beginning at about 28 m.y. (Engebretson et al., 1985). Three fault geometries have been associated with Basin and Range extension: high-angle normal faulting, listric normal faulting, and low-angle extension, all of which may be present in the vicinity of Yucca Mountain (DOE, 1988). Each of the three types are thought to merge at depth (15 km) at the brittle-ductile transition zone (Eaton, 1982; DOE, 1988). Right-lateral strike-slip faulting also continued through the Tertiary along the Las Vegas Valley Shear zone and Walker Lane (Hardyman et al., 1975). Using Mesozoic thrust faults in the Grapevine, Funeral and Cottonwood Mountains to the south of Yucca Mountain as markers across the Death Valley-Furnace Creek fault zone, Wernicke et al. (1988) proposed Neogene extensional displacement in the southern Great Basin of as much as 250 km along a NW trend. This large scale extension along low-angle features occurred predominantly during the last 15 m.y., with strain rates of 20-30 mm/yr from 15-10 m.y., slowing to 10 mm/yr from 5 m.y. to the present.

There is no evidence of Quaternary activity in the Las Vegas Valley Shear zone, but the 1932 Cedar Mountain earthquake may indicate historic activity along Walker Lane. The Yucca Mountain structural block itself has been tilted to the east along a series of north-trending high-angle Basin and Range normal faults (Figure 3-2).

3.4 NATURAL RESOURCES

To estimate the resource potential of an area, it is necessary to have some knowledge of the types of deposits (mineral, petroleum, geothermal, and groundwater) that have been discovered and produced, within the regional geologic environment of the area. For the purposes of the following discussion, this regional framework is proposed to be the Great Basin subprovince, although the adjacent subprovinces of the Basin and Range are also discussed where necessary. The types of potential deposits found in the Great Basin are reviewed in the following section, then the local geologic environments of these deposits are compared to the area of interest (Yucca Mountain). Clearly, there are a large number of mineral deposits found in other geologic and geographic provinces (e.g, banded iron, kimberlite pipes, bauxite, etc.) which may not reasonably be expected to occur in the Great Basin or its sub-components, and these will not be considered further. Only those types of resources (mineral, energy, groundwater) that either have been identified previously in Nevada (e.g., Figure 3-13), or which could be reasonably expected to occur in a geological environment such as the Great Basin given the current level of geologic understanding, will be discussed.

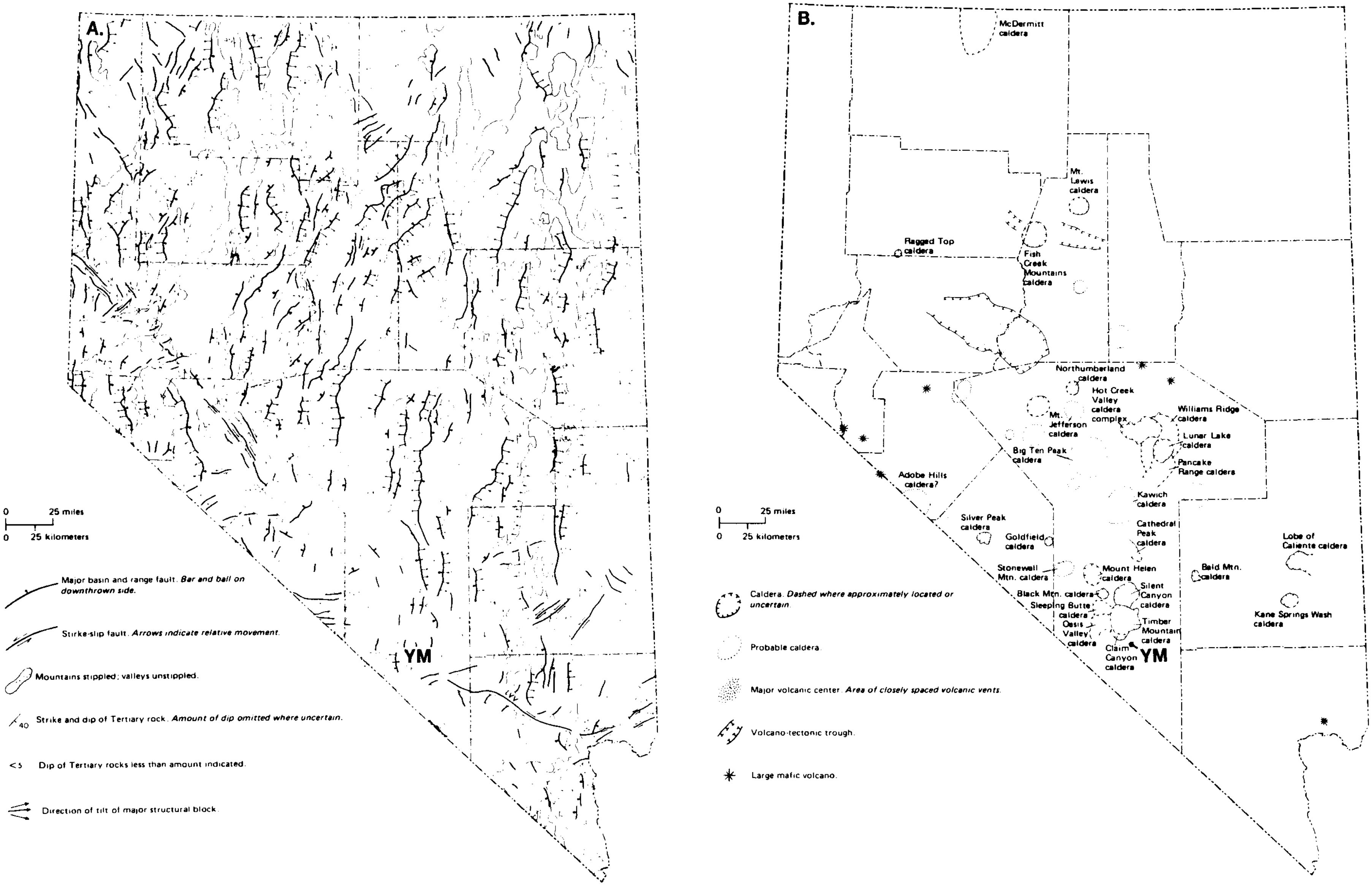
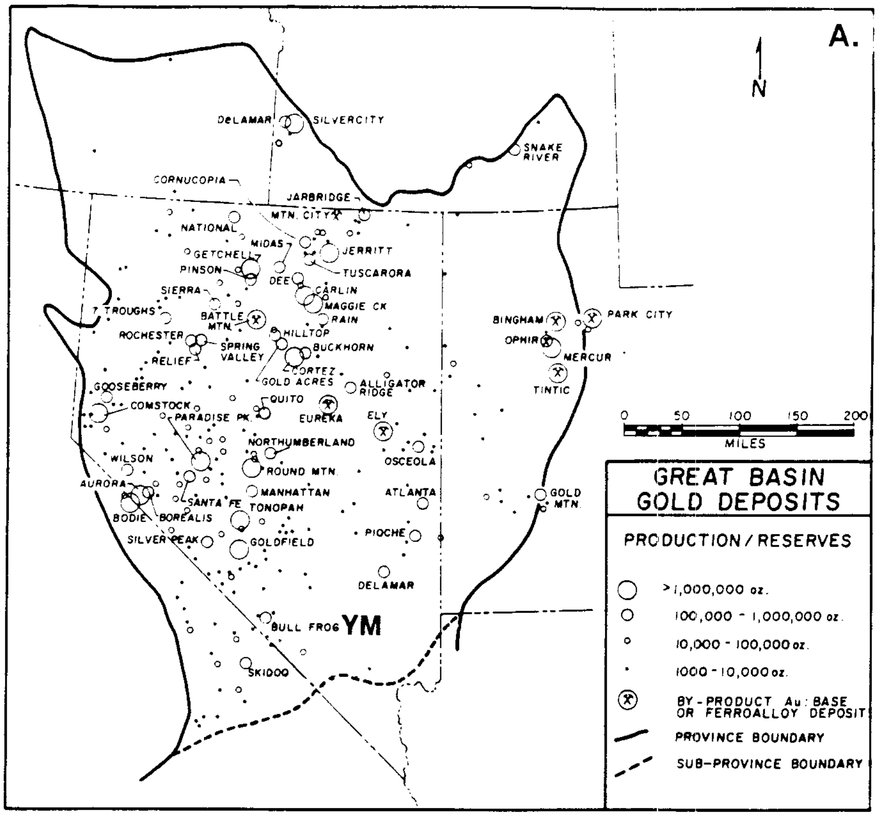


Figure 3-12. Tertiary structures of Nevada. a) Basin and Range-type extensional normal faulting. YM-Yucca Mountain; LVV-Las Vegas Valley Shear Zone. b) Major Tertiary calderas and vents (modified from Stewart, 1980).



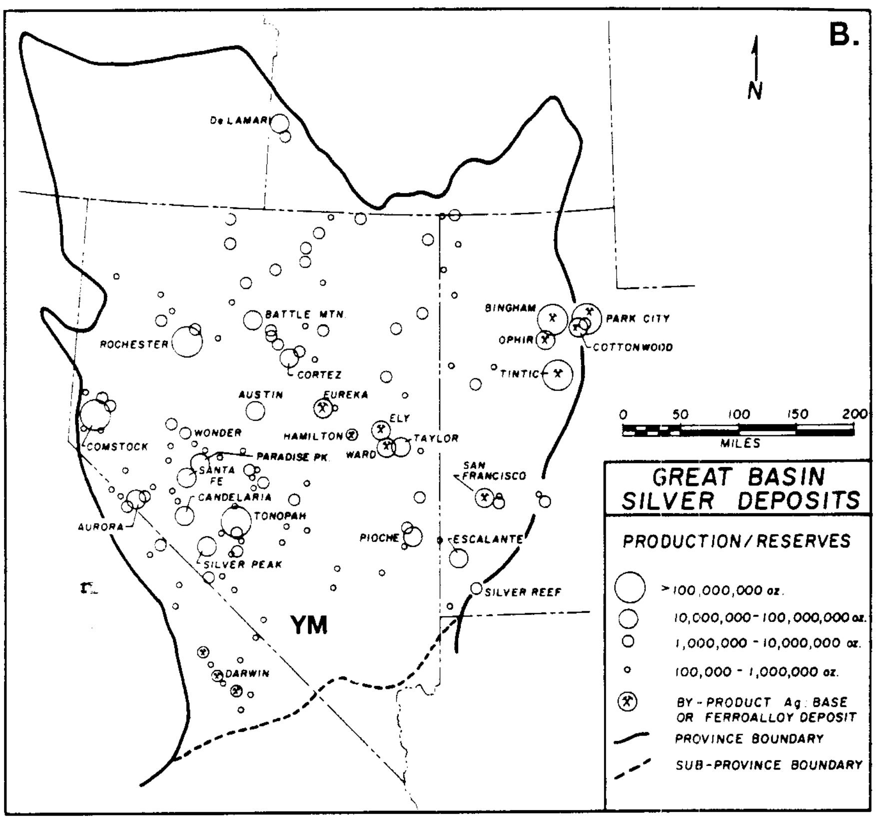


Figure 3-13. a) Gold deposits of the Great Basin b) Silver deposits of the Great Basin. Many of these districts also produced sizeable quantities of other metallic ores (e.g., Pb, Zn, Cu, Hg). YM-Yucca Mountain (modified from Wilkins, 1984).

3.4.1 Mineral Resources and Genetic Models

In an area with the rich mining history of the Great Basin of Nevada, there is a great body of literature covering the exploration, discovery, geology and production history for a variety of mineral deposits. An extensive list of mineral deposit models has been compiled by the U.S. Geological Survey (USGS, 1986). Raney and Wetzel (1990) and Wilkins (1984), among others, have compiled lists of the types of ore deposits found in the Great Basin, mostly for metallic ores (Figures 3-13 and 3-19). Deposits of similar type, but different metals (such as skarns) are grouped together for the purposes of this discussion. General characteristics, and the current level of understanding of the geologic model are discussed. It should be noted that there is often overlap between different types of deposits (e.g. Cu-porphyry and Cu, Zn-Pb skarns), and many of the physical-chemical conditions for one type will apply to some extent for others. Industrial mineral resources such as gravel, pumice, cinders, brines, and building stone are also located in Nevada, but these are readily available in other parts of the Great Basin (and the country), and there is no reason to infer that Yucca Mountain will become the only available source of these materials. In any event, these resources are of low bulk value, and can only be extracted profitably from large-scale shallow surface operations, suggesting the possibility of a minimal effect on the proposed underground facility in the event that any of the above mineral resources were to be developed within the controlled area.

3.4.1.1 Disseminated Gold/Silver Deposits

The Nevada precious metals boom of the 1980's and 1990's has been fueled for the most part by disseminated gold/silver deposits. These deposits are low grade (0.01 to 0.1 oz/ton cutoff grade), often quite large ($\sim$15-20 x 10^6 oz Au-reserves at Goldstrike, Nevada northwest of Carlin), and are generally only profitable as open-pit operations using minimal milling and cyanide leaching technologies. Mercury, arsenic, thallium, and antimony are elevated, and base metals are generally low in disseminated gold/silver deposits. In the Great Basin, these deposits occur in two types of host rock: Sedimentary rock hosted (Carlin, Nevada-type) and volcanic rock hosted (e.g., Round Mountain, Nevada).

Disseminated, Sedimentary Rock Hosted (Au,Ag,U)

Most of the sedimentary rock hosted gold/silver deposits are located in the northern and western Great Basin, and constitute the main part of the disseminated gold deposits found in the region. Most, but not all (e.g. Mercur, Utah; Alligator Ridge, Nevada), of the deposits are located (White, 1985) between the Sierra Nevada to the west, and the Paleozoic eastern assemblage of the continental shelf (see above, Section 3.2.2). In addition to clustered deposits, three major metallogenic trends are recognized, Carlin, Getchell, and Cortez (Bagby and Berger, 1985). The Roberts Mountain thrust of the Antler orogeny represents a fairly sharp demarcation between gold-bearing deposits and barren zones of mineralization. Local structural control is critical, with mineralization concentrated along both Basin and Range type normal (Carlin and Mercur) faults and thrust faults from the Antler, Sonoma, and Sevier orogenies (Carlin and Green Springs in Nevada). The host-rock of these sedimentary rock hosted gold/silver deposits is variable, ranging from the calcareous through clastic sedimentary rocks of Cambrian through Mississippian age (Wilkins, 1984; Tooker, 1985), although there appears to be some preference for argillaceous or carbonaceous carbonates.

Ages of mineralization also vary widely from Mesozoic [Mercur, Utah-193 to 122 m.y., Wilson (1990); Post, Nevada-156 to 111 m.y., Arehart et al. (1990); Getchell, Nevada-89 m.y., Tooker, (1985)] to Late Tertiary [Silver Peak, Nevada-5 m.y., White (1985)] (Figure 3-13). Silberman (1985) also noted a rough zonation in ages of hydrothermal mineralization that corresponds to that observed in Cenozoic igneous activity (Figure 3-9). Associated forms of primary alteration and mineralization include decalcification, argillization, silicification, and acid-leaching. Anomalous levels of As, Sb, Tl and Hg are frequently associated with disseminated deposits. Deposition occurred at relatively shallow depths, in zones of enhanced permeability, due to decalcification and/or fracturing. Although high temperatures (150° to 300° C; Radtke et al., 1980; Jewell, 1984; Ziegler, 1991) suggest a magmatic heat source, igneous intrusions are not always clearly associated with mineralization (Carlin, Alligator Ridge, Mercur). Low salinity fluid inclusions and stable isotope studies suggest that deep subsurface circulation of meteoric fluids along elevated geothermal gradients may have been the heat source for many of these deposits. The largest area of historic U_3O_8 production in Nevada was from the Tertiary disseminated uranium and associated U-vein deposits of the Apex Mine in Lander County (Garside, 1973).

Disseminated, Volcanic Rock Hosted (Au,Ag,U)

Relative to sediment-hosted, "Carlin-type" deposits, relatively few of the disseminated gold deposits in Nevada (Figure 3-13) are hosted in volcanic rocks. The bulk of these volcanic-hosted deposits (e.g., Round Mountain, Borealis, Paradise Peak) are found in southwestern Nevada, associated with a magnetic anomaly along the Walker Belt (Blakely and Jachens, 1991). The mines to the west of Yucca Mountain near Beatty (Gold Bar, Sterling, Montgomery-Shoshone) are of this type. These are generally hosted in Tertiary andesites, silicic tuffs and volcaniclastic sedimentary rocks. These disseminated gold/silver deposits are generally of similar size and grade to sediment-hosted deposits, and are also currently mined in open-pit, cyanide leach operations. Wilkins (1984) points out that these deposits are not disseminated in the sense of sediment-hosted deposits where mineralization is widely dispersed in the host rock, but rather, mineralization is confined to veins and micro-structures that cut across the fabric of the volcanic host. While the host rock differs, physical-chemical conditions of formation seem to be very similar to those reported above for sediment-hosted deposits. As in the sediment-hosted deposits, fracture and ground preparation played an important role in focusing mineralization. Volcanic-hosted deposits in the Great Basin are generally at the younger end of the range reported for sediment-hosted deposits, particularly those deposits in Walker Lane, which may be as young as 5 m.y. (Borealis). Disseminated uranium hosted in silicic volcanics is found in subeconomic quantities in the northwest corner of Nevada at the McDermitt Caldera on the Nevada/Oregon border (Nash et al., 1981). Nash et al. also proposed that economic uranium in Nevada may yet be found in granitic contact metasomatic aureoles similar to deposits at Spokane, WA.

3.4.1.2 Hot Spring (Au,Ag,Hg)

This type of deposit is generally young [1.7 m.y. at Sulphur, Nevada; 3 m.y. to present at Steamboat Springs, Nevada, White (1981)] and associated with silicified rhyolite plugs and/or geothermal systems. Argillic, silicic, and solfataric (alunite, jarosite) alteration are common. Like disseminated Au/Ag deposits, anomalous Hg, As, Sb, and Tl values are often associated with the system, and temperatures of formation are also similar (100° to 200° C). Deposit geometry is frequently controlled by fractures, resulting either from Basin and Range normal faulting, or caldera formation. Most of the Great Basin hot spring deposits are confined to the Walker Lane (Figure 3-3) with its younger volcanism, and evidence of recent (and ongoing) geothermal activity.

3.4.1.3 Porphyry (Cu,Mo,Au,Ag)

Many of the richest mineral deposits in the Great Basin (and in the world) are associated with fossil hydrothermal systems related to calc-alkaline porphyry systems (Ely, Nevada; Bingham, Utah). Ore-grades are generally low (0.5 to 1 percent Cu; 0.01 to 0.1 percent Mo), although there is commonly a cap of high-grade supergene enrichment. Gold and silver are frequent byproducts. Precious metal grades are very low, but because of the large volumes of material processed in the base metal mining operations, porphyry systems are among the largest gold and silver producers in the world. Intrusions are commonly small (1/2 to 3 km in diameter), and were emplaced at shallow depths (1 to 2 km) in a variety of wall rocks ranging from Precambrian basement and Phanerozoic sediments through comagmatic volcanics (Titley and Beane, 1981). Frequently, multiple intrusions and overlapping hydrothermal systems have resulted in a complex mineral paragenesis. Subsequent cooling and fracturing resulted in enhanced secondary permeability, and alteration and mineralization can extend up to several stock diameters into the country rock. Wall rock chemistry controls alteration type and zonation to a great degree. Mineralization is generally centered about the intrusion, and a "typical" alteration zonation from a central potassic (biotite-K-feldspar) zone through phyllic (sericite-quartz) and propylitic (chlorite-epidote) zones with an argillic overprint has been described by Lowell and Guilbert (1970). Alteration can vary, however, and frequently one or more of these zones is missing in an individual deposit. Copper and zinc/lead skarn deposits are frequently formed in the carbonate wallrocks affected by the porphyry hydrothermal system. Fluid inclusion (Nash and Theodore, 1971; Roedder, 1971; Bowman et al., 1987) indicate that porphyry formation temperatures were high (450° to > 650° C), and fluid salinity varied widely, from 0 to 60 wt percent NaCl. Stable isotope studies (Sheppard et al., 1971; Sheppard and Gustafson, 1976; Bowman et al., 1987) indicate that early hydrothermal fluids were magmatic in origin, and late stage argillic and propylitic alteration were possibly due to the infiltration of meteoric water during the waning stages of cooling.

Titley and Beane (1981) divide porphyry mineralization in western North America into three episodes: pre-Laramide, Laramide (i.e., Cretaceous/Tertiary), and episodic post-Laramide. In the Basin and Range province, porphyry deposits are generally 50 to 70 m.y. (Laramide) in age, although in the Great Basin, early Cretaceous ages are reported for Ruth (115 m.y.) and Yerington (~140 m.y.). With the exception of local episodes around 35 to 40 m.y. at Battle Mountain, Nevada and Bingham, Utah, porphyry formation in the Great Basin largely ceased after 45 m.y. The largest area of porphyry formation in the Basin and Range province is south of the Great Basin in southern Arizona and New Mexico (Figure 3-3) [Porphyry Copper Block of Wilkins (1984)]. Only a relatively few porphyry copper and molybdenum deposits have been found in the Great Basin (Titley and Beane, 1981; Harris and Pan, 1991), and those are largely restricted to the northern half (e.g., Yerington, Battle Mountain, Ruth, Bingham).

3.4.1.4 Skarn and Carbonate-hosted (W,Cu,Fe,Zn-Pb-Ag,Mo,Sn,Au)

Skarn Deposits

Skarn deposits have been exploited for iron, tin, tungsten, and a variety of base and precious metals. In the Basin and Range province, skarn deposits are largely limited to the northern Great Basin and the Porphyry Copper Block of Arizona/New Mexico to the south (Wilkins, 1984). Replacement of carbonate rock by a calc-silicate assemblage (garnet, pyroxene, amphibole, epidote, wollastonite, and/or vesuvianite, plus additional accessory minerals), is followed by deposition of ore minerals that may include: scheelite (W), magnetite (Fe), sphalerite/galena (Zn/Pb), bornite (Cu), and molybdenite (Mo)

(Einaudi et al., 1981). Gold is commonly associated with retrograde alteration of copper and iron skarns, while silver occurs in Zn-Pb deposits. The deposits usually occur at the carbonate/intrusive margins of Mesozoic and Tertiary calc-alkaline stocks, although there are cases of distal Zn/Pb skarns occurring in carbonates far from any known intrusive (Groundhog, New Mexico). Often, the stock itself has been propylitically altered or perhaps sericitized by the ore fluids along the skarn/intrusive contact. Ore geometries indicate that dikes, fractures, and faults often acted as conduits for ore fluid migration and localization, while favorable horizons were preferentially replaced and mineralized. Einaudi et al. (1981) also noted a correlation between skarn type and both silica content of the intrusion and/or carbonate host (pure or impure, limestone or dolomite). W, Cu, and Zn/Pb skarns are frequently associated with granodiorite/quartz monzonite, while Sn skarns are more commonly associated with granites. Cu and Zn/Pb skarns commonly occur in association with copper porphyry systems where carbonate formations have been intruded. Limestones tend to host Zn/Pb, Cu, Mo, and W skarns, while dolomites host Fe, Sn, and sometimes Cu skarns.

Temperatures of formation vary widely from 250° to 350° C for Zn/Pb deposits to temperatures ~650° C for copper skarns (Einaudi et al., 1981). Depths of formation (pressure) also vary substantially and systematically, from ~1.5 kb for W skarns to 150 bars for Cu and Zn/Pb skarns associated with porphyry systems. Stable isotope studies (Bowman et al., 1985; Turner, 1990) indicate that magmatic and meteoric waters are both important sources for mineralizing fluids. Fluid inclusion studies also support this, with salinities varying from near 0 wt percent NaCl to > 35 wt percent NaCl. Principal ore deposition mechanisms include cooling, secondary boiling, and reduction of hydrothermal fluids (Harris and Einaudi, 1982). Deposits in the Great Basin (Battle Mountain, Ward Mountain, Bingham) are generally Tertiary in age, although some skarns associated with areas of Mesozoic intrusive activity (W-skarn — Climax, Nevada; Zn-Pb skarn — Darwin, California) may be much older.

Carbonate-hosted Deposits

Carbonate-hosted replacement deposits are commonly associated with the distal edges of the skarn and/or carbonate wallrock near igneous intrusives, particularly in copper and zinc/lead systems. These deposits are also referred to as polymetallic replacement deposits. Carbonate replacement is not pervasive, but confined to pods, chimneys and stratiform lenses in fractures and bedding planes. Mineralization is usually restricted to silicification and dolomitization of carbonates and chlorotic or argillic alteration of shaley interbeds. Iron oxides and sulfides are the common ore minerals. Manto formation in zinc and copper skarns of the Basin and Range of Sonora, Mexico is apparently associated with retrograde alteration of the skarn calc-silicate assemblages (Meinert, 1982), implying similar temperatures (250° to about 400° C). Gold-bearing manto deposits in Nevada include Pioche, Hamilton, Ward Mountain and Eureka (Wilkins, 1984).

3.4.1.5 Epithermal Vein Deposits

Through-going normal faults and associated fractures have provided zones of high permeability for the circulation of hydrothermal fluids, resulting in veins containing economic concentrations of a variety of metals. Mineralization was clearly controlled by fracturing, and mineralization trends reflect the orientation of both the fault and the associated fracture sets. In the Great Basin, veining is largely controlled by normal and strike-slip faulting resulting from extension and ring-fracture sets associated with caldera formation. Thrust faulting has also played a role in localizing fluids (Easy Junior, Green Springs in western White Pine County)(Figure 3-6), but mainly through establishing an impermeable cap and through associated fracturing. Therefore, in the Great Basin, this broad class of hydrothermal deposits may be divided on the basis of normal and strike-slip fault orientation: high-angle, listric and detachment.

Veins-High-Angle (Polymetallic)

High-angle polymetallic vein deposits are common in the Great Basin, including many historic districts (Figure 3-13)(Comstock, Bodie, Aurora, Tonopah, among others). They are most commonly produced for high-grade gold (occasionally >4 oz/ton) and silver (some >150 oz/ton), although tin, antimony, lead, zinc, copper, and manganese may also be found in economic amounts (Garside, 1973; Wilkins, 1984). Uranium is found in 10 to 13 m.y. old vein deposits in Tertiary volcanics at Marysvale, Utah in the eastern Great Basin (Kerr, 1968). Near Yucca Mountain, gold and silver were produced in the Wahmonie district (25 km to the east) from high-angle veins. In Bullfrog (30 km west of Yucca Mountain), high-angle deposits associated with a low-angle detachment surface have been mined for gold and silver. While host rocks are highly variable, there is frequently a clear association with calc-alkaline or volcanic activity. Associated gangue minerals include quartz-chlorite at depth up through overlapping levels of quartz-illite-adularia, to quartz-illite, to quartz-kaolinite-montmorillonite at the top of the system. Mineralization is also frequently zoned with depth. Gold-silver-lead-zinc-copper at lower levels grades upwards into gold-arsenic-mercury at higher levels. Fluid inclusion studies (Nash, 1972; Roedder, 1984) indicate formation temperatures in the range 200° to 350° C. Low salinity fluid inclusions (<5 wt percent NaCl) and stable isotope data indicate a meteoric origin for hydrothermal fluids (Taylor, 1979). Cooling and possibly boiling of the hydrothermal fluids during ascension in the fault zone appear to be the most probable ore depositional mechanisms. In the Great Basin, most of these deposits are Tertiary in age [40 to 3.7 m.y., USGS, (1986)]. Older Mesozoic veins are found associated with dikes and porphyry copper-molybdenum systems (USGS, 1986). Host rocks are predominantly igneous, with propylitic, sericitic, and argillic alteration halos centered on the vein. Quartz and calcite are the principal gangue minerals, and zinc, lead, copper, and manganese are associated ore phases.

Veins-Listric Normal Faults (Polymetallic)

Listric normal faults flatten with depth, and are believed to merge with low-angle detachment faults. Vein deposits in these fault systems are similar in physical-chemical conditions to high-angle polymetallic veins. Wilkins and Hedrick (1982) have suggested that mineralization along these faults occurred both during and after movement. These deposits are considered to represent a transition between high-angle and detachment fault veins. Wilkins (1984) identifies five deposits of this type in Nevada: Goldfield, Searchlight, Tonopah, Seven Troughs, and El Dorado.

Veins-Detachment Fault Type (Polymetallic)

Low-angle detachment faults host several types of polymetallic mineralization, either as upper or lower plate breccia, veins, or replacement of reactive host rocks along the fault surface (Wilkins, 1984). Detachment faults can occur in metamorphic core complexes, as low angle extensional features in volcanic/sedimentary terrain, or along reactivated thrust faults. High-angle normal faults in the hanging wall can also host mineralized veins (Bullfrog and Bare Mountain, Nevada). Host rocks are variable, although igneous rocks are the most common host. To the south of the Great Basin, Mesozoic and Tertiary detachment fault deposits are most common in the Mohave Block (Figures 3-3 and 3-13) of California, Arizona, and southern Nevada (Stedman, California and Picacho, Arizona for example). In the Great Basin, deposits at Bullfrog, Bare Mountain, and Osceola in Nevada and Skidoo, California are Tertiary in age (Wilkins, 1984). Alteration in these deposits is generally simple (USGS, 1986), with hematite, quartz, calcite, and chlorite. Stable isotope data (Taylor, 1979) indicates a meteoric source of mineralizing fluids at Bullfrog, and fluid inclusion data (Nash, 1972) suggests temperatures on the order of 200° to 300° C.

3.4.1.6 Breccia (Au,Ag)

Gold, silver and base metals are found in association with both hydrothermal and tectonic breccias in pipes, stockwork fractures, and brecciated and silicified fault zones related to other deposit types (vein, porphyry, etc.). They are widely dispersed in the Great Basin, but make up only a small portion of the total reserves of the region (Wilkins, 1984). Included are deposits (Figure 3-13) at Paradise Peak, Borealis, Victoria, and Ortiz in Nevada, and a mineralized breccia pipe complex in the Sevier orogenic belt at Clark Mountain, California (Atkinson et al., 1982; Wilkins, 1984; Sharp, 1984). Breccia formation at Clark Mountain began with the intrusion of a felsic intrusion at 100 m.y., and continued sporadically through the Late Tertiary. Quartz, calcite, pyrite, and barite are associated with gold mineralization.

3.4.1.7 Massive Sulfide (Cu,Pb,Zn)

Volcanogenic massive sulfide deposits are generally believed to form at tectonic plate margins, and are associated with oceanic greenstone, chert, turbidites and ophiolites from Precambrian to Cenozoic age. Small deposits are found throughout the southern Basin and Range, at Iron King and Jerome, Arizona, and in the north-central Great Basin (Figure 3-13) at Big Mike and Mountain City in Elko County, Nevada (Rye et al., 1984; Coats and Stephens, 1968). Ore genesis is thought to occur through circulation of seawater near the vents of submarine hydrothermal systems. Roberts (1976) and Eldridge and Ohmoto (1980) have proposed a two-stage model for the formation of massive sulfide deposits in Saudi Arabia and Japan. Heated fluids leach metals from oceanic basalts, and upon discharge from the vent, mixing with the cooler ocean waters causes the precipitation of sulfides. After burial by sediments or volcanics, these syngenetic sulfides are recrystallized by subsequent hydrothermal activity. Stable isotope studies (Rye et al., 1984) supports two-stage genesis at Big Mike, indicating mineralization temperatures of about 300° C. Early pyrite precipitation was followed by later chalcopyrite. Circulation of later hydrothermal fluids of different origin resulted in recrystallization of primary mineralization and late-stage quartz-hematite precipitation. Both Big Mike and Mountain City are developed in the upper plate of the Roberts Mountain thrust, and the Big Mike post-dates the Golconda thrust, indicating a post-Sonoma (Permian/Triassic) age. In Arizona and New Mexico, massive sulfide deposits are Precambrian in age, and are enriched in silver and gold in addition to base metals.

3.4.1.8 Roll-Front (Ag, U)

Only one sandstone roll-front silver deposit at Silver Reef, Utah (Figure 3-13) has been discovered in the Great Basin subprovince (Proctor, 1953; Wilkins, 1984). Proctor (1953) proposed a depositional mechanism where oxidizing silver-leaching fluids migrated through the more permeable Jurassic host rock, depositing silver along a redox interface. This is similar to the mechanism proposed for roll-front uranium deposits of the Colorado Plateau (Nash et al., 1981). Although roll-front uranium has not been discovered in the Great Basin, the presence of abundant silicic volcanics with elevated uranium background values, and permeable sandstone aquifers suggest that these may be potential targets in the future.

3.4.1.9 Placer (Au,Pt)

Placer deposits for gold and platinum group elements (PGE) are fairly common in the Great Basin, and are usually clearly associated with a parent deposit (e.g., Round Mountain, Battle Mountain, and Manhattan in Nevada). Lateral transport is limited, and most placers are found in units adjacent to, and overlapping the source rock (Koschman and Bergendahl, 1968). Only the Snake River, Idaho and Spring Valley, Nevada placers are not associated with a significant lode deposit (Wilkins, 1984).

3.4.1.10 Bedded Barite

Bedded barite deposits are divided into two types based on stratigraphic, tectonic, and geochemical characteristics (Maynard and Okita, 1991). The first type (Arkansas) is assumed to have been formed in association with oceanic hydrothermal activity along a subduction zone. These deposits are associated with evidence of hydrothermal activity, and are frequently thrust onto stable continental assemblages. The second type (Selwyn Basin) are associated with stable continental platforms, and appear to have no oceanic association. Stratiform barite deposits are found at many locations in Nevada (Northumberland, Greystone, Mountain Springs). These are frequently associated with epithermal gold and carbonate Cu-Pb-Zn replacement deposits (USGS, 1986), and are generally hosted in oceanic sediments of chert, shale, or carbonate. Deposit geometry suggests formation in association with sea-floor hydrothermal vents (Poole, 1988), although there is some evidence to suggest a biological origin (Jewell and Stallard, 1991). Surface mining techniques are appropriate due to low unit value of the resource. Barite is also associated with a number of other types of hydrothermal mineral deposits due to solfataric alteration and boiling of hydrothermal fluids. Past production defines a restricted northwest-trending zone of mineralization in central Nevada, to the west and north of Yucca Mountain (Papke, 1984).

3.4.1.11 Mn Replacement

Manganese oxide occurs as vein and vug filling deposits in marine carbonates, and may be associated with igneous activity (USGS, 1986). Deposits are found in Arizona and New Mexico, and are found in the Great Basin at Steptoe, about 30 km north of Ely, Nevada in White Pine County. Ages are variable, and the association with fractures and intrusive contacts suggests a hydrothermal origin.

3.4.1.12 Platinum group metals

Anomalous platinum is reported in association with hydrothermal manganese mineralization in the Gibellini Mine in western Lander County in the Fish Creek Range (Lechler et al., 1988).

3.4.1.13 Borax deposits

Borax and calcium borates are commonly found interbedded with stratified playa deposits or produced from brines in enclosed lakes. Enrichment through evaporation of these isolated lakes in arid climates is the principle formation mechanism (Hurlbut and Klein, 1977).

3.4.1.14 Mercury Deposits

Mercury deposits in the Great Basin are predominantly associated with evidence of fossil hydrothermal activity. Most of the mercury in Nevada occurs as vein and fracture filling in argillized andesitic volcanics, and with opaline layers in silicified and altered silicic tuffs. Historic mercury production is focussed in the western part of the state, with the largest deposits found at the north end of a north-south trend running from California to Oregon. Nevada is currently the main producer of mercury in the country, with most of the production from the McDermitt mine on the Nevada/Oregon border (Jones and Papke, 1984). Mercury is also recovered as a byproduct of gold production from the disseminated gold deposits in the state, where anomalous mercury has been used as a pathfinder element. Deposit formation temperatures generally ranged from 100° to 200° C, suggesting the precipitation of cinnabar (Hg_2S), native mercury, and calomel ($HgCl_2$) from ascending fluids at shallow depths. Associated alteration is argillization, silicification, and opalization, also indicative of relatively low temperatures of formation.

3.4.1.15 Beryllium Deposits

Beryllium is found in the eastern part of the Great Basin, particularly at Spor Mountain and Gold Hill in western Utah. Beryllium occurs in a variety of associations, but in the Great Basin, deposits are typically associated with Tertiary igneous activity as beryl in pegmatites, disseminated in beryl in granites and tuffs, replacement of carbonate clasts in Tertiary tuffs, and metamorphic aureoles (Hewitt, 1968; Shawe, 1968). Limited laboratory solubility data suggest formation temperatures of at least 225° C at Spor Mountain (Hewitt, 1968). Although upper temperature limits have not been established for Great Basin Be-deposits, fluid inclusion temperatures from beryl and quartz in pegmatites in Connecticut and the Black Hills suggest formation temperatures on the order of 500°-600° C (Roedder, 1972). K/Ar age determinations for the principal deposits in western Utah are consistent with mid- to late-Tertiary mineralization (30 to 8 m.y.)(Hewitt, 1968).

3.4.1.16 Gallium/Germanium Deposits

Gallium and germanium are principally used in the manufacture of semiconductors. In the eastern Great Basin, breccia pipe mineralization in Pennsylvanian carbonates at the Apex Cu-Pb mine near St. George, Utah, has recently been reactivated for production of these metals. In the Apex mine, Ga/Ge are typically associated in trace amounts (up to 5,300 ppm) with main stage chalcopyrite and later jarosite (K-Fe sulfate)/iron oxide overprinting of earlier illite/alunite alteration (Petersen and Mahin, 1988). Ga association with minor phases may reach as much as 60,000 ppm. Oxygen and strontium isotope data suggest deep circulation of meteoric water, leaching rare (Ga/Ge) and base (Cu/Pb) metals from overlying Paleozoic carbonate and shale source rocks and/or Precambrian basement. Main stage mineralization (Cu-Pb sulfides) suggest temperatures ranging from 200° to 400° C. K/Ar age determinations indicate, however, that the jarosite mineralization (mid-to late-Miocene) coincides with the onset of Basin and Range type extension, postdating main-stage mineralization (200 ± 7 m.y.) significantly (Petersen and Mahin, 1988).

3.4.1.17 Zeolite Deposits

The unique ion exchange and sorptive properties of zeolite minerals have lead to numerous applications as molecular sieves, water softeners, paper processing, and even kitty litter. Zeolites can form through low-grade regional metamorphic processes, in alkaline lake environments, and by low temperature alteration of silicic volcanic tuffs and glasses during interaction with infiltrating groundwaters. The latter two processes have operated to form thick zeolite deposits at various locations in Nevada, including the Yucca Mountain vicinity (Papke, 1972; Vaniman et al., 1984).

3.4.1.18 Fluorspar Deposits

Largely made up of fluorite (CaF_2), fluorspar has a number of industrial uses, principally in chemicals, ceramics, and metallurgy. From solubility considerations and field relations (Holland and Malinin, 1979; Papke, 1979), CaF_2 deposition likely occurs at relatively low temperatures, on the order of 150° C in NaCl solutions. Papke (1979) identified a broad belt of fluorspar deposits in the central part of Nevada that exhibits a general southeast-to-northwest trend. A second area of fluorspar mineralization occurs in Walker Lane along the California/Nevada border to the west of Yucca Mountain. In general, fluorspar deposits are closely associated with fossil (and active) hydrothermal systems, occurring along faults and fractures as stockwork, disseminated, and vein type deposits. Host rocks vary from Paleozoic sedimentary rocks to Tertiary volcanics. The largest fluorspar producing region in Nevada is the Bare Mountains 15 km west of Yucca Mountain, with nearly half of the total historical production in the state coming from replacement and/or breccia deposits in Paleozoic dolomites in the Daisy Mine (Papke, 1985).

3.4.2 Petroleum and Natural Gas Resources in Nevada

Oil and natural gas have been discovered and produced in eastern Nevada, primarily in Railroad Valley, northern Nye County (Figure 3-14)(Garside et al., 1988). Oil seeps are also reported in several areas, including the Alligator Ridge mining district (Pinnell et al., 1991). There has been additional production from the Blackburn Field discovered in 1982 in Pine Valley to the northwest in Eureka County. Exploration and discovery to date has occurred in three time periods from discovery of the Eagle Springs Field of Railroad Valley in the mid-1950's, through development and extension of Eagle Springs in the mid-1960's, to discovery and development of the Trap Springs, Kate Spring, Bacon Flat, and Grant Canyon Fields in Railroad Valley in the late 1970's to mid-1980's. Fields tend to be small. Average production is on the order of hundreds of barrels/day, with a maximum of about 7,000 barrels/day at the Grant Canyon Field. Total production at Grant Canyon, the biggest field to date in Nevada, has reached about 14 million barrels total (1990), already in excess of initial reserve estimates of 13 million barrels (Veal et al., 1988; Hulen et al., 1991). Oil is currently transported by tanker truck, and distance to refining facilities leads to increased production costs. Participation of major oil companies is currently (1990) limited to Chevron, Mobil, and Marathon oil, although a number of small independents still operate in the area. Current exploration is focussed on Railroad Valley, although exploratory wells have been drilled in White River, Jakes, and Long Valleys to the east and north. Oil and gas seeps near Fallon in Churchill County, and in Elko County have also been the focus of activity, and subthrust plays have been developed and drilled in Clark County with little success. Oil and gas drilling is difficult and expensive due to the hard rocks of the region, and volcanic cover limits the ability of seismic and gravity methods to define targets.

All oil production to date has come from Tertiary basins in the Sevier orogenic belt (Armstrong, 1968), between the Devonian/Mississippian Antler highland and the Paleozoic continental shelf. The main area of production, Railroad Valley, contains over 15,000 feet of Tertiary and Quaternary valley fill. Production in Nevada is from a variety of different reservoirs, and several source rocks and trap types have been identified. Production in the Eagle Spring and Trap Springs fields of Railroad Valley is at 4,000 to 7,000 feet from fractured Tertiary ignimbrites and Eocene Sheep Pass formation. The traps are Tertiary fault blocks with associated rollover, and the seal is unconformable Tertiary valley fill. Chemical analyses indicate both Mississippian Chainman Shale and Tertiary Sheep Pass source rocks (Bortz and Murray, 1979). Production at Bacon Flats, Kate Springs, and Grant Canyon is from fractured

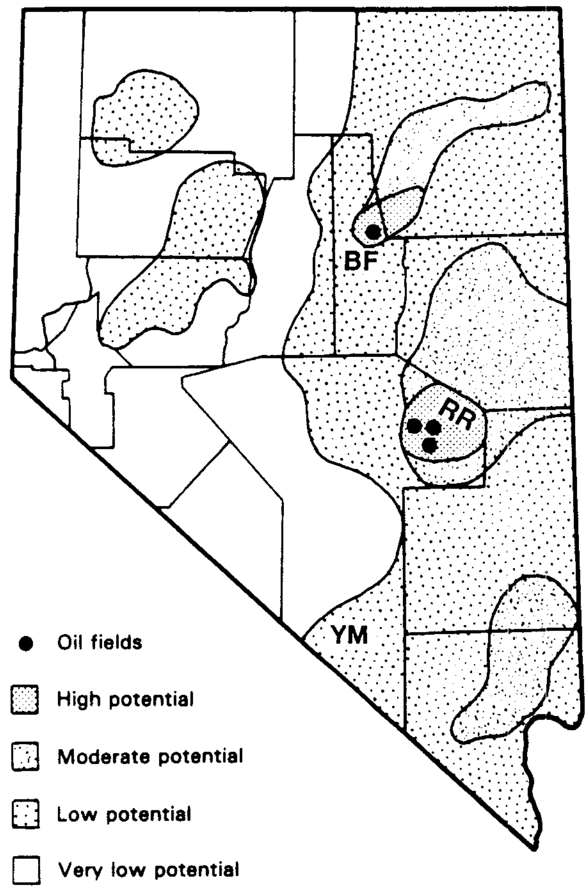


Figure 3-14. Petroleum potential of Nevada. YM-Yucca Mountain; RR-Railroad Valley; BF-Blackburn Field (modified from Garside et al., 1988).

upper Devonian dolomites in the Simonson and Guilmette Formations (i.e., Nevada and Devils Gate, respectively) beneath a Tertiary seal at 4,000 to 5,500 feet. Structures at Bacon Flats and Grant Canyon are poorly understood at present. Interpretations include Tertiary Basin and Range normal faulting, emplacement of Devonian carbonates as slide blocks from low angle detachment faults in the Grant Range to the east with subsequent downdrop along range front normal faulting, or east-vergent thrusting of the Sevier orogeny emplacing Devonian carbonate on Chainman Shale (Kleinhampl and Ziony, 1985; Veal et al., 1988). The hydrocarbon source rock in these fields is believed to be the Chainman Shale. There is fluid inclusion evidence to suggest that hydrothermal fluid flow played a role in hydrocarbon maturation and transport in the Grant Canyon and Bacon Flat Fields (Hulen et al., 1991). The Blackburn Field is the sole producing field outside of Railroad Valley. Although hydrothermal activity enhanced porosity in the Devonian Simonson reservoir rock, in contrast to Railroad Valley, fluid inclusion and core analysis indicates that hydrothermal activity was prior to hydrocarbon migration (Hulen et al., 1990). The producing trap is a normal fault block of Tertiary age, and the Chainman Shale has acted as both source and seal for the field.

Recent exploration in Nevada (1990) is focussing on subthrust plays associated with the imbricate thrusts and folding related to the Mesozoic Sevier Orogenic Belt, from Elko to Clark County. Targets include Devonian reservoirs in the hanging wall, sealed by stratigraphically higher Chainman Shale, and sourced by subthrust Chainman. Stratigraphic and structural traps are both possible, particularly with the anticlinal folding of hanging wall units associated with compressional thrusting. Imbricate thrusting and associated folding may give rise to a several layers of structural traps in overlying hanging walls. Tertiary traps associated with Basin and Range normal faulting and related rollover are also being pursued. Maximum depths on the order of 20-25,000 feet for the oil generation window are likely, given the elevated thermal gradient of the Great Basin, but this will be highly dependent on the burial history of the source rock. The deepest well drilled to date in Nevada is at 19,500 feet in Clark County. Particular areas of interest include Railroad Valley, Pine Valley, White River Valley, Long Valley, Jakes Valley, and Newark Valley, all in the Sevier orogenic belt of eastern Nevada (Garside et al., 1988).

3.4.3 Geothermal Resources in Nevada

In spite of local variations, the Basin and Range is generally an area (Figure 3-15) of elevated heat-flow [about 2 heat-flow units (HFU)], relative to other continental settings (about 1 HFU). This is believed to be due to the thin crust and near-melting conditions at the crust/mantle boundary beneath the Basin and Range (Garside and Schilling, 1979; Bott, 1982). While numerous lower temperature hot springs and warm-water wells occur throughout the state, with almost 300 occurrences of thermal springs and wells reported (Garside and Schilling, 1979), hot spring activity is greatest in the west-central and north-central parts of the state (Figure 3-16). Host rocks are variable, from Paleozoic carbonates through Tertiary/Quaternary volcanics and alluvium.

The bulk of the high temperature (> 90° C at the surface) hot springs and water wells are associated with (Figure 3-16) the Battle Mountain heat-flow high in north central Nevada (avg 3 HFU). These include the Beowawe geothermal field in Eureka County, Sulphur Hot Springs in Elko County, Leach and Kyle Hot Springs in Pershing County, Senator Fumaroles in Churchill County, Darrough's Hot Spring in northern Nye County, and Smith Creek Valley Springs in Lander County. In addition, a north-trending, 50 mile-wide zone of high temperature waters extends from Steamboat Springs south of Reno to the Nevada/Oregon Border 200 miles to the north. Springs are commonly associated with Tertiary extensional faulting and/or recent volcanism, occurring in calderas, valleys, and in linear arrays along range-bounding normal faults. Temperatures are frequently zoned about surface fault scarps, and some deep drill holes have encountered recent volcanics at depth (Garside and Schilling, 1979). Geothermal activity can be quite long-lived, as shown at Steamboat Springs, where hydrothermal adularia yields a K/Ar age of 1.1 ± 0.1 m.y., similar to 1.14 ± 0.04 m.y. K/Ar ages obtained for associated rhyolite domes (White, 1981). The Eureka heat-flow low located immediately north of Yucca Mountain (Lachenbruch and Sass, 1977), is an area of below average heat-flow, possibly due to intrabasinal groundwater flow.

Travertine, fumaroles, mudpots, sulfur, cinnabar, and/or siliceous sinter spring deposits are nearly ubiquitous surface indications of hot spring activity. Hydrothermal alteration of the host rock is also frequently observed. With a few exceptions (Gerlach, and The Needle Rocks in Washoe County, Kyle and Colado Springs in Pershing County, and deep wells in Railroad Valley), total dissolved solids are below about 2000 ppm (Garside and Schilling, 1979). Anomalous levels of H_2S, Hg, Sb, As, Tl and B are associated with modern activity, and some hot springs (Beowawe; Tingley and Bonham, 1986)

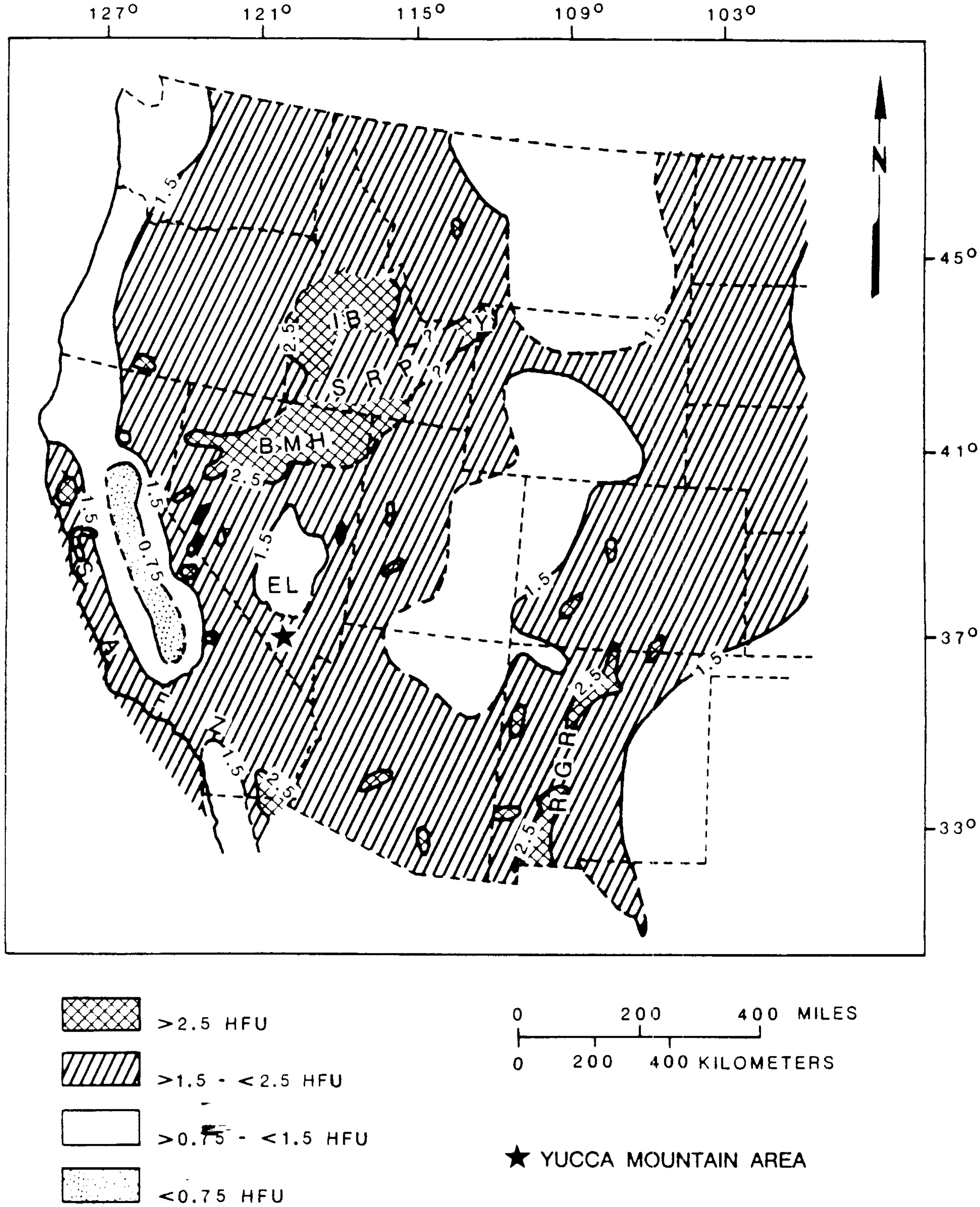


Figure 3-15. Regional heat-flow of the western United States measured in heat-flow units. BMH-Battle Mountain Heat- Flow High; EL-Eureka Heat-Flow Low; IB-Idaho Batholith; Y-Yellowstone Geothermal Area; SRP-Snake River Plain; RGR-Rio Grande Rift; SAFZ-San Andreas Fault Zone (after DOE, 1988).

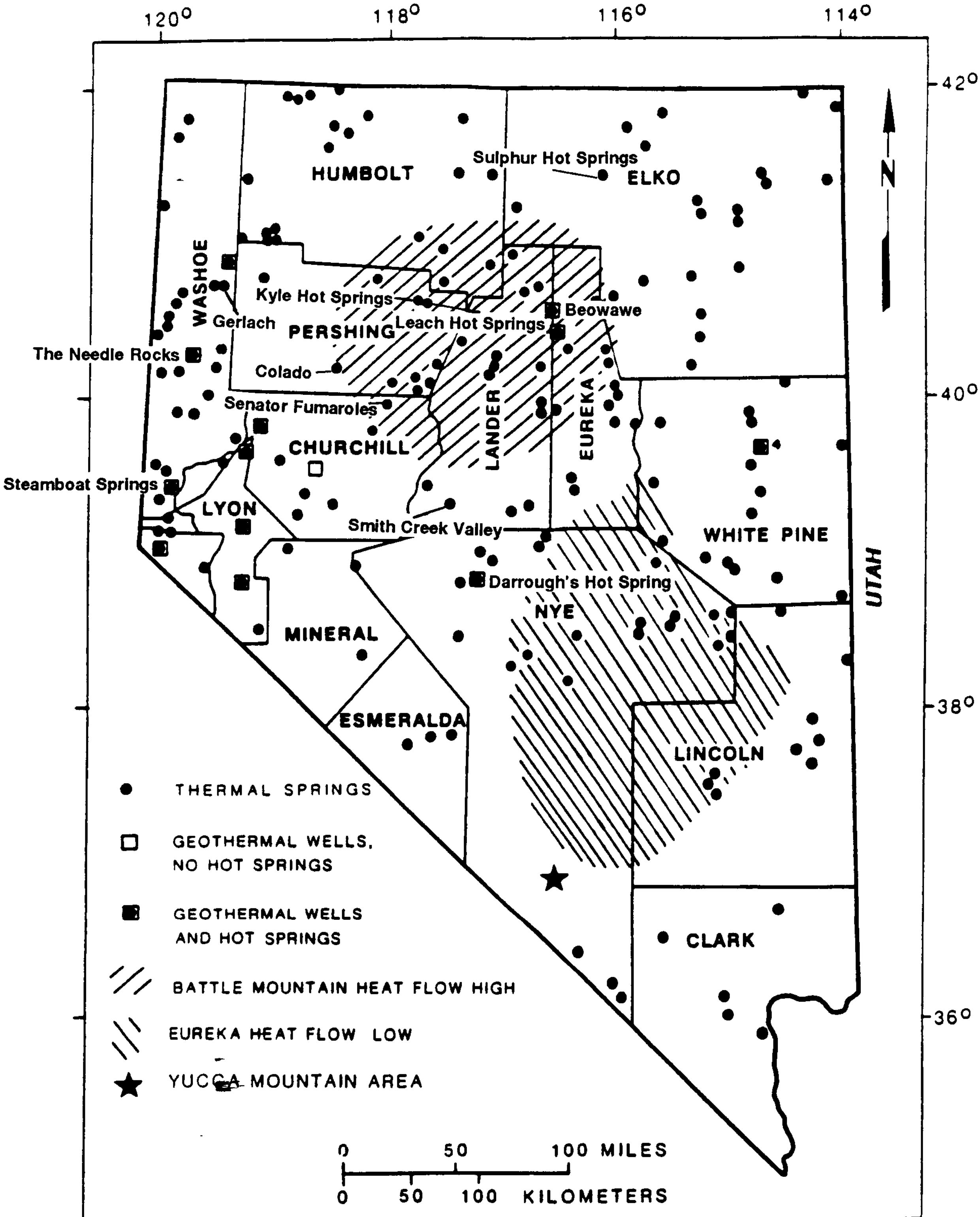


Figure 3-16. Known geothermal areas and thermal waters in Nevada (modified from DOE, 1988).

contain detectable gold. Temperatures of up to 210° C are encountered in wells (Steamboat Springs, Garside and Schilling, 1979), and geochemical thermometers indicate reservoir temperatures as high as 230° C (White, 1981). All known fields are water-dominated rather than the more desirable steam-dominated systems such as those at Geysers, California. Stable isotope data (Garside and Schilling, 1979; White, 1981) indicate a meteoric water source for the fluids, although up to 10 percent magmatic component may not be detected. $\delta^{18}O$ shifts to more positive values are observed, and are believed to indicate high-temperature, water/rock interaction (White, 1981).

3.4.4 Groundwater Resources

Due to the arid climate of Nevada, any groundwater in the region should be considered as a future resource. In addition to amounts, accessibility, and drilling and production technology, the value of this resource is also dependent on the population of the area. Current estimates are only believed accurate for the next 20 years, and indicate that the area of greatest population growth (to 1.2 million) will be the Las Vegas metropolitan area in Clark County (ABC, 1989). Total population for the other counties surrounding the Nevada Test Site (Nye, Lincoln, and Esmeralda) will be less than 40,000 in the year 2010 based on current predictions. Lake Mead, and other surface water sources are currently able to provide over 2/3 of the water for this region. Based on these population estimates, the total water requirements for all uses are approximately 900,000 acre-feet/year by 2010, with approximately equal amounts coming from surface and subsurface sources (ABC, 1989). These predictions also include extrapolations of precipitation and recharge rates, resulting in additional uncertainties.

Current estimates of available groundwater storage in the four county area is about 72 million acre-feet (Nevada, 1982). Major groundwater basins (Figure 3-17) are found in Amargosa Valley to the south of Yucca Mountain, Pahrump Valley to the southeast, and Railroad and Pahranagat Valleys to the north and northeast, respectively. The bulk of this is in Tertiary/Quaternary alluvium, although additional production may be possible from Paleozoic carbonate aquifers as well (ABC, 1989). The Amargosa Valley and possibly the Pahrump Valley systems are the most closely related to local groundwater flow in the Yucca Mountain vicinity. Local groundwater generally flows from recharge zones in topographic highs to the north and east of the site, and discharges into Ash Meadows in Amargosa Valley to the south (DOE, 1988)(Figure 3-18). With the exception of Clark County, groundwater resources within a given county are more than adequate to support predicted population growth. Therefore, the ability of Clark County to acquire water rights to surrounding counties will largely determine the "value" of the water resources of the Yucca Mountain vicinity. Limits on this ability are both regulatory and economic in nature.

Current "safe-yield" water policies in the State of Nevada limit water usage to 100 per cent of perennial yield. This is approximately 653,000 acre-feet (Nevada, 1982), adequate to meet estimated water needs in 2010. Additional constraints, however, are in place due to the Protected Wetlands and the Endangered Species Act for springs and fish sanctuaries in the region (e.g. Big Springs, Amargosa Valley). Interstate water importation is also limited, given the current state and federal regulatory structure. Importation costs from Amargosa, Pahrump, Railroad, and Pahranagat Valleys to Clark County have been estimated through 2010 based on development costs and distance of importation (Nevada, 1982; ABC, 1989). These estimates suggest that imported water could cost from $900 to $1300/acre-foot (1990 dollars) depending on the distance of importation, approximately twice the current justifiable limits of $600/acre-foot (Nevada, 1982; ABC, 1989).

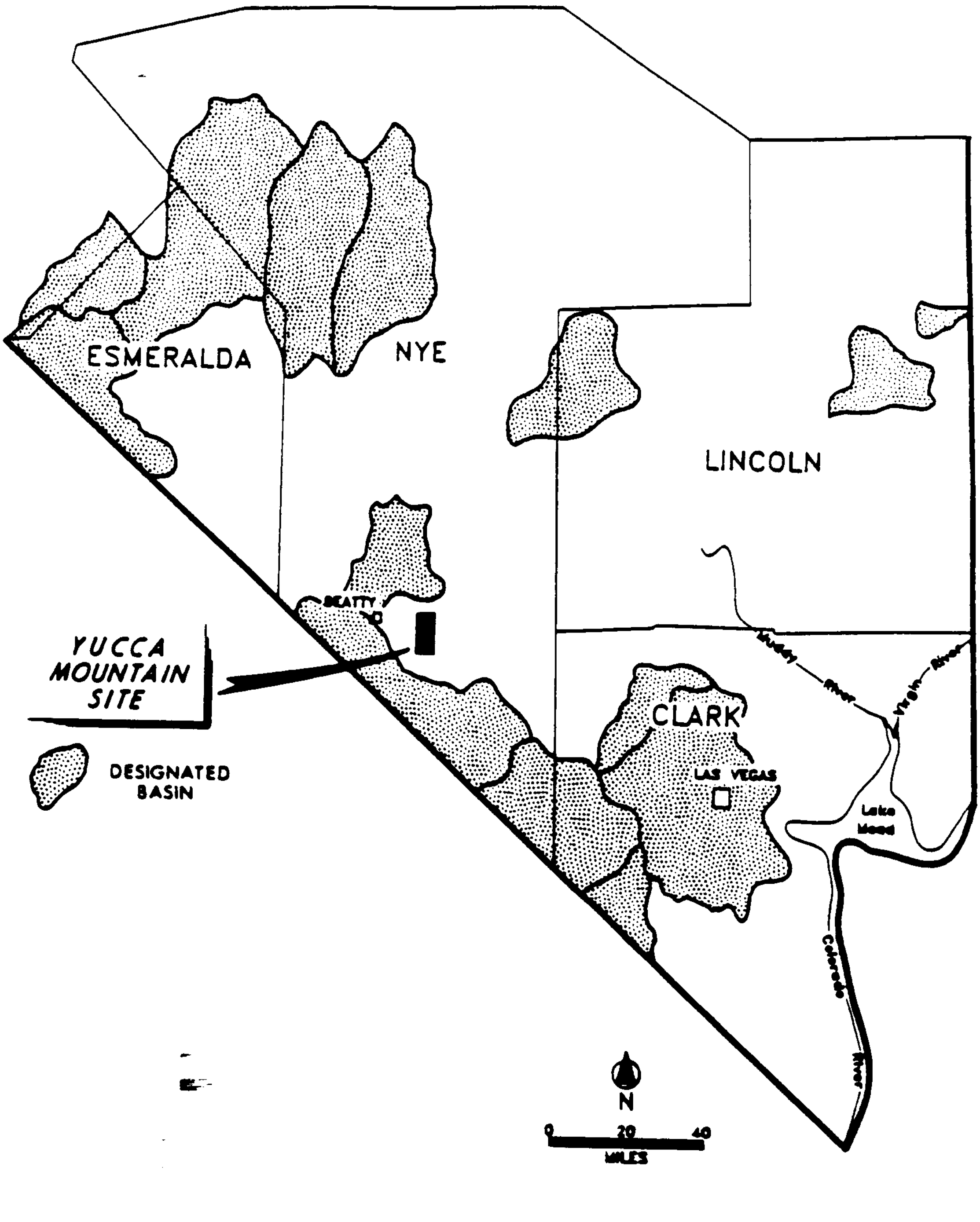


Figure 3-17. Major groundwater basins in the vicinity of Yucca Mountain and Clark County (after Basse, 1990).

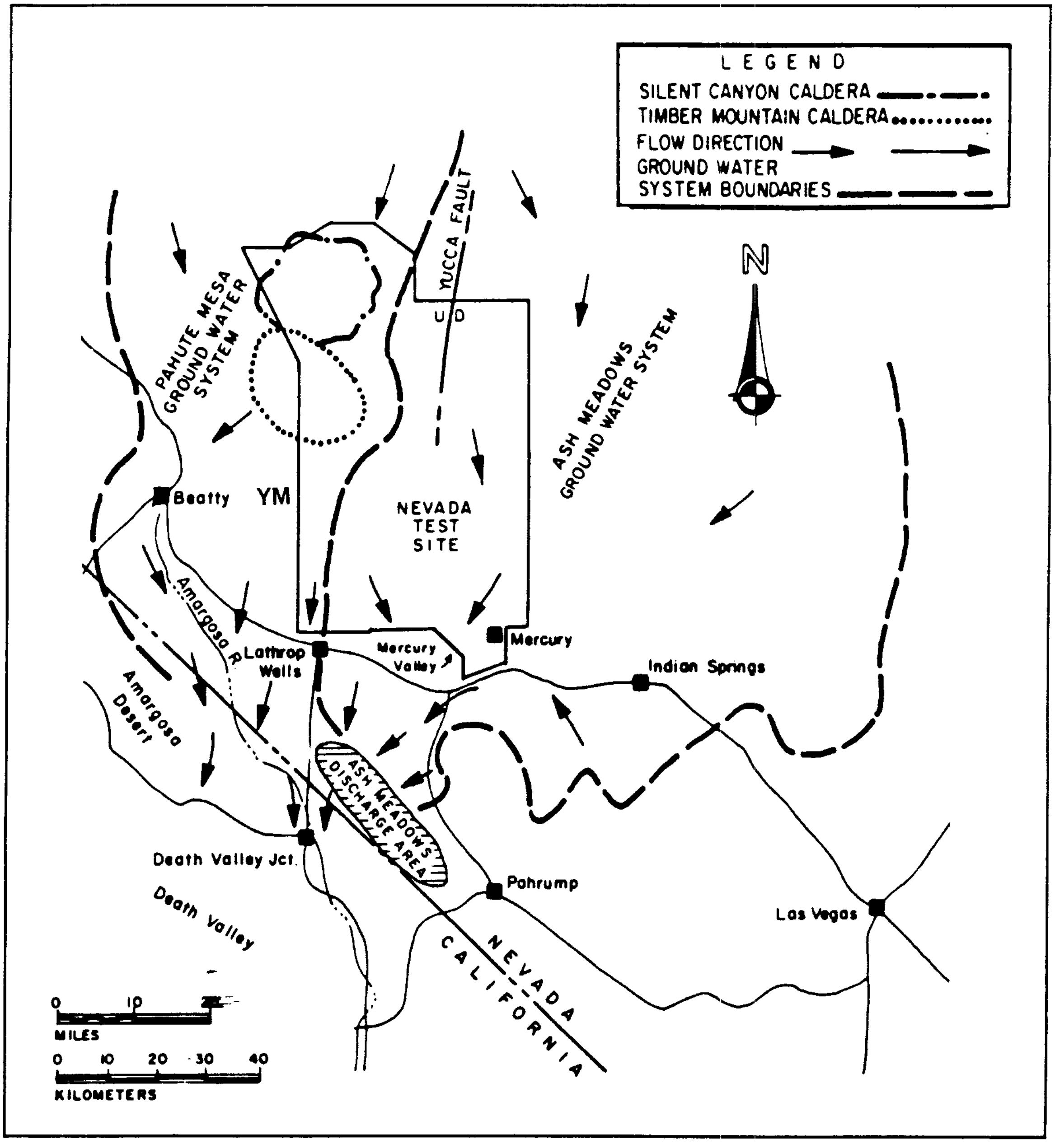


Figure 3-18. Local groundwater flow in and around the Nevada Test Site. YM-Yucca Mountain (after DOE, 1986).

3.4.5 Coal Resources in Nevada

Preliminary estimates (Schilling, 1980) indicate that only minor coal resources of poor quality are available in Nevada. The closest known coal reserves to Yucca Mountain occur in Tertiary lacustrine deposits at Coaldale, Esmeralda County, some 150 km to the northwest.

3.5 NATURAL RESOURCES RELATED TO YUCCA MOUNTAIN

3.5.1 Historical Production Near Yucca Mountain

As of July, 1990, there are six active Au/Ag properties within a 30-mile radius of Yucca Mountain that are in various stages of exploration, development, or production (BOM, 1990a, b), with a total production of about 300,000 oz Au in 1990 (Nevada, 1990; Johnson and Hummel, 1991). These are in the Bullfrog (Bullfrog, Gold Bar, Montgomery-Shoshone) and the Bare Mountain (Sterling, Mother Lode, and Cordex) Mining Districts to the west of Yucca Mountain (Figure 3-19). From June, 1987 through December 1988, a block of 31 lode mining claims was staked at the south end of Yucca Mountain. Besides surface sampling, there was no work by the claim holders to produce resources, and by October, 1989, the DOE had purchased the mineral rights for all of the claims. Additional production of fluorite from the Daisy Mine in the Bare Mountains, and bentonite from the New Discovery in the Bullfrog Hills has also been reported. Mercury has been produced from fissure deposits in the Thompson Mine at the north end of Yucca Mountain and the Telluride and Tip Top mines in the Bare Mountains, although total production is less than about 200 flasks (Cornwall, 1972). Borax is produced to the south in Amargosa Valley near the California/Nevada state line, and industrial minerals such as perlite, and cinders have been produced in southern Nye County (Nevada, 1990).

No energy-related resources (uranium, geothermal, hydrocarbons) have been exploited in the immediate vicinity of Yucca Mountain. To date, groundwater has been perhaps the most heavily utilized resource. The main users historically have been the communities and farms of the Amargosa Desert to the south, the towns of Beatty, Pahrump, and Furnace Creek, the Nevada Test Site, Nellis Bombing and Gunnery Range, Indian Springs Air Force Base, and the mining operations in the area. Springs and pools also depend on the groundwater flow and recharge to maintain the habitat of endangered species of pupfish (DOE, 1988). Aquifers are largely Quaternary-Tertiary valley fill and Tertiary tuffs, although there is also contribution from the underlying Paleozoic carbonates.

3.5.2 Mineral Resources near Yucca Mountain

The above discussion of types of mineral deposits in the Great Basin subprovince of the Basin and Range should not be considered exhaustive and complete, as there will undoubtedly be additional discoveries that will add to the list. However, given the extensive mineral exploration that has been conducted in the Great Basin, it seems unlikely that major ore deposits of a previously undiscovered type or resource will be discovered and developed in the foreseeable future. Therefore, identification of the underlying trends and similarities of the deposits listed above can be a useful reconnaissance tool in the mineral resource evaluation of a given area in Nevada. The presence or absence of similar characteristics at Yucca Mountain will provide some evidence for characterizing the resource potential of the area.

The bulk of the mineral deposit types discussed above require a heat source (porphyry, disseminated gold/silver, polymetallic veins, volcanogenic massive sulfides, etc.). Additional requirements are fluid circulation through zones of enhanced permeability (disseminated gold/silver,

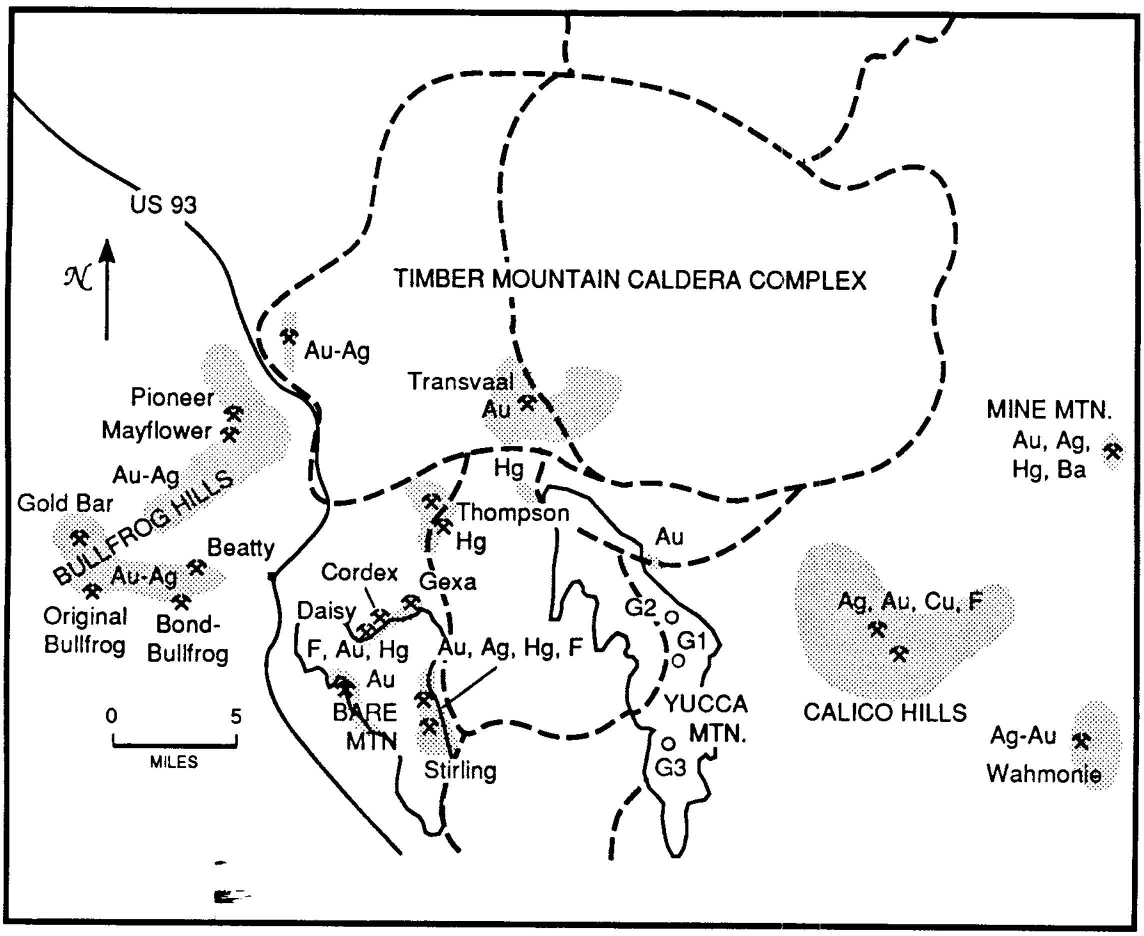


Figure 3-19. Location of historic and currently active mines and prospects in the vicinity of Yucca Mountain (modified from Johnson and Hummel, 1991).

manto, breccia). Structural and stratigraphic traps are frequently identified as important features for localizing mineralizing fluids (polymetallic veins, disseminated gold/silver). Finally, a reactive host rock such as a carbonate is commonly associated with many types of mineral deposits (disseminated gold/silver, skarn and manto). Frequent indications of mineralization include zoned alteration (argillic, propylitic, etc.), anomalous concentrations of Au, Ag, Hg, As, Tl and Sb, and surface gossans and veining.

At Yucca Mountain, the large amounts of volcanic rock indicate that heat was probably available, at least in the short term, for possible mineralization. Diagenetic alteration including smectite, illite, zeolite and feldspar has been largely controlled by host rock lithology. Geochemical studies based on clay mineralogy (Bish, 1986) indicate that temperatures may have reached as high as 275° C at the north end of the exploratory block (drill hole USW G-2), within the temperature ranges for many types of ore deposits. The same studies indicate, however, that maximum values decrease towards the south to less than 100° C in drill hole USW G-3 at the south end of the block. In addition, evidence for these temperatures is only found at depth (> 1100 m). There is no indication that temperatures reached values similar to high-temperature deposits such as porphyry copper and copper skarns (450° C to 650° C). Current alteration zonation at Yucca Mountain supports diagenesis at an elevated geothermal gradient, and K/Ar age dating of clays suggests timing of the alteration at 10.5-11.5 m.y., approximately coincident with the formation of the Timber Mountain caldera to the north (Broxton et al., 1987, Bish, 1986).

Broxton et al. (1987) has proposed that diagenetic alteration has largely occurred in more permeable nonwelded tuff. In addition, permeability of the nonwelded zones decreased with diagenesis, gradually choking off hydrothermal circulation, and restricting the transport of solutions in groundwater with depth (Broxton et al., 1987). Currently available data suggests little or no hydrothermal alteration has occurred since the Timber Mountain volcanism (Bish, 1986).

While volcanic-hosted disseminated gold deposits do occur in Nevada, the mineralization is normally distributed in veins and microveinlets, a characteristic which has not been observed at Yucca Mountain. In addition, there is only minor surface evidence of alteration (adularia, alunite, jasperoid, jarosite, gossan, etc.). Tracer elements such as Au, Ag, Hg, Sb, As, Tl associated with many of these deposits have not been observed in systematic anomalous abundance at Yucca Mountain, and covariance between these elements typical of disseminated gold/silver has not been observed (Castor et al., 1989). Reactive calcareous host-rock, of critical importance for many types of ore deposits (skarns, manto, sediment-hosted disseminated gold/silver), does not crop out in the exploratory block, and only limited exposure occurs in the controlled area. Paleozoic carbonate has been encountered at depth, and may host as yet undiscovered deposits. However, the minimum depth to Paleozoic rocks in the vicinity of Yucca Mountain is 1200 m in drill hole UE-25p#1, and pre-Tertiary rocks have not been encountered at depths up to 1800 m beneath the exploratory block. Because current technologies rely on open-pit mining of near surface deposits, these depths would appear to preclude economic production of low-grade gold/silver or base metal deposits. Elements associated with hydrothermal systems (Cu, Pb, Zn, U, Th, V, Cr, Ni, and Co) are not found in anomalous amounts in the tuffs of Yucca Mountain (Mattson, 1988). In addition, although hydrothermal alteration is present in the vicinity of Yucca Mountain (Bish, 1986; Johnson and Hummel, 1991), the extensive alteration zoning typically associated with porphyry systems has not been discovered to date at Yucca Mountain.

Extensive Tertiary faulting could possibly have provided zones of high permeability for hydrothermal solution, and calcite and opal deposits are associated with some faulting (Trench 14 on the

Bow Ridge Fault east of Yucca Mountain). At present, however, no polymetallic mineralization has been observed in association with these deposits, and isotopic evidence (Quade and Cerling, 1990; Szabo and Kyser, 1990) suggests a pedogenic origin. High-angle faults and breccias in the hanging wall of a Mesozoic thrust in the Bare Mountains east of west of Yucca Mountain host vein gold deposits at the Sterling Mine (Odt, 1983). Low-angle detachment faults have also been observed to host mineralization in the Bullfrog Mountains, and a similar detachment has been postulated to underlie Yucca Mountain at the Tertiary/Paleozoic contact (Scott and Bonk, 1984). Balanced cross-sections (CNWRA, 1990c) based on the work of Scott and Bonk (1984) indicate, however, that a detachment, if present may lie as much as 4 km deep, well below the Paleozoic contact located in drill hole UE-25p#1.

Distribution of disseminated gold deposits in Nevada is influenced on a regional scale. Roberts et al.(1971) identified the hanging wall of the Roberts Mountain thrust as a key structural feature affecting gold distribution. The fault trace represents a fairly sharp eastern boundary to the disseminated gold districts known at present. The fact that Yucca Mountain lies in the footwall of the thrust beyond its known extent suggests that the area may be a lesser target for exploration for Carlin-type sediment-hosted disseminated gold/silver. In addition, while volcanic-hosted disseminated gold/silver deposits are associated with magnetic anomalies in the Walker Lane Belt (including Yucca Mountain), this region appears to lack known pluton-related and sediment-hosted gold deposits (Blakely and Jachens, 1991).

Historical production of mercury and fluorspar indicate the potential for future development. If deposits of mercury and fluorspar are present, the low bulk value of these commodities would require either large amounts or shallow burial of the resource for economic production. At Yucca Mountain; however, there is little surface alteration to indicate the presence of these deposits. The zeolites present in the tuffs at Yucca Mountain are predominantly clinoptilolite and analcime, with minor heulandite and mordenite components (Vaniman et al., 1984). Four commonly zeolitized intervals have been identified across Yucca Mountain. Largely limited to tuffs below the proposed repository horizon in the Topopah Springs Member, zeolite comprises over 70 percent of the rock by volume in some places. Calculations by Vaniman et al. (1984) indicate that, when normalized to 100 percent zeolite, equivalent thicknesses range from 24 m to 73 m, suggesting a significant amount of zeolite reserves. However, these thicknesses are at depths of over 1700 feet. Given the low unit value of zeolites, and the common, near-surface occurrence of significant reserves in other areas of Nevada (Churchill, Pershing, and Eureka Counties) and other states (Papke, 1972; Sheppard, 1975), it seems unlikely that deep zeolites at Yucca Mountain will become a major resource in the foreseeable future.

3.5.3 Petroleum Resources near Yucca Mountain

Petroleum production has been limited to a relatively few areas in Nevada. Garside et al. (1988) identify southern Nye County as either low or very low in petroleum potential (Figure 3-14). Although four permits have been granted, only three wildcat wells have been drilled to date (early 1992) in Nye County. One has been drilled to about 1200 m in Oasis Valley, 25 km to the northwest of Yucca Mountain. Two other wells have been drilled on opposite sides of a normal fault extended southwards from Fortymile Canyon about 20 (about 1500 m deep) and 25 (about 450 m deep) km south of Yucca Mountain. The deeper of the two wells drilled into Paleozoic carbonate at about 670 m. As of this writing (1992), drilling has not begun at the other permitted wildcat well also about 25 km to the south of Yucca Mountain. Large subthrust plays are considered the desirable potential targets in southern Nevada (Chamberlain et al., 1987; Johnson and Hummel, 1991). Tertiary plays are also possible in the vicinity of Yucca Mountain. The most common Tertiary reservoir and source rocks (the Sheep Pass

Formation, see above, Section 3.4.2) may correlate with the Titus Canyon Formation to the southeast of Yucca Mountain. Silurian carbonate in drill hole UE-25p#1 indicates that erosion prior to volcanism removed the principal Devonian and/or Tertiary reservoir rocks at depth. Mesozoic thrusting has been identified east of Yucca Flat (Mine Mountain and CP thrust, Stewart, 1980). Thrusting in the Spotted and Spring Mountains has also been identified, but Cambrian units in the hanging wall are thrust to the south on Ordovician, Silurian, and Devonian rocks. Although the Ordovician Vinini formation may be preserved as a source rock at depth, it has not been identified in the area, and the thrusting has occurred too deep in the section to preserve either the proposed Chainman Shale (Eleana Formation) as a source rock, or much of the Devonian reservoir rock. Large-scale thrust faulting involving Cambrian through Permian sediments has been tentatively identified to the north and east in the Timpahute range of western Lincoln County, and may be related to thrusting in the Pancake and Grant Ranges. If these thrusts are rooted to the west, the possibility may exist for subthrust petroleum reserves such as those proposed by Chamberlain et al. (1987). The proposed root zone has not been identified to date, however, and would potentially lie well to the north of Yucca Mountain. It is also important to note that none of the petroleum production in Nevada to date has come from subthrust structures of this type (Mattson et al., 1992). In addition, the Mississippian clastics change in character to the south, becoming more calcareous and less favorable as a source rock candidate. Finally, the high heat-flow associated with the extensive Late Tertiary volcanism of southern Nevada suggests the possible overmaturing of any potential hydrocarbons in the area. The Conodont Alteration Index (CAI) of Paleozoic rocks in the vicinity of Yucca Mountain ranges from 3 to 6, indicating that the thermal history of the rocks is largely outside of the oil generating window with paleotemperatures as high as 300° C. The lower CAI (3) values, however, are within the gas generating window (Mattson et al., 1992).

3.5.4 Geothermal Resources near Yucca Mountain

Because of the proximity to the Eureka heat-flow low, there are below average (for the Basin and Range) geothermal gradients in the Yucca Mountain region (DOE, 1988; Sass and Lachenbruch, 1982). Because geothermal gradients are a key feature in geothermal exploration, this makes the region less likely as a geothermal exploration target. Surface indications are present that suggest fossil geothermal activity, but only minor travertine is reported in Amargosa Valley. There are some warm springs near Beatty and in Ash Meadows to the south of Yucca Mountain, and some low- to intermediate-temperature geothermal wells are documented, (e.g., J-12 in Jackass Flat, and UE-20f about 40 km north of Yucca Mountain at Pahute Mesa). However, water chemistry and stable isotope analysis (DOE, 1988; Benson and McKinley, 1985) indicate that most maximum water temperatures were on the order of 60 to 90° C, well below values of geothermal interest. In addition, the depth to warmest temperatures in the wells are on the order of several thousand meters (125° C at 3700 m in UE-20f at Pahute Mesa; DOE, 1988), below the 1 km depth defined for the economic production of a low-temperature geothermal energy by Sammel (1979). Radiocarbon techniques provide groundwater ages of 3,000 to 17,000 years, suggesting that no significant geothermal activity has occurred in the Yucca Mountain region for at least this time interval.

3.5.5 Groundwater Resources near Yucca Mountain

As discussed above, groundwater is currently the most utilized resource in the Yucca Mountain area. As of 1986, the bulk of the wells drilled are used for residential and agricultural needs. Most of current production is from aquifers in the Tertiary/Quaternary alluvium, although there is some stable isotope evidence to indicate a contribution from underlying Paleozoic carbonates in the deeper wells

(Benson and McKinley, 1985). Additional users are industry (principally mining), military, and government agencies. In 1985, the water usage at the Nevada Test Site and the surrounding communities (population about 10,000) was approximately 2600 acre-feet and 10,000 acre-feet, respectively (DOE, 1988). Heavy agricultural use in the Amargosa Valley has lead to over allocation of groundwater resources and groundwater mining in some areas. Also, water quality has limited the availability of potable water in some communities (e.g., Beatty, DOE, 1988). Recently initiated mining activity (BOM, 1990b; Johnson and Hummel., 1991) is likely to lead to increased water usage, both through industrial requirements and in increased population in the region.

Groundwater water in the vicinity of Yucca Mountain may also be diverted to meet the rapidly growing needs of the Las Vegas area. Considering current estimates of population growth and water needs, it seems unlikely that importation of groundwater to Clark County (Las Vegas area) from the Yucca Mountain vicinity is feasible in the next 20 years (ABC, 1989). This timeframe is far short of periods considered in performance assessment. It should be noted, however, that there is a great deal of uncertainty even in the 20 year population estimates used in this type of exercise. There is undoubtedly a great deal of interplay between both population and water availability and usage, which is not reflected in the current population estimates. Limits on water availability may in turn restrict population growth. Conversely, as population increases, available water in the surrounding region will have an enhanced value making previously uneconomic water sources accessible. Also, conservation may lower per capita usage, further skewing predicted values. Finally, it is difficult, if not impossible, to predict future regulatory restrictions on water usage with any degree of certainty. Given these limits, extrapolation of water needs beyond 20 years is not possible with any degree of confidence.

3.6 CONCLUSIONS

Although Nevada has historically been a resource-rich region, resource potential is highly site-specific. The occurrence of a given resource nearby does not guarantee the existence of similar types of deposits (mineral, energy, groundwater) in an area of interest. Nearby deposits should be used as tools for identifying exploration trends and understanding the genesis of a given type of deposit for subsequent comparison to the area under consideration. If certain key geologic controls are missing, or certain associated features are absent, the resource potential for that area is correspondingly reduced, and the likelihood of further exploration decreases.

Natural resource potential is important with respect to possible inadvertent human intrusion into the repository environment following permanent closure (10 CFR Part 60). In most reconnaissance exploration, the initial stages involve a literature review, remote sensing, reconnaissance geology, and surface sampling (Figure 3-20)(Eimon, 1988). Only if the results of each of these studies are considered favorable will a commercial project proceed to the more expensive steps of exploratory drilling, excavation, and target definition. Therefore, it is critical to evaluate both the local (and perhaps regional) geologic environment, and possible deposit-forming processes currently operating at the site, or that may have operated in the past. Knowledge of the type and extent of human intrusion which is likely to be associated with each successive step of the exploration and production process can then be combined with a firm geologic understanding of the repository environment to evaluate the effect on system performance. For the purposes of a HLW repository, this approach will provide valuable information for scenario development associated with the performance assessment modeling of the proposed site.

STAGES AND EXPENDITURES IN A MINERAL EXPLORATION PROGRAM

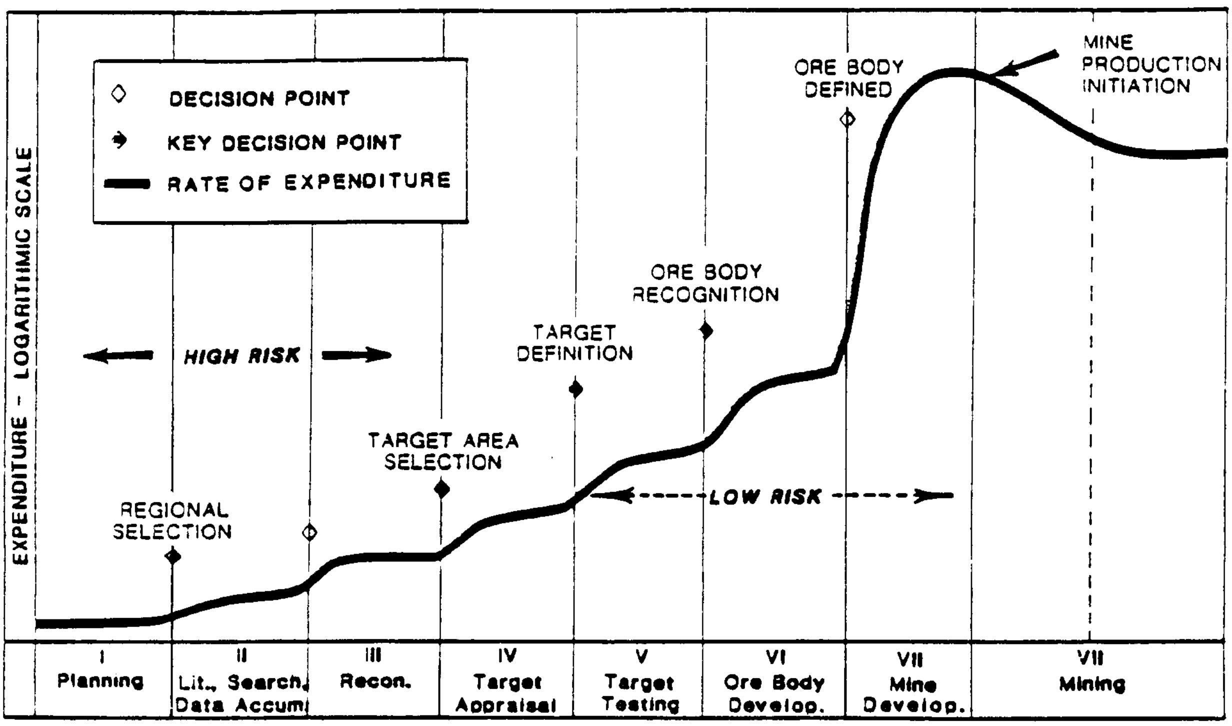


Figure 3-20. General outline of the steps and decisions involved in resource exploration programs. Expenditure is expressed in a relative sense on a logarithmic scale. The outline is developed from mineral exploration, but a similar approach is suitable for other resources (after Eimon, 1988).

4 CONSIDERATION OF COMPLIANCE METHODOLOGIES TO SATISFY THE POTENTIALLY ADVERSE CONDITIONS RELATED TO NATURAL RESOURCES

This chapter discusses the regulatory language contained in each of the four natural resource related PAC Presence of Naturally Occurring Materials [10 CFR 60.122(c)(17)], Evidence of Subsurface Mining [10 CFR 60.122(c)(18)], Evidence of Drilling [10 CFR 60.122(c)(19)], and Human Activity and Groundwater [10 CFR 60.122(c)(2)]. Generic methods identified by CNWRA to fulfill the requirements of the regulatory language are discussed.

4.1 COMPLIANCE WITH REGULATORY LANGUAGE IN PAC — Human Activity and Groundwater

The information in this section is the product of a CNWRA study of the regulation and presents CNWRA approaches to satisfying the intent of the regulation. The regulatory language of 10 CFR 60.122(c)(2) is as follows:

> "(2) Potential for foreseeable human activity to adversely affect the groundwater flow system, such as groundwater withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activity or construction of large scale surface water impoundments."

This regulatory requirement, concerning a PAC, focuses on the potential for foreseeable human activities to adversely affect the groundwater flow system. These are activities such as groundwater withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activity, or construction of large-scale surface water impoundments. For most radionuclides of concern to geologic repository performance, groundwater is the principal transporting agent. Any process that serves to accelerate groundwater velocities has the potential to adversely impact the geologic barrier and repository performance. Human activities, of the types described above, clearly have this potential. CNWRA and NRC staff have interpreted "foreseeable human activities" in the language and context of the regulation to mean those activities that are occurring today and are likely to continue through the near and distant future. For example, groundwater is generally obtained by drilling wells and installing pumps to lift water to the surface. This basic approach to groundwater acquisition is not expected to change, even in the distant future.

A number of other PACs are related to this regulatory requirement. For example, 60.122(c)(6) relates to the potential for hydrologic changes due to reasonably foreseeable climatic changes. Human effects on climate should be covered under the climate PAC and not under this requirement, even though such climatic effects might directly affect the groundwater flow system. Another related PAC is 10 CFR 60.122(c)(22), which addresses the potential for the water table to rise high enough to saturate a repository located in a vadose zone. This analysis of 10 CFR 60.122(c)(2) assumes that rises in the water table at Yucca Mountain would more likely be caused by long-term climatic changes (involving cooler temperatures and increased precipitation and recharge) rather than by human activities. Groundwater as an exploitable, naturally occurring material which might engender inadvertent human intrusion into a repository should be addressed by DOE under 10 CFR 60.122(c)(17).

Perhaps the PAC most related to this regulatory requirement is 10 CFR 60.122(c)(5) — Changes In Hydrologic Conditions, which relates to hydrologic changes that would affect radionuclide migration by altering hydraulic gradients, groundwater velocities, hydraulic conductivities, etc. The nature of the hydrologic changes referred to under 10 CFR 60.122(c)(5), whether human- or naturally-induced, is not specified. This discussion proceeded, based on the assumption, that direct, human-induced changes in the hydrologic system should be addressed under the PAC — Human Activity and Groundwater regulatory requirement. The consequences of a potential thickening of the vadose zone (i.e., lengthening of vadose zone flow paths) will be evaluated under 10 CFR 60.122(c)(5) and under 10 CFR 60.112.

Irrigation is considered to be intimately linked to the issue of groundwater withdrawals. Generally, if groundwater is used for irrigation purposes, the wells are located close to the irrigation sites. CNWRA and NRC staff have assumed that the extremely dry climate, poor soil conditions, and generally steep topography at the Yucca Mountain site will prevent it from being used for agricultural purposes in the future. However, use of water for irrigation may be one of the key reasons for large-scale groundwater withdrawals in the region beyond the controlled area. This region includes Jackass Flats, Rock Valley, Amargosa Valley, and the Amargosa Desert.

Large-scale surface impoundments require perennial sources of surface water, which are not present at the proposed Yucca Mountain site. The very high evaporation rates during most of the year in southern Nevada would also discourage the construction of large impoundments under present-day climatic conditions. Underground injection and pumped storage are considered to be unlikely events. Any of these activities would have to occur directly at Yucca Mountain itself in order to have significant effects on repository performance. Military activity in the form of underground nuclear testing is presently occurring at the Nevada Test Site. DOE (1988, p. 8.3.5.17-21) considered that the seismic effects of weapons testing are bounded by the scenario classes for tectonic disturbances. The ongoing testing reportedly causes only minor, transient effects on the groundwater system at Yucca Mountain. Strip charts at wells UE-25 B#1 and USW H-4 have measured responses to nuclear tests and very small earthquakes. The water level responses in these open holes were a small fraction of a foot (personal communication, Richard Luckey, USGS, November 1991). It is noted that packers were not used to obtain pressure responses. The issue of the effects of nuclear testing would have to be re-examined if testing should begin at sites closer to the proposed Yucca Mountain site. No other future human activities or combinations of activities that are expected to have significant adverse effects on the groundwater system and repository performance were identified.

Previous DOE evaluations of this PAC — Human Activity and Groundwater were reviewed. In the Environmental Assessment for the Yucca Mountain Site, DOE (1986b) gave preliminary evaluations of both favorable conditions and PAC. With regard to this PAC, DOE concluded that the Yucca Mountain site has very limited potential for large-scale development of water resources and that modification of the groundwater flow system is unlikely. In fact, DOE considered that any changes that may increase the thickness of the vadose zone are likely to favor waste isolation. Therefore, based on available data at the time, DOE considered that this PAC was not present at Yucca Mountain.

DOE's conclusion regarding the absence of this PAC was reiterated in the report on early site suitability (SAIC, 1992, p. 2-138). One of the reasons given for the PAC not being present was "great depth to groundwater." It is certainly true that beneath Yucca Mountain proper the depth is great, ranging from about 500–700 m. Given this information, this analysis ends with DOE's conclusion that large-scale development of groundwater resources at the Yucca Mountain "site" is unlikely. However, it should be noted that large-scale future development could occur in the Yucca Mountain vicinity because the water table is much shallower in surrounding areas beyond the controlled area. For example, borehole UE-29, northeast of the site, has a water table depth of less than 30 m (Waddell et al., 1984). At well J-12, southeast of the site, the depth is less than 230 m (DOE, 1988, p. 3-158). Well data from Amargosa Valley (formerly Lathrop Wells) indicate water table depths of less than 100 m (Waddell et al., 1984). These depths are not so great as to preclude extensive exploitation, should the need arise. As discussed later, within less than 15 years the Las Vegas Valley will have to import groundwater from adjoining basins (personal communication, David Donnelly, May 1992).

Extensive groundwater withdrawals and lowering of water tables appears to be the most likely human effects on the groundwater system in southern Nevada. Historically, lowering of groundwater tables has been the trend in large areas of the west where groundwater has been drawn in quantities that exceed recharge. The mid-western Ogalalla Aquifer is one of the best-known examples of the effects of extreme groundwater "mining." Local examples of smaller-scale groundwater mining in Nevada include previous groundwater overdrafts in the Las Vegas Valley, Amargosa Desert, Crater Flat, and Pahrump Valley. An overdraft of 3000 acre-ft/yr (3.7×10^6 cubic m/yr) exists in the Amargosa Valley. Crater Flat is overdrawn because of an appropriation for mining purposes (DOE, 1988, p. 3-121). Groundwater overdraft in the Ash Meadows area of the Amargosa Desert resulted in water level declines in Devil's Hole, habitat for the endangered Devil's Hole pupfish which resulted in court action to restrict groundwater withdrawals in a way that would maintain water levels (Dudley and Larson, 1976; DOE, 1988, p. 3-123).

Water use in Nevada is currently governed by the Office of the State Engineer and the Division of Water Resources. If there is evidence that an aquifer overdraft is occurring, measures can be taken to regulate withdrawals. The Nevada State Engineer can designate groundwater basin boundaries in areas where groundwater resources are being depleted (DOE, 1988, 3-134). Such designation orders have been issued in:

- Amargosa Desert groundwater basin
- Pahrump Artesian Basin
- Oasis Valley West
- Indian Springs Valley

Although groundwater mining is currently prohibited in Nevada (DOE, 1988, p. 3-114, 3-121), the statutes allow overdrafts for mining for periods less than five years.

The need for additional development of groundwater resources in southern Nevada will continue to grow in the foreseeable future. This conclusion is based on projected water demands in the Las Vegas area and on the finite allocation received by the State of Nevada from the Colorado River. Future water needs in southern California can also be expected to rise. The Las Vegas Valley Water District has already begun a serious effort to find a regional approach to solving the water supply problem. Water Resources Management, Inc. (WRMI) refers to the magnitude and urgency of the water supply problem for the district (WRMI, 1992). It noted that without any action, projected development cannot be supported beyond the year 1995. Allocation of the rest of Nevada's Colorado River water will extend that time to the year 2002, and along with the imposition of a responsible program of water conservation measures will extend that time further to the year 2006. After 2006, additional water will be needed to support the region's projected needs. WRMI (1992) recommended that the Las Vegas Region aggressively pursue any possible new sources of water and immediately plan to construct facilities to import additional water to the region. Based on a personal communication with David Donnelly (May

1992), Chief Engineer with the Las Vegas Valley Water District, additional groundwater resources will have to be acquired from adjoining groundwater basins.

As discussed above, available predictions indicate the total utilization of available water resources in the Las Vegas Valley by ~2006. One can foresee the need for the Las Vegas Valley to import groundwater from basins to the north and west. The proposed Yucca Mountain site and the Amargosa Desert lie to the northwest of Las Vegas valley. Technically, groundwater mining is not legal in the State of Nevada. However, given that the only controls are statutory (i.e., political), it would be prudent to assume that future political decisions by the state, in the face of finite water resources and expanding needs, may result in renewed groundwater mining and overdrafts in this region. Such overdrafts would result in a lowering of water tables and the potential for increased hydraulic gradients. Such human activities would result in locally increased groundwater velocities in the saturated zone which, if they occurred near Yucca Mountain, could result in adverse effects on geologic repository performance with respect to the EPA radiation standards. Conversely, corresponding lowering of the water table beneath Yucca Mountain could actually be favorable with respect to isolation by artificially increasing the thickness of the vadose zone. However, it is not yet known whether the consequences of greater velocities in the saturated zone would be balanced by thickening of the vadose zone (i.e., lengthening of vadose zone flow paths). The consequences of a potential thickening of the vadose zone should be evaluated by DOE under 10 CFR 60.122(c)(5) and 60.112.

Based on current trends in the use of water resources in southern Nevada, this analysis considers that the region's groundwater flow system could be strongly influenced by future human activities. However, without more extensive site characterization data, this analysis cannot reliably determine the full extent to which large-scale groundwater withdrawals could adversely impact geologic repository performance.

The following technical uncertainty relative to the evaluation of future human activity affecting groundwater has been identified by CNWRA and NRC staff: "The ability to predict the locations and extent of foreseeable human activities that may adversely affect the groundwater flow system." For this initial assessment of foreseeable human activities, only groundwater withdrawals were considered as having possibly significant effects on repository performance.

Apostolakis et al. (1991, p. 128) discuss why predictions about future human activity are very different from predictions of natural processes. Predicting the magnitude of future human effects on the groundwater flow system is linked to the impractical task of forecasting human behavior. However, it is possible to identify a range of groundwater extraction scenarios that would influence the water table beneath Yucca Mountain. Therefore, in this way, this technical uncertainty can be bounded and reduced. One approach was identified by ABC, in a report (see Appendix A) prepared for the CNWRA (ABC, 1990b). This report described a methodology for assessing groundwater resources as a potential source of human intrusion. They analyzed various scenarios, including open borehole pathways and effects on the hydraulic gradient caused by pumping. ABC analyzed the frequency of well drilling in the region and, considering practical aspects of groundwater exploration, came to the conclusion that there is a very low probability of direct human intrusion due to drilling for groundwater. ABC also considered an active pathway scenario with one (single-family domestic) pumping well (400 gal/day), and concluded that there is little likelihood of groundwater pumping adversely affecting the performance of a repository. However, they did not consider the effects of a field of pumping wells used to extract water for transport to another part of the region (such as southern California or the Las Vegas Valley). In another report (see Appendix B), ABC cited a State of Nevada report (1971) that noted that the only area in southern

Nevada that is expected to have a significant water deficiency in the future is the Las Vegas Metropolitan area (ABC, 1990b).

Future large-scale groundwater withdrawals near the site may accelerate the migration rates of radionuclides in the saturated zone along paths to the accessible environment. This may lead to violations of 10 CFR 60.112 and each of its three performance requirements. All three performance requirements are at risk because of the identified technical uncertainty, even though they cover different time frames (e.g., the containment requirements applies over 10,000 years whereas the other performance requirements apply over a period of 1,000 years). This is true because all three requirements relate to conditions in the saturated zone, and because adverse human effects on the groundwater flow system may just as reasonably occur over the next 1,000 years as they may occur over the period between 1,000 and 10,000 years in the future. It should be noted that if "special sources" of groundwater are confirmed not to exist in the vicinity of Yucca Mountain, then there can be no violations of the groundwater protection requirements. Nuclear Waste Consultants, Inc. (1987), in a report (see Appendix C) prepared for NRC, gave a preliminary assessment that no "special sources" of groundwater exist in the Yucca Mountain vicinity.

Although drawdowns in unconfined aquifers generally do not laterally propagate as fast as in confined aquifers, it is noted that the very small horizontal hydraulic gradients east and southeast of Yucca Mountain would require little perturbation to significantly change groundwater travel time (particularly in the saturated leg). For example, DOE (1988, p. 3-221) calculated particle velocities over two segments in the saturated zone along a line connecting wells UE-25b#1 and J-13. Different particle velocities were derived for the two segments because the water table occurs in different tuff units. For that segment in the Topopah Spring unit, a particle velocity of about 14 m/yr was obtained. The gradient for this segment, which has a length of 2 km, was found to be 1.1×10^{-4}. If the head difference over this 2 km distance were to be increased by only ~0.2 m (less than 1 ft), the particle velocity would double and the corresponding groundwater travel time over this segment would be cut in half. Thus, very small reductions in hydraulic heads southeast of the site could significantly accelerate groundwater fluxes away from the site.

If the vadose zone at Yucca Mountain is subsequently found to have such favorable characteristics that DOE does not need to rely on the saturated zone to insure the isolation of the waste, then the effects of a thickened vadose zone would outweigh accelerated groundwater velocities in the saturated zone. Based on estimates of GWTT time to the accessible environment described in DOE's SCP, travel time for the saturated zone is less than 200 years, and ranges from 9,000 to 80,000 years for the vadose zone (DOE, 1988, p. 3-219). These numbers for the vadose zone appear to be highly uncertain at this time.

DOE analysis assumes that all flow in the vadose zone occurs within the rock matrix, and that no fracture flow occurs. There is evidence to suggest that enhanced flow paths can and do exist in unsaturated tuffs. Russell et al. (1987) and Clebsch (1960) describe analyses of tritium data from a groundwater sample collected in the U12e Tunnel in Rainier Mesa. Results indicated a residence time of eight months to 6 years. These results were duplicated using a sample from a spring near the northern end of Rainier Mesa. The sampling sites were believed to be sufficiently far from nuclear testing sites to prevent tritium contamination from such testing. The presence of rapid flow paths in unsaturated tuffs has also been detected at the Apache Leap site. Bassett et al. (1992) note that the travel time for water from Queen Creek seepage through fractures into the Never Sweat Tunnel is on the order of 1 to 3 months. If enhanced flow paths of this type are discovered at Yucca Mountain, it may be necessary for

DOE to place greater reliance on the saturated leg of the groundwater flow path to maintain waste isolation within the prescribed performance objectives.

In evaluating this regulatory requirement, this analysis considered the implications of 10 CFR 60.121 as it relates to DOE's future acquisition of water rights in the vicinity of Yucca Mountain. In accordance with 10 CFR 60.121, DOE shall "exercise any jurisdiction and control over surface and subsurface estates necessary to prevent adverse human actions that could significantly reduce the geologic repository's ability to achieve isolation." CNWRA and NRC staff consider that 10 CFR 60.121 imposes a postclosure, institutional control of finite duration. This institutional control should not be assumed to exist for a significant period beyond closure of a repository, and thus cannot serve to mitigate potential adverse effects on the groundwater system caused by foreseeable human activities. For example, as discussed by EPA (1985), active institutional controls cannot be relied upon to isolate waste for more than 100 years after disposal.

To summarize, the following assumptions have been made in this discussion:

- For purposes of discussion, the current regulatory position in 40 CFR Part 191 is assumed. Human activities and human intrusion must be considered when evaluating compliance with the "Containment Requirements" of 40 CFR Part 191. The regulation does not exclude <u>human activities</u> from consideration of the "Individual Protection" and "Groundwater Protection" requirements, even though <u>human intrusion is excluded</u> from these requirements.

- With respect to groundwater resources, foreseeable human activities are those activities that are occurring today and are likely to continue through the near and distant future.

- Large-scale groundwater withdrawals are considered to be the only reasonable, future human activities affecting groundwater that may adversely affect waste isolation.

- Although future human activities and their effects cannot be reliably predicted, it is possible to identify and evaluate the effects of a range of such activities which could adversely affect the groundwater flow system. Within 15 years or less, the Las Vegas Valley will have to import large amounts of groundwater from adjoining sub-basins. Water resource needs will also continue to grow in southern California.

- DOE may have to rely significantly on the isolation potential of the saturated zone between the repository and the accessible environment if the proven isolation potential of the unsaturated is significantly less than expected.

- Conditions at the proposed Yucca Mountain site will preclude future agriculture on any significant scale.

- Future nuclear testing will not occur at magnitudes much larger than recent tests, or at locations significantly closer to the site.

- The consequences of a potential thickening of the vadose zone (i.e., lengthening of vadose zone flow paths) will be evaluated by DOE under 10 CFR 60.122(c)(5) and 60.112.

4.2 COMPLIANCE WITH REGULATORY LANGUAGE IN PAC — Presence of Naturally Occurring Materials

The information in this section is the product of a CNWRA study of the regulation and presents CNWRA approaches to satisfying the intent of the regulation. The regulatory language of 10 CFR 60.122(c)(17) is as follows:

> "(17) The presence of naturally occurring materials, whether identified or undiscovered, within the site, in such form that:
>
> (i) Economic extraction is currently feasible or potentially feasible during the foreseeable future; or (ii) Such materials have greater gross value or net value than the average for other areas of similar size that are representative of and located within the geologic setting."

The likely methods of compliance with the regulatory language will be discussed in the following subsections. The meaning of the terms "within the site" and "foreseeable future" were discussed in Section 2.4. Definitions, earlier.

4.2.1 Description of the Generic Attributes of a "Geologic Setting" for Natural Resources

The site (controlled area) of the repository is located in the geologic setting and it is the geologic setting which is relied upon to contain the emplaced wastes after failure of the engineered barrier systems. Because the geologic setting is the natural component of the dual EBS/geologic barriers selected to isolate the waste, the geologic setting must be part of the consideration of the effects of inadvertent human intrusion on the performance of the repository. Also, the geologic setting must be understood in the context of natural resources [i.e., "naturally occurring materials" in 10 CFR 60.122(c)(17)] because it is included in the regulatory language. In 10 CFR 60.122(c)(17), the geologic setting is given as the location of the areas to be compared to the site to determine the relative importance of the site as a target for the future exploration/exploitation of natural resources.

4.2.1.1 Definition of Geologic Setting

The term "geologic setting" was defined in the proposed rule 10 CFR Part 60 of July 1981 as follows: "Geologic setting or site is the spatially distributed geologic, hydrologic, and geochemical systems that provide isolation of the waste" [46 Fed. Reg. 35286 (1981)]. The proposed rule further stated that "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 standards as may have been established by the Environmental Protection Agency" [46 Fed. Reg. 35286 (1981)]. It was later noted in that "This is too restrictive a definition to cover the wider region of interest which the Commission seeks to encompass by 'geologic setting' [48 Fed. Reg. 28202 (1983)]. The definition has accordingly been extended to include the geologic, hydrologic, and geochemical systems of the region in which a geologic repository operations area is or may be located." This change in the definition of geologic setting necessitated other changes in the definitions. As stated in the preamble to 10 CFR Part 60 in 49 Fed. Reg. 28202 (1983), "'Site' had been defined in the proposed rule as being equivalent to 'geologic setting.' This was appropriate where geologic setting referred to only an area having isolation capability. In the final rule, isolation is to be provided within a controlled area rather than within the geologic setting and accordingly "site" now refers to the location of the controlled area." At the same time, the term "geologic repository" was clarified with the explanation that "The new definition includes only that portion of the geologic setting that provides isolation—not the entire geologic setting. The term [geologic repository], as defined, is considered to be synonymous with "repository" as defined at Section 2(18) of the Nuclear Waste Policy Act" [48 Fed. Reg. 28205 (1983)].

NRC staff has since recognized the current definition of "geologic setting" in 10 CFR 60.2 is inadequate and potential regulatory uncertainty exists in that it does not constrain the limits of the "natural systems" which are to be considered as a part of the "geologic setting." The geologic setting is to be judged on the basis of its contribution to the attainment of the performance objectives. The waste packages, and underground facility, together known as the engineered barriers system, and the geologic setting or natural barrier comprise the multi-barrier means to ensure that the performance objectives will be met. "An engineered barrier system is required to compensate for uncertainties in predicting the performance of the geologic setting, especially during the period of high radioactivity. Similarly, because the performance of the engineered barrier system is also subject to considerable uncertainty, the geologic setting must be able to contribute significantly to isolation" [48 Fed. Reg. 28195 (1983)]. "The engineered barriers shall be designed to assist the geologic setting in meeting the long-term performance objectives" [48 Fed. Reg. 28214 (1983)]. Additionally, the staff "recognizes that processes operating more remotely from the geologic repository must be taken into account" [48 Fed. Reg. 28211 (1983)]. "However, the Commission recognizes that at some point the design capabilities of the engineered system will be lost and that the geologic setting—(at the) site—must provide the isolation of the wastes from the environment, and has translated this requirement into a performance objective for the geologic setting" (Fed Reg. 10246 No. 130, Wed. July 8, 1981/Proposed Rule. FR 35280).

4.2.1.2 Size of Geologic Setting

The size of the geologic setting has been debated but NRC staff has given the following guidance: "The staff agrees that the "site" connotes a smaller area than is intended by the term 'geologic setting.' The staff also recognizes the validity of arguments which suggest that the term 'site' is more closely linked to a tract of land. . . The extent of the geologic setting for particular areas will be determined on the basis of the evidence presented in the licensing process. Obviously, however, the geologic setting must be sufficiently extensive to permit an evaluation of the relevant geologic, hydrologic, and geochemical factors" (NRC, 1983, p. 187). Further, NRC staff has indicated the potential size of the geologic setting in the following quote: "Because of the large area that could be relied on to provide isolation (the controlled area could approach approximately 150 square miles) and realizing that the geologic setting itself could cover hundreds of square miles. . ." (NRC, 1983, p. 187).

Because the geologic setting size will be "sufficiently extensive to permit an evaluation of the relevant geologic, hydrologic, and geochemical factors" (NRC, 1983, p. 187), it is necessary for DOE to describe those relevant factors on the basis of the effect of each pertinent factor on waste isolation (i.e., the performance objectives). A reasonable approach for DOE would be to consider only those natural systems and perturbations within each which might affect the performance objectives as being a part of the geologic setting of a specific site.

4.2.1.3 Attributes of a Geologic Setting

The term "region" in the definition of "geologic setting" is important because the term implies that a line can be drawn about a site such that the area encompassed by the line and contained within its bounds has a set of homogeneous properties or attributes which can be used to characterize the contained natural systems. Figure 4-1 illustrates a series of overlapping sets which could be identified for a specific site based on natural system attributes. The naturally occurring conditions associated within each set could have an effect on the ability of a given site to meet the performance objectives. For example, an earthquake-prone area encompassed by an equal probability line defining an area within which earthquakes of a magnitude which would cause the performance objectives to be compromised could be drawn. Similarly, a line could be drawn representing the groundwater flow system within which the repository is located. This line, for instance, would delimit the area which could be affected by radioactive releases from the site into the groundwater table. A line could be drawn around the physiographic region or subregion in which a likely repository is to be located. The area encompassed by this boundary would have similar geologic, hydrologic (including meteorologic and climatologic attributes), and other natural properties which, acting in concert, had caused the region to acquire the appearance which allowed the physiographic region to be defined. Such a physiographic region would be useful in the comparison of similar areas to the controlled area in natural resource considerations. Comparable boundaries demonstrating other considerations relative to the performance objectives, favorable conditions, and PAC could be constructed. A decision determining which parts of the identified regions should be included within the confines of a "geologic setting" for a given site based on the series of regions defined by the boundary lines will have to be made and defended.

CNWRA has identified potential approaches to defining a "geologic setting":

- Include in the "geologic setting" only those portions of the described regions which have all the identified attributes which might affect performance

- Include within the area of the geologic setting all the area that has at least one of the attributes which might affect the performance objectives

- Identify those attributes at a site which seem to have the most likely effect on performance and to include the outermost effective limits as the "geologic setting"

- Define the geologic setting on the basis of a composite of attributes but not all possible attributes, such as the region identified as a physiographic region

Any of the above approaches has deficiencies. The first might circumscribe an area which is extremely small and site-specific, while the second might encompass an area that is of a scale so much larger than the controlled area as to provide an unworkable size for characterization and consideration. As noted earlier, a physiographic region is identified on the basis of its geology, hydrology (including meteorologic and climatologic attributes), topography, specialized structures, regional tectonics, and other characteristics as deemed important. Physiographic regions can and have been described for very small subregions through continental sized masses. In the case of the proposed Yucca Mountain site, the Southern Nevada Volcanic Zone, the southern Great Basin, or the Great Basin would warrant consideration as appropriate "geologic settings." DOE will be required to justify the selection of a given region as the "geologic setting" and to identify the attributes which it deemed important in such a selection.

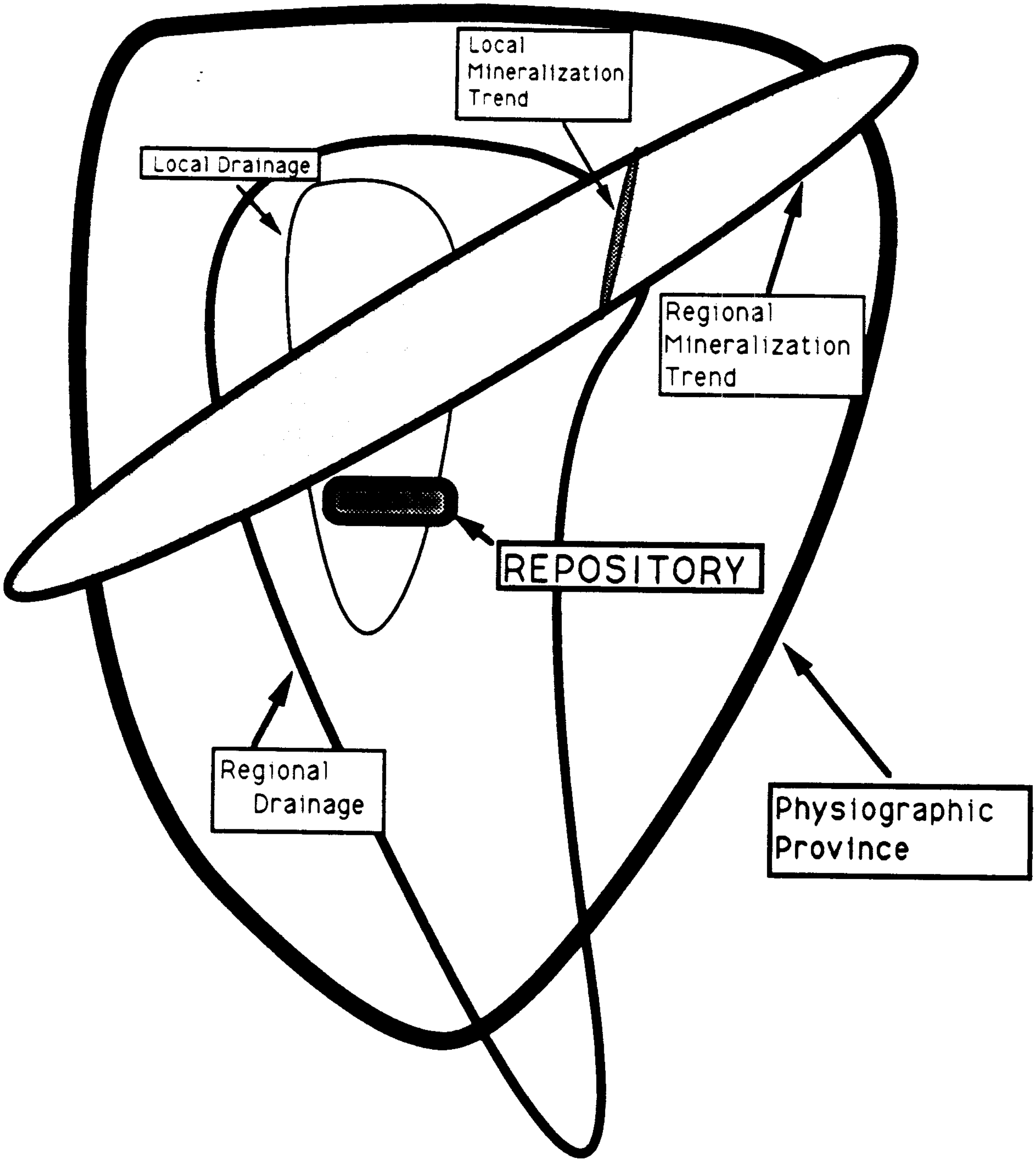


Figure 4-1. Selected geologic attributes which could be used to define a generic geologic setting

It may not be necessary that a given selected region encompasses all the locations within a natural system which might cause an effect on the performance objectives but it is essential that those possible perturbations outside the limits of a selected "geologic setting" boundary which might affect the performance objectives on a rare basis be identified and their importance discussed. For example, a magnitude 8.6 earthquake in the western Sierra Nevada range might generate a ground-wave of sufficient magnitude to cause shaking at Yucca Mountain which could affect release of radionuclides from the canisters. If sufficient quantities of radioactive materials are released, the EBS performance objectives could be breached. This postulated earthquake in the western Sierra Nevada range might be identified as an occurrence outside the "geologic setting" of Yucca Mountain since the area is in a different physiographic and tectonic regime, yet the seismic event might affect the performance of a geologic repository within the Yucca Mountain geologic setting. Even though outside the region identified as the Yucca Mountain "geologic setting," an extreme seismic event which would impact performance would have to be discussed in the context of its probable effect on a geologic repository for HLW at Yucca Mountain. Similarly, climatic change in the western Pacific might engender changes in the types and quantity of rain-bearing storms which would contact land in the western United States, potentially resulting in increased precipitation at Yucca Mountain which might cause the performance objectives to be breached because infiltration and ground water flow velocity in the water table would be enhanced. Even though the projected climatic change occurred in a realm far-removed from the identified "geologic setting" at Yucca Mountain, the potential effects on the performance objectives of local climatic change resulting from worldwide climatic perturbations outside the geologic setting would have to be described.

Through the Nuclear Waste Policy Act as amended in 1987, the Congress of the United States has specified that the site at Yucca Mountain, Nevada be characterized for the location of a proposed geologic repository for HLW. Thus, the site-selection process originally promulgated in the NWPA has been modified by Congressional mandate and the "geologic setting" must now be determined based on a known site rather than a geologic setting being identified based on a set of generic attributes deemed acceptable for a geologic repository. The reasoning supporting the desirable conditions for site-selection within a specific geologic setting is based upon known and predefined attributes. The desirable site attributes can be evaluated to predetermine that a given area or "geologic setting" for a proposed repository site appears acceptable. Original site selection is based on the current knowledge which exists prior to beginning of extensive, expensive in-depth site characterization.

The general attributes which should be those considered for inclusion in the definition of a "geologic setting" include the following:

- Lithology
- Geomorphology
- Physiography
- Topography
- Hydrology
- Tectonic structure
- Seismicity
- Geochemistry
- Historical geology
- Physical geography including climate, landform, soils, and vegetation
- Specialized features

Any one of the attributes could be used to define a region within which a homogeneity relative to the particular attribute exists; likewise any combination of these and/or other attributes could be used to define a homogeneous region based upon the selected attributes. It is possible, that one or more of the possible attributes would be considered uniquely important such that the presence or absence of the particular attribute would dominate the definition of the "geologic setting" at a given site. For example, a unique structure such as a salt dome for the location of the proposed repository would exclude the majority of the contiguous United States from further consideration as part of a homogeneous "geologic setting." An attribute such as the presence of a thick unsaturated zone would preclude only about one-half of the contiguous United States from further consideration. The selection of the various attributes to be identified and used as "geologic setting" descriptors can have a profound influence upon the selection of appropriate sites to be characterized. The definition of "geologic setting" in 10 CFR 60.2 includes the geologic, hydrologic, and geochemical systems within a region as the systems to be considered. Each system itself has a subset of attributes which should routinely be considered when defining the "geologic setting."

Because Yucca Mountain, Nevada was designated for site characterization by mandate in the 1987 ammendment to the NWPA, and only limited study of the site and region has been accomplished for the purposes of repository location and evaluation, it is primarily the responsibility of DOE to determine the attributes of the Yucca Mountain "geologic setting" and to define the limits of homogeneity of attributes at whose boundaries will be the transition between the area within the "geologic setting" and the area outside the "geologic setting." The area encompassing the regional groundwater flow system might be considered the working portion of the "geologic setting" for the hydrological concerns, while the southern Great Basin might be considered to be the working portion of the "geologic setting" for the mineral resource considerations of the site. The aggregate of the various "working portions" of the "geologic setting" should comprise the entire "geologic setting" itself. DOE will be required to support the definition of the geologic setting for the aggregate of the geologic, hydrologic, and geochemical systems which are considered. DOE will be expected to provide evidence that no adverse or undesirable conditions which might affect performance were purposefully or inadvertently excluded from the discussion of the aggregate of working portions which taken together comprise the entire "geologic setting."

4.2.2 Methodologies to Satisfy the Regulatory Requirement Language in PAC — Presence of Naturally Occurring Materials

4.2.2.1 Methodology to Identify Identified Natural Resources within the Controlled Area and Nearby a Proposed HLW Repository

The text of 10 CFR 60.21(c)(13) refers to "undiscovered deposits" and "undiscovered deposits of resources" while the text of 10 CFR 60.122(c)(17) refers to ". . . naturally occurring materials whether identified or undiscovered. . ." It is assumed based on statements such as "Consistent with the references to resources in the requirements for the content of the safety analysis report, Section 60.21(c)(13), the presence of naturally occurring materials for which economic extraction is currently feasible or potentially feasible during the foreseeable future may give rise to a potentially adverse condition." [48 Fed. Reg. 28212 (1983)] that "resources," "deposits of resources," and "naturally occurring materials" are synonymous terms.

Discovered resources are defined by the United States Geological Survey (USGS, 1976) as "identified resources which are specific bodies of mineral-bearing material whose location, quality, and quantity are known from geologic evidence supported by engineering measurements." Thus, natural resources which may exist in the controlled area must be objectively identified in order to be classed as "discovered" or "identified." It is assumed in this discussion that the "identified" naturally occurring materials referred to in 10 CFR 60.122(c)(17) are the same as "discovered" resources of the USGS. A systematic evaluation of existing geologic information should be collated and assessed for importance relative to a proposed HLW repository site. If the site has been well-explored it may have considerable extant information within the files of cognizant government agencies, the scientific literature, pertinent industry data bases, and/or resident with individuals such as prospectors and university professors. All the available information sources should be queried, particularly, but not limited to, the USGS, the U.S. Bureau of Mines (BOM), the U.S. Bureau of Land Management (BLM), and the state agency counterparts of these federal agencies. A compendium of information about the site and its geologic setting including a comprehensive bibliography should be developed.

The search of the scientific literature including pertinent computerized databases should provide DOE with information not only specific to the site but also with regional information from which inferences might be drawn relative to the resources which are expected to be found in the site and its environs. The compilation of existing geologic, engineering, and economic information should be used by DOE to establish, as thoroughly as practical, the known resources of a site before site-specific data acquisition programs are established and accomplished.

The overall site characterization program conducted during a site evaluation should include the collection of data which would provide insight into the presence or absence of potential resources at the site. Although it is not anticipated that a specific mineral, geothermal, oil/gas, or groundwater resource exploration effort be conducted by an applicant at a given site it is desirable that DOE plan to acquire information on resources be integrated and in concert with other geophysical or physical data acquisition programs to acquire the greatest amount of information at the least amount of cost. A site evaluation program which integrates the needs of scientists and engineers to understand the physical nature of the site for design, construction, and performance purposes with the needs of the geological investigators to understand the physical, chemical, and hydrologic nature of the site and the surrounding geologic setting should be designed and implemented. For example drilling for hydrologic investigations should be integrated with geophysical logging and rock sampling (e.g., geochemical analyses of cuttings) which would be accomplished in sufficient detail to delineate the existence of mineral resources. If the known data about a site indicates that a particular test or suite of tests would determine the presence or absence of certain resources at a site, then those tests should be accomplished at the site within the purview of the already planned DOE site investigation activities.

An adequate study should document all data collection activities and acquired information from archival sources as well as from on-going field data collection efforts. The LA should contain a DOE evaluation of the resources known to exist at the site. Additionally, the study should plan to report to the NRC any data which is collected during the site characterization process and subsequent evaluation which indicate that previously unknown resources are present at the site. The applicant is meant to take into consideration in the natural resources regulations, particularly the Adverse Condition — Presence of Naturally Occurring Materials [10 CFR 60.122(c)(17)], the presence of both identified and undiscovered materials which would engender exploration and/or exploitation which might cause the performance objectives to be violated. It is the drilling of holes, drifting of drifts, and potential off-site activities which might impact repository performance objectives that are herein identified as primary DOE interests by NRC.

Identification of "identified" (or "discovered") resources could be based on the existence of naturally occurring substances at the site which are in excess of worldwide "average crustal abundances" (as listed in various texts such as Levinson, 1974). It may not be prudent to use such a classification based only on worldwide average crustal abundances for "identified" resources because too many materials of little or no current value will be identified and subsequently treated. However, it is possible that worldwide average crustal abundance could be used as part of a discrimination strategy intended to identify those resources of importance at a given site. There are two categories relative to worldwide average crustal abundance versus site abundance of a given mineral resource into which a proposed repository site can be placed as follows:

- Worldwide Average Crustal Resource Abundance is greater than the Site Average Crustal Resource Abundance (WACRA > SACRA)

- Worldwide Average Crustal Resource Abundance is less than Site Average Crustal Resource Abundance (WACRA < SACRA)

Similarly, there are two broad categories comparing relative crustal resource abundances of the geologic setting to the abundances at the proposed repository site as follows:

- Worldwide Average Crustal Resource Abundance is greater than the Geologic Setting Average Crustal Resource Abundance (WACRA > GACRA)

- Worldwide Average Crustal Resource Abundance is less than the Geologic Setting Average Crustal Resource Abundance (WACRA < GACRA)

The proposed repository site is required by 10 CFR 60.21(c)(13) and 10 CFR 60.122(c)(17) to be compared to the geologic setting (using "comparison areas" of similar size to the site which are both representative of and within the geologic setting) in terms of average resource abundance based on the wording "...average for other areas of similar size..." in 10 CFR 60.122. The possible relationships can be described as follows:

- Site Average Crustal Resource Abundance is greater than the Geologic Setting Average Crustal Resource Abundance (SACRA > GACRA)

- Site Average Crustal Resource Abundance is less than Geologic Setting Average Crustal Resource Abundance (SACRA < GACRA)

An analysis of the implications of these comparisons can relatively efficiently focus technical interest on a given resource based on the relative importance of that given resource. The intent of the Commission in its suggestions that comparison areas be evaluated relative to the proposed repository site appears to have been to encourage location of a site away from areas which have a higher than average probability of containing resources. Mattson (1988) describes an assessment approach relying on chemical data on mineral resources at the proposed Yucca Mountain, Nevada repository site. Table 4-1 shows a possible assignment of relative importance and required subsequent actions to each of the possible comparisons mentioned earlier.

Table 4-1. Generic relationship of site/geologic setting/average crustal abundance and suggested resolution

SACRA < GACRA < WACRA	No additional work/explanation required. Site will always be less desirable than the "average" for the earth. Comparison area portion of regulation is satisfied; no adverse condition is present.
SACRA < GACRA > WACRA	No additional work required. Site is less attractive than the average for other areas within the GS. The regulatory requirement for PAC - Naturally Occurring Materials (10 CFR 60.122(c)(17)) is satisfied for the comparison area portion of the regulation; no adverse condition is present based upon the evaluation of the resources within the site with the comparison areas.
SACRA > GACRA < WACRA	No additional work required. Site, although more attractive than GS, has resources which are found more abundantly elsewhere (albeit not in the same region) and would not be considered a likely target for exploration/exploitation. The regulatory requirement for PAC - Naturally Occurring Materials (10 CFR 60.122(c)(17)) is satisfied relative to comparison areas; no adverse condition is present; site is deemed to be acceptable.
SACRA > GACRA > WACRA	Additional work is required to determine if the presence of greater than average resources within the site, could cause the performance objectives to be breached.

SACRA = Site Average Crustal Resource Abundance
GACRA = Geologic Setting Average Crustal Resource Abundance
WACRA = Worldwide Average Crustal Resource Abundance

As a site is more thoroughly investigated during the characterization, verification, and eventual repository construction processes, it is anticipated that data collection will proceed in sequence from surface reconnaissance and testing, to subsurface drilling and sampling, to the mining of the Exploratory Shaft Facility (ESF), to the actual construction of the underground repository. During each stage of characterization, evaluation, and eventual construction it is thought that additional, more substantive, information leading to a conclusion regarding the presence or absence of natural resources at a particular site will be acquired. DOE should incorporate this on-going data collection and subsequent assessment of the mineral and other resources at a proposed repository site into their required reporting of progress and accomplishments.

It is to be expected that the surface based-exploration and geophysical-based evaluation of natural resources will be greatly enhanced by subsequent application of down-hole geophysical methods and acquisition and analysis of physical samples from greater than shallow depths at a given site. Certainly, the development of an ESF will provide the geologist with the best information of conditions, at depth, at a given site, and may lead to a reevaluation of previously hypothesized occurrences or non-occurrences of certain resources, both identified and theretofore undiscovered. During the site-characterization efforts, DOE should plan on acquiring downhole samples at regular intervals and testing for likely minerals and other resources of interest. Although an exploration program for a particular mineral is not required by NRC, the use of all boreholes and drifts for collection of natural resource related data is highly desirable and should be integrated into DOE field data collection efforts as feasible.

At a given site, all potential resources which might exist, given the site-specific and regional geology, must be considered. For example, at the proposed repository site at Yucca Mountain Nevada, the inclusive evaluation for known mineral resources should include surface deposits such as sand and gravel, minerals such as the zeolites within the volcanic tuff, syngenetic and epigenetic occurrence of other minerals within the tuff and/or dikes, sills, and veins; minerals at the contact of the underlying Paleozoic rocks with the overlying tuff, and minerals within the Paleozoic rocks themselves. Natural resources considered should include oil and gas, various metallic minerals such as gold, silver, and tungsten, and the previously mentioned sand, gravel, and zeolites, among others as indicated by the regional evaluation of potential mineral occurrence models. Additionally, DOE should consider other resources including geothermal and ground water in its site specific evaluations. Some materials such as germanium, gallium, or other rare earths may become an important resource and their presence at a proposed repository site should be documented and evaluated. The prediction of the occurrence and location of such resources along with likelihood of occurrence of each will be a part of the scenario development for future human intrusion and should always be viewed in that context.

4.2.3 Methodology to Identify Undiscovered Resources Characteristic of the Controlled Area and Nearby a Proposed HLW Repository

Undiscovered resources are defined for the purposes of this discussion as those occurrences of a useful mineral or ore, in sufficient extent and degree of concentration to invite exploitation, that are estimated to exist, from broad geologic knowledge and theory, outside of known accumulations. The beginning text of 10 CFR 60.21(c)(13) directs the license applicant to identify and evaluate natural resources of the geologic setting, including undiscovered deposits, the exploitation of which could affect the ability of the geologic repository to isolate radioactive wastes. 10 CFR 60.21(c)(13) requires that "Undiscovered deposits of resources characteristic of the area shall be estimated by reasonable inference based on geological and geophysical evidence." It is assumed that "reasonable inference" means scientifically sound logical and rational deduction. The development of a reasonable inference about estimates of undiscovered resources would be expected: (i) to draw on all applicable data; (ii) to apply broad geological and geophysical knowledge and theory; and (iii) to use a defensible assessment methodology that relates directly to the requirements of 10 CFR 60.21(c)(13).

The methodology for assessment of undiscovered resources is a subject of active interest, especially by government agencies involved in resource management and land use planning. Examples that demonstrate the use of reasonable inference in assessing undiscovered resources include: (i) the national assessment of undiscovered oil and gas (DOI, 1989); (ii) the national assessment of U.S. uranium resources (DOE, 1980); and (iii) the assessment of Alaskan mineral resources (USGS, 1980). DOE may well utilize these or similar approaches to develop a defensible methodology for determining likelihood of resource occurrence at a proposed geologic repository appropriate to an LA.

Each of the methodologies cited and most other credible mineral assessment methodologies require the establishment of a team of experts with credentials in evaluation and assessment of the appropriate resource in the discipline and region being considered. The methods used to assign occurrence probabilities and the eventual rankings will vary from method to method; however, the final result is a weighted value for given attributes and a final summation to arrive at probabilities of resource occurrence, likely grade, size of deposit, likely depth to occurrence, and other pertinent considerations as required. The prediction of mineral and other resource occurrences should be factored into further predictions of likely exploration for and subsequent exploitation of postulated deposits to develop probabilities for each step in the resource assessment process. The ultimate output from the panel of experts should be a series of exploration/exploitation scenarios with determined probabilities of intrusion in and near a repository and likely numbers and types of intrusions (boreholes, drifts, etc.) described for given scenarios. The performance assessment effort will use these predictions to evaluate the performance of the repository in relation to the performance objectives established by EPA and NRC.

At a given site, all potential undiscovered resources must be considered and evaluated. Occurence models such as those discussed in Chapter 2 should be evaluated at the Yucca Mountain proposed repository site. The prediction of the occurrence and location of such undiscovered resources and the likelihood of occurrence of each should be used as the basis of the scenario development for future human intrusion and should always be viewed in that context.

4.2.3.1 Methodology to Satisfy the Requirement to Identify Undiscovered Resources that are "Characteristic of the Area"

The means to establish the undiscovered resources which are "characteristic" of the area [as required in 10 CFR 60.21(c)(13)] are not defined in the regulation. In the case of resources, a set of attributes or properties shall have been used to describe the geologic setting of the proposed site. The resources which are commonly associated with a particular geologic setting having the described attributes are said to be "characteristic" of the area. It is these resources common to a particular geologic setting and the occurrence models for these resources which can be found within the geologic setting which should be considered by DOE when determining the likelihood of resource occurrence within or nearby a proposed repository controlled area. Each proposed site will have a unique geologic setting and consequently will have a different suite of resources which are considered "characteristic" of the particular geologic setting and the proposed repository site within the selected geologic setting.

4.2.3.2 Methodology to Estimate by "Reasonable Inference Based on Geological and Geophysical Evidence"

For an inference to be reasonable, the information, statements, and/or statistics and the subsequent evaluation of the information must be rationally based or motivated as judged by the Commission. The wording in 10 CFR 60.21(c)(13) requires that the evidence used to make the inference will be both geological and geophysical. Thus, in the context of geologic investigations necessary to support the licensing of a HLW repository "reasonable inference" must be used to extrapolate from known geologic and/or geophysical information dealing with natural resources from both on and off a site to the likely occurrence of the same or similar resource conditions within or adjacent to a proposed HLW repository site (see BOM, 1990c).

It is likely that subjective probability techniques (either simple or complex) will be used to assess undiscovered resources at a given site because of the relatively low cost and the efficacy of the application of subjective probability techniques where physical data are limited. Because these subjective estimation methods rely upon the combined judgement of experts, the results contain some uncertainty. The identification of uncertainty in the use of expert judgement to infer the existence of undiscovered natural resources at a given site should be discussed by DOE. In order for the Commission to make an informed judgment on the acceptability of DOE results presented in the LA, all uncertainty in the use of subjective analyses (including expert opinion) in mineral resource assessment will have to be discussed, in detail.

Geological evidence which can be used to infer the presence or absence, grade, quantity, and location of natural resources at a given site include the following methods: (i) geologic mapping, (ii) geologic sampling including reconnaissance and detailed surveys, (iii) geomathematical analyses, (iv) analogs, and (v) geochemical exploration. Each of these types of geologic evidence are discussed further in BOM (1990c).

Geophysical evidence which can be used to infer the presence or absence, grade, quantity, and location of natural resources at a given site include the following methods: (i) seismic, (ii) gravimetric, (iii) magnetic, (iv) electrical and electromagnetic, (v) radiometric, (vi) borehole electronic and physical (well-logging), and (vii) miscellaneous including thermal and chemical. Each of these types of geophysical methods are discussed further in BOM (1990c).

4.2.4 Methodology to Identify Comparison Areas (i.e., "Areas of Similar Size That Are Representative Of and Are Within the Geologic Setting")

The language of the regulations in both 10 CFR 60.21(c)(13) and 10 CFR 60.122(c)(17) requires that "areas of similar size that are representative of and are within the geologic setting" be evaluated for identified and undiscovered resources. 10 CFR 60.122(c)(17) requires, further, that the areas of similar size be compared to the site to ascertain whether the site has a "greater gross value or net value than the average for other areas of similar size that are representative of and located within the geologic setting." 10 CFR 60.21(c)(13) makes no mention of the need to compare the resource value of areas within the geologic setting to the inferred resource value at the repository site.

The language in 10 CFR 60.122(c)(17) requires that the resources of the controlled area be compared to the ". . .average for other areas. . ." of resources. The term "average" can be interpreted in two ways in this context. One interpretation is that on a resource by resource basis each resource is "averaged" for the comparison areas (e.g., studied grid polygon) and that "average" of each of the resources in the comparison areas is compared one by one to the value for the particular resource which is determined for the controlled area. A second interpretation is that all the known resources in each comparison area (e.g., studied grid polygon) are "averaged" to produce a single resource value number for each comparison area, and then the single resource value numbers for each comparison area are, in turn, "averaged" to produce an average resource value for a controlled area-sized comparison area found within the geologic setting. The value of resources at the proposed controlled area would then be computed by adding the aggregate of values for each resource within the controlled area and the resulting single value compared to the single value for the "averaged" geologic setting to determine if the proposed repository site has present resources which have "greater gross value or net value than the average for other areas of similar size that are representative of and located within the geologic setting."

The purpose of the evaluation of comparison areas within the geologic setting to the Yucca Mountain site is to determine if the Yucca Mountain site has resources equal to or greater than the average for the other comparison areas selected within the geologic setting. If the perceived value of resources at Yucca Mountain is less than the average for the comparison areas, the natural resources present at the Yucca Mountain site would not be considered as a PAC. If the resources present or perceived are less than the average the performance objectives would not be expected to be compromised because there would be only a small likelihood that the Yucca Mountain site would be explored for resources relative to the totality of the remainder of the geologic setting. In other words, if the value of the site is perceived as less than the average, the likelihood of future human intrusion of the site would be sufficiently low that the performance objectives relative to isolation of the waste would not be anticipated to be compromised by future inadvertent human intrusion. If, on the other hand, the resources at the Yucca Mountain site are perceived to be of greater value than the average for the other selected areas within the geologic setting, the resources at Yucca Mountain would be considered as an adverse condition. In order for the site to be used, the presence of the natural resources in greater than average quantities would have to be shown either to not increase the likelihood of inadvertent human intrusion, or to be compensated by the presence of a combination of the identified favorable conditions. NRC staff has commented on one favorable condition that ". . . wastes buried at least 300 meters below the surface are less subject to disturbance, especially by human intrusion, than wastes closer to ground level would be" [48 Fed. Reg. 28212 (1983)]. If the PAC was capable of being remedied by mitigative engineering or other measures, NRC has noted that ". . . the Commission anticipates a high standard of engineering will be necessary—not only to compensate for geologic uncertainties at even the best reasonably available sites, but perhaps also to mitigate the consequences of unanticipated processes and events (including potential intrusion) during the years when fission product inventories remain high" [48 Fed. Reg. 28204 (1983)].

It is suggested that both the single resource and combined resource approaches be accomplished by DOE because the accomplishment of both approaches will enhance the ability to predict whether the site will be desirable to future explorationists for both individual resources and/or the aggregate of resources. It is possible to envision a site having gold of marginal value and silver of marginal value which would not be developed if either the gold or the silver was absent but which would be developed based on the aggregate value of the two mineral resources being present. Also, it would be possible for a site to have only one resource of moderate profitability which is overshadowed by the comparison sites which have highly profitable or larger deposits. It would be expected that the higher-valued sites would be explored and developed first. Sites with moderate profitability would also be developed, as time progresses. Such anticipated stages in developmental exploration/exploitation activities should be factored into the performance assessment of each site to realistically determine the relative probability of inadvertent human intrusion at the proposed repository site during the 10,000 year regulatory future.

The requirement for the comparison areas to be investigated has three separate components as follows:

- "Similar size"
- "Representative of the geologic setting"
- "Within the geologic setting"

The first requirement is that the areas to be studied have a "similar size" to the site. The site is defined in 10 CFR 60.2 as "the location of the controlled area." The "controlled area" is defined in 10 CFR 60.2 as "a surface location, to be marked by suitable monuments, extending horizontally no more than 10 kilometers in any direction from the outer boundary of the underground facility, and the underlying subsurface, which has been committed to use as a geologic repository and from which incompatible activities would be restricted following permanent closure." This definition is a modification of the original definition of "site" in the proposed rules which was as follows: "'Site' means the geologic setting" [46 Fed. Reg. 35286 (1981)]. The area of interest, then, may extend as far as 10 kilometers from the outer boundary of the underground facility. If the outer boundary of the underground facility was a square encompassing an area of four square kilometers it would be 2 kilometers on a side and the controlled area could extend up to 10 kilometers outward from the boundary. The size of the controlled area, would approach 400 square kilometers (or about 154 square miles). The "geologic setting" is the region in which a geologic repository operations area is or may be located and, thus, must be of a larger size than the controlled area such that several comparably sized comparison areas could be located within the geologic setting. Depending on the design of the proposed repository and the area to be controlled the size of the areas to be compared to the site would be as large as about 400 square kilometers. NRC (1983, p. 217) supports this view in the following statement "Because of the large area that could be relied on to provide isolation (the controlled area could approach approximately 150 square miles) and realizing that the geologic setting itself could cover hundreds of square miles, . . ." This discussion also allows the reader to imagine the required size of the geologic setting to accommodate location of several of these areas to be used for comparison "within" the geologic setting. Item (3), above, requires a geologic setting which is many times larger that the controlled area even if only a few other areas which are comparably sized to the controlled area are to be found within the boundaries of the geologic setting.

The second phrase requiring discussion of its intended meaning is the term "representative of." The approach taken in the past (e.g., SCA) with respect to "representative data" is that such data is necessary to establish the range(s) of events and processes at a site. Therefore, "representative of" would mean that alternative comparison areas would lie within the range of resource values determined for the region of the geologic setting and would require consideration of the range in both site characterization and evaluation. In other cases, such as the location of the Experimental Studies Facility (ESF), it has been difficult historically to define the criteria which are to be used to determine "representativeness." In the case of a geologic setting and areas within it being "representative of" the geologic setting, the identified criteria determining "representativeness" should be those attributes that were used to define the character of the geologic setting. Using the proposed repository site at Yucca Mountain as an example, the chosen attributes of the overall geologic setting might be attributes such as location within the southern Great Basin physiographic region, internal drainage, unsaturated host rock, Basin and Range extensional faulting, and a prevalent arid climate, among other attributes. Numerous sites within the southern Great Basin have these geologic setting attributes and thus would be representative of the geologic setting. Yucca Mountain is definitely located within the "geologic setting" which displays the previously mentioned attributes. In addition, the Yucca Mountain site has other specific attributes such as volcano-clastics conformably overlying Paleozoic rocks, location on the periphery of a crater complex, primarily upland area, and local faulting which serve to distinguish the Yucca Mountain site from other specific areas within the geologic setting (see Chapter 3, earlier, for discussion).

The third phrase requiring explanation is "within the geologic setting." Since the geologic setting is defined as a "region" with certain homogeneous attributes, then, by definition, the "geologic setting" has described boundaries since a "region" must encompass a bounded area. The requirement is that any selected comparison area be selected from within the defined boundaries of the geologic setting. The following are assumed:

- Geologic setting is contiguous
- Boundary limit for the geologic setting can be identified and mapped
- Areas selected for comparison must be located within the contiguous area defined by the defined boundary limit.

If the "geologic setting" for Yucca Mountain is defined as the physiographic region known as the "Southern Great Basin," for example, then the comparison areas must be selected within that same physiographic region.

Once the intent of the phrases comprising the requirement is understood, a methodology to accomplish the selection of such comparison areas or a methodology to arrive at the necessary evaluation of the likelihood of human intrusion at a given proposed repository site must be accomplished by DOE. Options to select comparison areas or other means to accomplish the intent of the regulation can be simple or complex including:

- Random selection of areas for comparison with subsequent evaluation of each individual resource as averaged for all the selected comparison areas and, also, a composite "average" of all the resources within each of the comparison areas

- Directed selection and subsequent evaluation of selected controlled area-sized portions of the geologic setting for each individual resource within a selected comparison area and an overall composite "average" of all the resources of each comparison area in order to ensure that dissimilar areas within the geologic setting are not compared with the controlled area to produce a biased DOE evaluative outcome

- Evaluation of the entire geologic setting which has been subdivided into areas the approximate size of the controlled area for natural resources with both individual resources being averaged for each of the comparison areas and a composite average value for all resources within a comparison unit calculated for each comparison unit within the geologic setting

Each of the resulting three data sets would be compared to the controlled area for individual resources and the resource composites.

4.2.4.1 Methodology to Randomly Select Comparison Areas Within the Geologic Setting

Any method to accomplish the random selection of comparison areas within the geologic setting embrace the following assumptions:

- Defined boundary to the geologic setting

- Known area for the controlled area

- Subdivision of the geologic setting into units of comparable size to the controlled area

- Means to randomly select the comparison areas to be evaluated and then compared to the controlled area.

The definition of a boundary of the geologic setting and the size of the controlled area are assumed to be derived routinely before the study of comparison areas is begun.

Area subdivision can be accomplished by constructing a grid of appropriately sized polygons and overlaying the grid on the entire geologic setting. In geographical terms, equidimensional polygon (e.g., hexagons) provide the best coverage and are relatively easy to work with to assure complete coverage of the geologic setting.

Random selection can be accomplished by any defensible means to randomly select grid polygons from the available population of grid polygons for further analysis. A random number table or mathematic random number generator could be used to select from an appropriately numbered population of grid polygons.

One advantage of the random analysis method is that it provides a collection of appropriately sized polygons to facilitate comparison of resources between the selected polygons and the controlled area. A second advantage is that the number of evaluations required can be lessened by the appropriate statistical selection of such comparison areas. One disadvantage of the random selection method is that it is possible that a bias might be introduced in the selected population of grid polygons such that the population is not factually representative of the average resources of the entire geologic setting. A second disadvantage is that it is possible that the extent of available information will vary considerably from one selected polygon to another and that the extent of knowledge for the controlled area will be significantly greater than the extent of knowledge for a randomly selected grid polygon.

4.2.4.2 Methodology For Directed Selection of Comparison Areas within the Geologic Setting

Any method to accomplish the directed selection of comparison areas within the geologic setting should embrace the following:

- Defined boundary to the geologic setting
- Known area for the controlled area
- Establishment of a study grid polygon of comparable size to the controlled area to be used to define the selected areas to be evaluated and compared to the controlled area
- Definition of criteria to define consistent selection of location of selected grid polygons to facilitate comparison of resources of the grid polygon to the resources of the controlled area

The definition of a boundary for the geologic setting and the size of the controlled are assumed to be derived routinely before the study of comparison areas is begun.

Grid polygon definition can be accomplished by constructing a grid polygon of appropriate size which will be overlaid at selected locations within the geologic setting in a directed manner to ensure that all known resources of the geologic setting are evaluated for comparison to the controlled area. In geographical terms, an appropriately-sized hexagon provides excellent coverage and is relatively easy to work with.

The directed evaluation of the geologic setting could be constrained by attributes which are site-specific for the proposed repository. Using the proposed repository site at Yucca Mountain, the grid polygons for resource comparison purposes might be located only where lithologies which mirror the proposed site are found (for example, tuff overlaying Paleozoic age rocks). Another discriminator would be to investigate crater complexes and the tuffs which are adjacent to, or within crater complexes combined with selected lithologies and dominant local geologic processes. The location of grid polygons in this "directed" way would ensure that like-areas within the geologic setting are studied and used in the comparison of resources resulting in valid comparisons of resources of similar geologic, stratigraphic, process units. By using these "directed" comparisons DOE could defuse criticism that it had "watered down" the likelihood of the proposed site having resources of greater value than the average of the geologic setting. DOE could include known mineral deposits or other resources from the randomized geologic setting for comparison with the site at which, by virtue of lack of site-specific information, relative few resources are known to exist. With the "directed" grid polygon/site comparisons the relative level of exploration and knowledge of such similar sites within the geologic setting will become evident and the relative resource "richness" of the proposed repository site in comparison to other similar sites within the geologic setting will be obvious.

4.2.5 Methodologies to Economically Assess Natural Resources with Current Markets

As stipulated in 10 CFR 60.21(c)(13), the methodology for economic assessment of natural resources is developed and applied to the assessment of both discovered and undiscovered resources at a proposed repository site. The methodology chosen for the natural resources economic evaluation should, at least, include the assessment of available background information including results of analysis of field samples and geomorphologic, geophysical, mineralogic, hydrologic, seismologic, and geochemical analyses. It is suggested that subjective probability values can be developed by application of expert judgement which collates and evaluates the existing information into predictions of undiscovered deposits including their tonnage, grade, and location. The logic of the general approach is shown in Figure 4-2. The logic begins with the analysis of geologic, geophysical, and field observation data, and then incorporates worldwide distribution and marketing information with intuition founded in the experience of experts. The analysis of all the pertinent information should be reduced to subjective probabilistic judgements identifying the distribution of prospects, expected tonnage, grades, and likely location and other considerations for each specific resource of interest. It is probable that differing "sets" of experts will be required in order to adequately constrain the analyses of the myriad resources which require consideration at a given proposed repository site. For groundwater and energy resources, the empirical distribution of quantity, quality, and potential extraction rate and/or slope of utilization are the major probabilistic parameters which must be a part of the assessment. Geologic models should be used to define the probabilistic physical distribution of resources, recoverable quantities of such resources, and as the basis for calculating the gross and net values of the various resources. The final product of this economic assessment should be a probabilistically described distribution of physical endowment, anticipated exploration costs, anticipated extraction costs, anticipated market value, and anticipated economic return including gross and net value for all discovered and perceived likely (but undiscovered) resources at a proposed repository site (BOM, 1990c, p. 106).

4.2.5.1 Identification of Natural Resources with Current Markets

Natural resources "with current markets" are those resources which are perceived to have a monetary or other value in the existing marketplace and for which there is a demand such that the product can be sold or for which there is a subsidy given due to extraneous circumstances. Any resource which can be produced and sold (or for which there is a bona fide demand or value) in the current world, regional, and/or local economies would be classed as "with current markets." The marketing or sale of resources may not be only on a local or regional scale but in the case of oil and gas, for example, would respond to conditions in the international trading environment. Likewise, unique circumstances

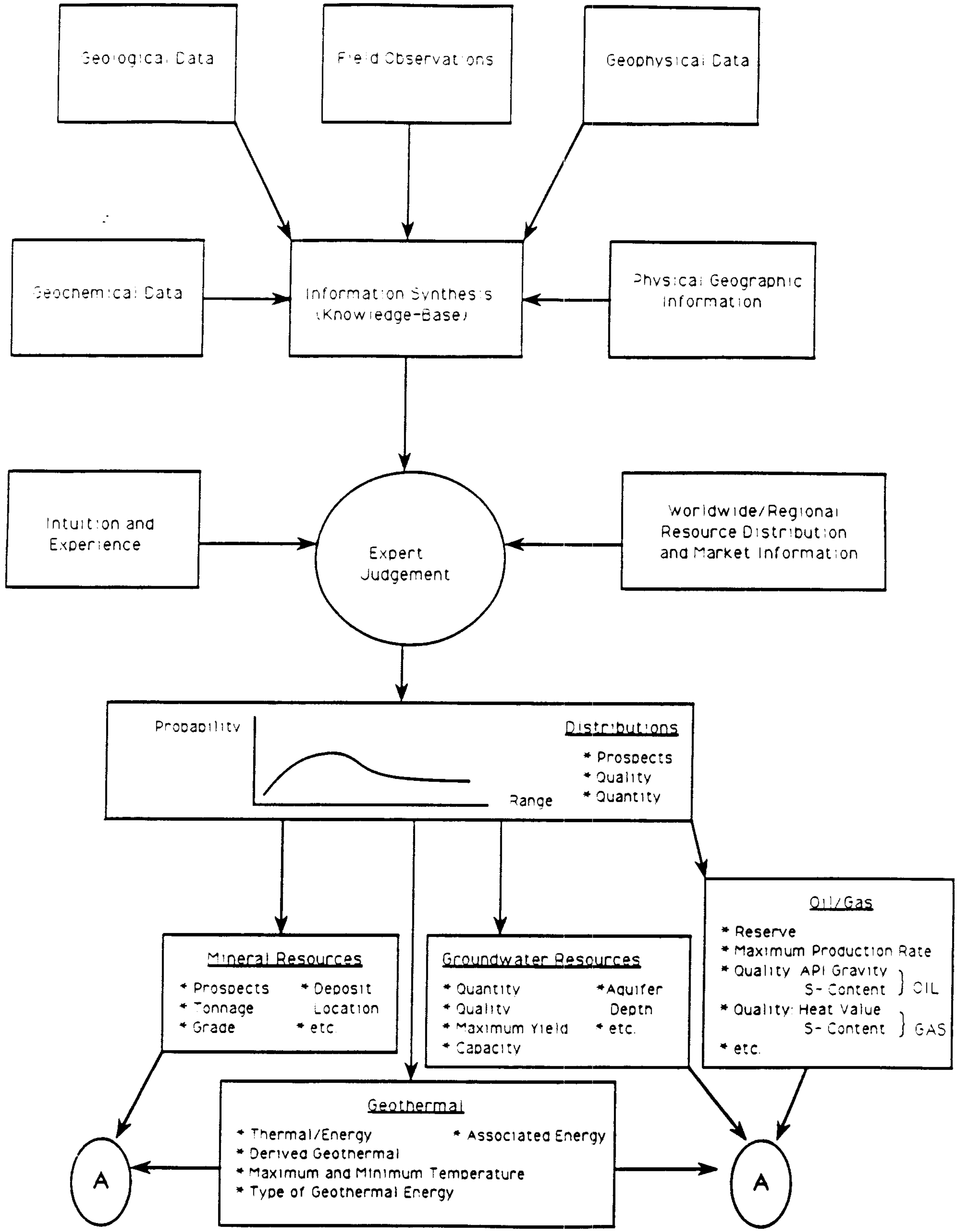


Figure 4-2. Flowchart of resource assessment [After ROCKVAL approach to mineral resource assessment (BOM, 1990c)]

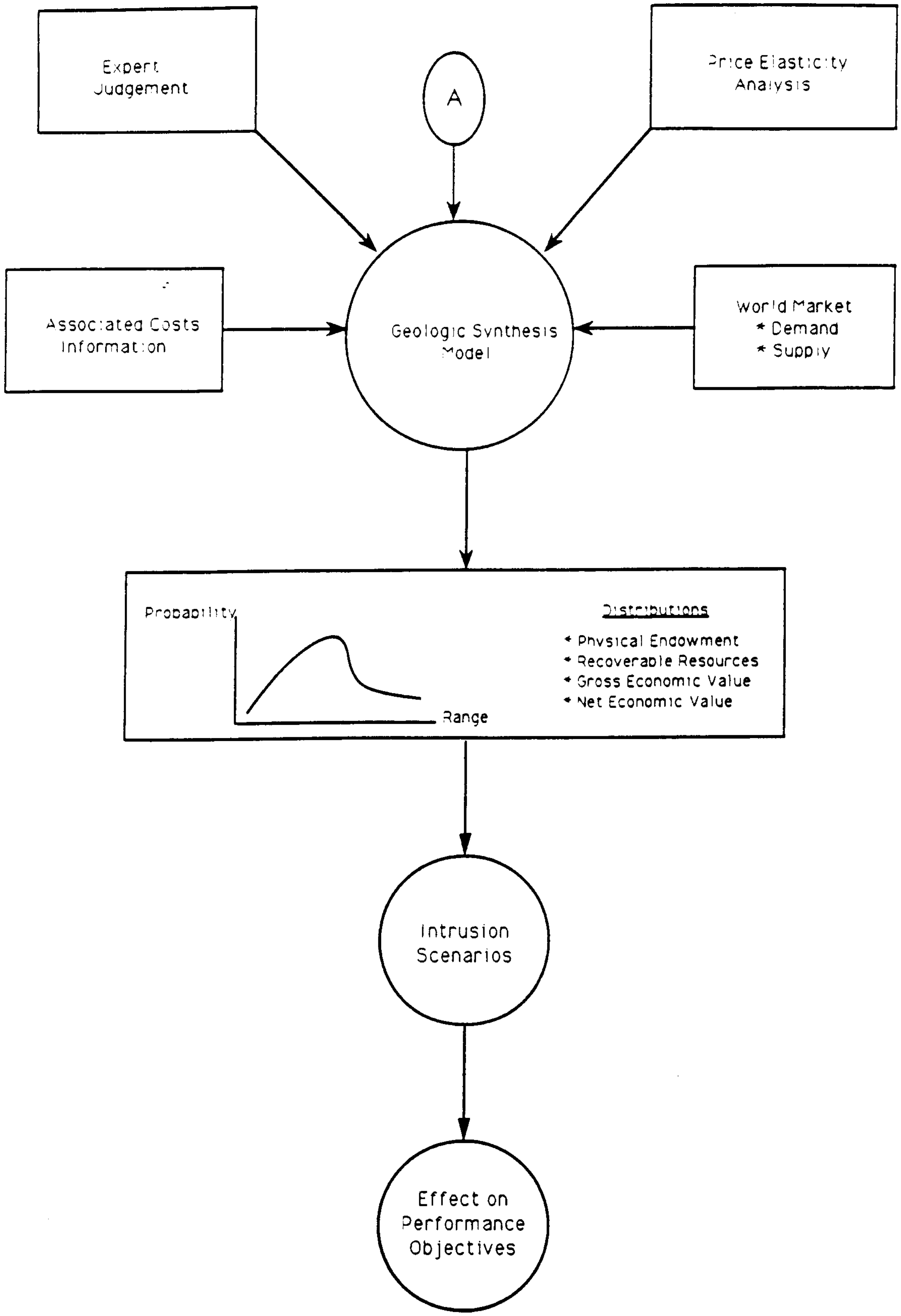


Figure 4-2. Flowchart of resource assessment [After ROCKVAL approach to mineral resource assessment (BOM, 1990c)] (Cont'd)

engendered by governmental or private sources may enhance the value of a resource such that an artificial market is created.

For the purposes of natural resource assessment, any resource which can be sold at a profit or which is "in demand" can and should be classified as "with current markets." Both discovered and undiscovered resources can be dealt with in the same way in the economic analysis because the analysis requires the nature, grade, and amount of the natural resource which is of interest but the economic analysis is insensitive to the means by which those particular parameters were discovered (i.e., probabilistically or deterministically; by inference or by measurement). (See BOM, 1990c for complete discussion of an economic assessment methodology)

4.2.5.2 Economic Assessment of Natural Resources with Current Markets

The regulation in 10 CFR 60.21(c)(13) reads as follows: "For natural resources with current markets the resources shall be assessed, with estimates provided of both gross and net value." In 10 CFR 60.122(c)(17) the following is stated: "Such (naturally occurring) materials have greater gross value or net value than the average. . ." An economic assessment of natural resources (naturally occurring materials) which determines both gross and net values, not only for each resource of interest, but, also, for the average of the comparison areas versus the proposed repository site (as discussed earlier), is required by the regulation.

The evaluation of the gross and net values of different natural resources with current markets could be conducted based on the approach as outlined in Figure 4-2. The evaluation of both gross and net values associated with each type of perceived natural resource with current market can be based on a modeling approach with the probabilistic assessment of the quantity and quality of the specific resources as the desired target values. The intrinsic and derived economic values of those natural resources can be determined based on a series of judgmentally derived probability functions. It is apparent that the evaluation process for currently marketable discovered resources can be accomplished with much less "fuzziness" associated with the various value judgements than the "fuzziness" which inevitably will be associated with the perceived to be present but still undiscovered deposits. When developing revenue projections, the current and long-term pricing trends and price elasticities for specific natural resources should be included in the subsequent modeling and analysis. As natural resources with current markets can be readily related to the existing world or regional markets, the revenue projections may be extracted based on probabilistic models describing the expected extension of existing market situations by regression analysis or by forecasting future market change through means other than linear regression. Cost projections, including both capital and operating costs, can be estimated based on resource exploitation and development experiences in and near a proposed repository site bolstered with economic experience in other areas and regions which exhibit similar environmental settings to the geologic setting of the proposed repository site.

Given the current local, regional and world markets for a natural resource, the resources of the controlled area should be evaluated for marketability. An aggregate of field data including the geologic, geochemical, hydrologic, and mineralogic information compiled by DOE during site characterization should be used to determine the likely bounds for production and marketing of on- or near-site resources.

Estimating Gross Value of Natural Resources with Current Markets

The basic methodology to be applied for the estimation of gross values of natural resources, either discovered or undiscovered, that have been identified as having a current market may consist of the projection of anticipated absolute value of a resource, in situ, without exploitation based on probable price variations and anticipated price elasticity for the supposed in situ quantity each specific resource of interest. The projection of gross value is intended to be used as a guide for the evaluation of likely human intrusion. It must be remembered, however, that the "foreseeable future" for economic projections is thought to be no more than 50 or so years into the future. For example, if a resource is present but its calculated gross value is low, it can be assumed that the area would be less likely to be explored/exploited than a nearby area in which the calculated gross values are higher [a comparison required by 10 CFR 60.122(c)(13)]. Likewise, a resource value for a site which is low when compared to resource valued in the ground in a worldwide and/or regional geologic setting would, by inference, imply that areas with a higher gross value, in situ, would be explored/exploited before the given repository site. The absolute perceived value of a mineral deposit or other resource, in dollars, serves to indicate a relative level of importance in the "economic picture" of resource development. The site should be, at least, less desirable than average for a given geologic setting from a gross value point of reference, and, if possible, for the value of resources of a site to be perceived as being so low on the economic scale that the site would not be expected to be of economic interest to future generations throughout the anticipated (and as defined in the remanded 40 CFR Part 191) 10,000 year period for which performance of the repository must be evaluated.

Estimating Net Value of Natural Resources with Current Markets

The estimation of the net values associated with specific natural resources, either discovered or undiscovered, with current markets may be determined based on a discounted cash flow schedule of all revenues and costs associated with such specific natural resources at a marketplace. The current economic climate and the projected economic situations throughout the 50 or so years planning horizon of the "foreseeable future" are key parameters in the development of economic projections. It is envisioned that such net value estimation may involve multiple scenario analyses for varied economic growth projections for the United States and the world. As the resources to be included in the net value determinations should be evaluated individually, a probabilistic projection model, as depicted in Figure 4-2, may be developed for the evaluation process. The measure of economic effectiveness may be accomplished for specific resources with the application of such economic analysis parameters as rate of return, return on investment, and/or benefits to cost ratio. In the process of this net value estimation, the basic concerns for the economic externalities associated with specific natural resources and their extraction, development, refining, and marketing must be included in the overall economic evaluation to determine net value.

Cost Components of Gross and Net Value Determinations for Resources With Current Markets

Capital costs are an important consideration in resource pricing. Included in capital costs are the cost of purchase, lease, or rental of any land and/or surface or mineral rights in the subsurface. Exploration cost is an important component which is not mentioned in 10 CFR 60.21(c)(13). The regulation lists only current development, extraction, and marketing costs. Exploration costs include the costs of finding the resources as well as the initial investments required for the exploratory efforts related to a particular resource.

Development costs include the costs to develop and install resource production facilities which encompass construction of transportation routes, acquisition of right-of-way, and environmental permitting. Engineering costs for design, construction, and management should be evaluated. The actual equipment to extract the particular material and transfer it on-site, site storage, and site utility requirements are other related cost factors which should be evaluated when determining net values.

Processing costs are a required consideration. Processing includes all expenditures associated with the purchase, installation, and operation of specific equipment needed for a given resource to be developed and marketed profitably. Labor costs to sustain the production of a specific resource and the costs of fuels, electricity, chemical additives, materials, and other supplies needed to sustain the production or extraction of a specific resource must be evaluated. The cost to maintain the extraction and processing equipment can be sizable and includes, but is not limited to, parts, consumable materials, fuels, and replacement components for all extraction and processing equipment.

Additional ancillary costs derive from infrastructure development, construction, and operation which is needed to support the economic production of a particular resource. A cost that is often overlooked is the cost associated with all measures to treat wastewater, install emission controls, dispose of solid wastes, mitigate significant environmental damage and pay for the resource commitments as well as for land reclamation and subsurface structure restoration as required by federal, state and local environmental regulations. Finally, administrative cost must be considered. Administrative costs include management and administrative functions, personnel services, security, and associated overheads.

Any model or other means used to calculate net costs should include, as a minimum, the above-mentioned cost considerations. BOM (1990c) contains examples of BOM printouts from their economic models which demonstrate the BOM program to calculate the costs associated with the production of various mineral resources. Established models which calculate the economics of extractive industries, such as the program of the BOM, provide acceptable cost information for use in the evaluation of economics of natural resources at a proposed repository site.

4.2.5.3 Economic Assessment of Natural Resources Without Current Markets

The economic assessment of natural resources "without current markets" is required by the wording in 10 CFR 60.21(c)(13) which reads as follows: "For natural resources without current markets, but which would be marketable given credible projected changes in economic or technological factors, the resources shall be described by physical factors, such as tonnage or other amount, grade, and quality." The wording in the Presence of Naturally Occurring Materials adverse condition in 10 CFR 60.122(c)(17) implies similar future considerations in the following text: ". . .Economic extraction is ...potentially feasible during the foreseeable future." Extraction which is "economic" (i.e., profitable) in the foreseeable future implies that the particular resource either is marginal or uneconomic, at the present, and that some predictable change in the marketplace will cause the resource to attain market profitability, or that some future change will cause items of currently marginal value or which are not currently recognized as a resource to attain marketability through technologic or economic change.

Critical to an acceptable analysis of the future marketability of perceived resources or marginal materials which might attain future marketability which engenders exploration and exploitation of the materials is the definition of the "foreseeable future."[1] The changes in economic or technologic factors which can be anticipated by the present generation and which would translate into heightened interest in exploration/exploitation of a given repository site should be identified and the rationale for their selection and subsequent consideration presented.

The evaluation of natural resources at a potential repository site should consist of a series of sequential steps which could each be the end point of the investigation/evaluation of a particular resource at the given site. For a given resource, a thorough investigation of the particular resource within the scientific literature pertinent to the geologic setting of the site should be conducted. This literature investigation will serve to identify the resources which are common to the particular geologic setting and which should or should not be pursued dependent on the resource models and the actual conditions at the site. For example, placer gold might be found in gravel deposits within a given geologic setting but the site might consist entirely of uplifted tuffaceous rock with no alluvial or colluvial deposition evident. The likely occurrence of placer gold at the proposed site would be nil and a placer gold model would not be considered further. However, if gold within the setting was found in conjunction with igneous intrusions (veins, or hydrothermal alteration, for example) which could occur in any variety of rocks within the setting, then an intrusive gold model would have to be considered for the proposed site and additional information on such deposits would need to be collected and the site properly evaluated for same. It is assumed that significant surface exploration will occur in the vicinity of the controlled area in order to characterize the site.

Collection of information on resources should be a planned part of the characterization effort. The surface of the controlled area should be perused for indications of mineral deposits, geothermal activity, water resources, and any other naturally occurring materials which could be construed as currently or potentially valuable. Any collection of below-surface information should routinely include samples to be analyzed for materials determined to be potentially present at the site based upon the evaluation of resource occurrences within the geologic setting. The information regarding naturally occurring materials which are or might become resources should be collated and evaluated as part of an integrated study of the site. Any geophysical techniques which are applied to the site should be a part of the integrated analysis for naturally occurring materials.

Based on all the acquired information DOE will be expected to make a judgement call on the likelihood of the presence of currently marketable materials or materials with future potential as resources. DOE will be required to evaluate the extent of such resources or likely resources, if found, or to postulate the probability that such resources exist, albeit undiscovered, at the site and adjacent to it. Discovered resources will be the ones most readily capable of being evaluated by DOE since comparisons of the resources and their imputed values can be done deterministically within the context of the resource base of the geologic setting. Undiscovered resources require a probabilistic assessment, however, and will likely present DOE with the need to convene panels of experts to evaluate the likelihood of occurrence.

The outcome of both identified (discovered) and undiscovered resources relative to potential human intrusion at a site is, or can be, viewed as requiring the same rationale in their respective evaluatory approaches. It appears that the Commission believes that the likelihood of future human

[1]"Foreseeable future" was defined in 1.4.2.10 earlier as no more 50 or so years into the future.

intrusion should be considered in the light of certain assumptions relative to "unanticipated processes and events" which are noted in the preamble to the Final Rule as follows:

> "First, the monuments required by the rule are assumed to be sufficiently permanent to serve their intended purpose. . .While it assumes that the monuments will last, it does not automatically assume that their significance will continue to be understood. Second the Commission requires an assumption that the value to future generations of potential resources can be assessed adequately at this time. . .Consistent with its previously stated views, it thinks that the selection of a site with no foreseeably valuable resources could so reduce the likelihood of intrusion as to reduce, or eliminate, any further need for it to be considered. Third, the Commission requires the assumption that some functioning institutions—though not necessarily those undertaking the intrusion—understand the nature of radioactivity, and appreciate its hazards. The extent of intergenerational transfer of knowledge is, of course, debatable; it is conservative, in the light of human history to date, to predict this minimal level of information and to take it into account in assessing the likelihood that intrusion will occur. Fourth, the Commission provides that relevant records are preserved, and remain accessible, for several hundred years after permanent closure" [48 Fed. Reg. 28199 (1983)].

Any scenario for future inadvertent human intrusion within a site should presume that resources at the site are initially "undiscovered." That is, some occurrence or long-term degradation has erased from human memory the location and importance of the HLW repository. It must be assumed that any happenstance which erases the memory of the location and function of the HLW repository will also result in loss of any records pertinent to the site including the records of past exploration and evaluation of the site for mineral resources. Thus, the site would be treated as would any other site in the geological setting and would be considered as a potential target for mineral resources by future explorationists. The future explorationists would be expected to conduct their exploration as a precursor to site exploitation for economic gain. The likelihood of future exploration for "undiscovered" resources will depend on the perceived potential for valuable resources to be present at the site. The nature of site exploration for resources in the future may be dependent on techniques which can be classified broadly as follows:

- Comparably as sophisticated as late 20th century
- More sophisticated than late 20th century

The reasoning for these two possibilities derives from the Commission in the definition of Unanticipated Processes and Events in Section 6.2 Definitions of 10 CFR Part 60 in which the Commission says the following:

> "... Processes and events initiated by human activities may only found to be sufficiently credible to warrant consideration if it is assumed that:...(4) institutions are able to assess risk and to take remedial action at a level of social organization and technological competence equivalent to, or superior to, that which was applied in initiating the processes or events concerned;..."

4.2.5.4 Assessment Methodology for Evaluating Groundwater Resources in the Vicinity of the Proposed Yucca Mountain, Nevada Geologic Repository Site

CNWRA contracted with Adrian Brown Consultants, Inc. (ABC) to produce a report entitled "A Methodology for Assessing Ground Water Resources As A Potential Source of Human Intrusion" (ABC, 1990b) which is reproduced in its entirety as Appendix A. The report develops and illustrates a methodology for incorporating information on ground water resources into an evaluation of potential for human intrusion. The approach assumes that the user of the methodology will be NRC Staff and that the methodology will be suitable for licensing assessments. Alternative approaches may also be suitable for such analyses, and the approach presented in Appendix A is for consideration by NRC Staff as the basis for one methodology that the Staff may find acceptable by an applicant in performing the ground water resource evaluations.

EPA Standard (40 CFR Part 191) contemplates a probabilistic approach to assessing long-term repository performance. Therefore, the methodology assumes the need to develop a probabilistic assessment. The proposed approach is based upon a Fault-Tree Methodology, such as has been developed and applied in probabilistic assessments of power reactors and other industrial facilities. The basic assessment methodology for groundwater has five steps:

- Define a conceptual geologic repository system, identifying the hydrologically functional parts of the system
- Define one or more undesired states (or events) of the system
- Identify all credible pathways in which the undesired event can occur
- Identify the data necessary to assess the likelihood that each pathway is complete
- Identify the data necessary to quantify the probability of the undesired event

The methodology begins by establishing a conceptual model that includes the minimum features of the real geohydrologic system necessary to qualitatively determine the relevant behavior of the system. For the purpose of this evaluation, the relevant behavior includes:

- Drilling or excavating into the functional part(s) of the flow and transport system
- Transport of radionuclides from the repository to the accessible environment

Undesired events include both direct human intrusion during ground water exploration and indirect human intrusion associated with shortening the flow path or adversely affecting the hydraulic gradient of the saturated flow system.

The report defines credible pathways associated with ground water exploration and exploitation on the basis of:

- Identifiable water resource and
- Existence of a drilling technology capable of exploiting such a resource.

Finally, the data needed to quantify the likelihood of human intrusion are defined in terms of a conditional probability structure, and the report shows that a Bayesian-style analysis using current data to assess the conjunctive probability of drilling and intrusion can be applied.

The methodology is illustrated with examples and discussion based on a repository environment and design like that of the proposed Yucca Mountain, Nevada site. Because a ground water resource has already been defined for the vicinity of the Yucca Mountain site, there is no need to develop a new methodology for determining a hidden natural resource at this specific potential repository location. Evaluations of the NEPA and those economic aspects of ground water resources required by 10 CFR Part 60 can proceed based on current information. In projections of regional ground water needs in southern Nevada were addressed. In the more generic case, the approaches described in Section 2.0 of Appendix A could be applied to identification and quantification of ground water as a natural resource. The approaches illustrated in Appendix A could be applied along with physical resource data to assess likelihood of ground water development at other potential repository sites.

To illustrate the potential application of the proposed methodology, ABC (1990b) utilized the following:

- Conceptual geologic model of a repository in fractured, unsaturated volcanic rock in an uplifted Basin-and-Range fault block, drawn from the applicant's conceptual model of a proposed geologic repository located at Yucca Mountain.

- Drilling and other hydrogeologic information from the defined ground water basins near Yucca Mountain and selected information on the geology and geohydrology of the Yucca Mountain site. It is recognized that these data from DOE (1988) are preliminary and that the Yucca Mountain site is currently undergoing site characterization as required by the NWPA, as amended. The specific data are used only to exercise the methodology and provide examples of the style of calculation appropriate to the methodology. Specific predecisional judgments on licenseability of the site are not to be drawn from these examples.

- Test water-exploitation case based on assumptions suitable for a rural, single-family domestic well. As with the use of site-specific data, this assumption is for illustrative purposed only, and the full exercise of the methodology by the applicant or NRC staff would require assessment of other exploration and exploitation scenarios.

For the example considered, it is determined that data are available to indicate that at least one pathway is complete and that other pathways are possible under certain assumptions. Design parameters for the Yucca Mountain repository and Part 60 definitions of the controlled zone are used to define potential targets for both direct and indirect intrusion scenarios. Data on completion of water wells in a 110,000 acre area of two designated ground water basins near the site are used to estimate drilling densities. Based on this outline analysis and the data selected for the examples, there is a very low probability that ground water exploration or exploitation under credible assumptions would lead to adverse effects on long-term repository performance for a site like the proposed Yucca Mountain site. For any given set of drilling density assumptions, the maximum probability of impact, based on this methodology, will likely be for the active, indirect (pumping scenario) pathway. The target area for this scenario (i.e., the area of influence of a pumping well) will often be the greatest within the possible range for the target area.

Although the ABC report states the following on p. A-39:

> "Based on this outline analysis ... there is very low probability that ground water exploration or exploitation under credible assumptions would lead to adverse effects on long-term repository performance for a site like the Yucca Mountain site."

it is probable that the assumptions and conclusions presented in the ABC report are not an adequate basis for projecting repository performance over a period from 1,000 to 10,000 years in length. Discussions of actual probabilities for the 10,000 year regulatory timeframe should be limited to those calculated for events constrained by a well-defined set of scenarios and not just a single scenario. Because only a singular, extremely limited scenario was considered by the ABC report, the conclusion that "... there is a very low probability of exploration or exploitation..." cannot be broadly applied.

4.2.6 Assessment Methods for Evaluating Human Intrusion for Natural Resources

4.2.6.1 Assumptions in Human-Intrusion Scenario Construction

The potential causes of containment failure for a nuclear waste repository at the Yucca Mountain site can be divided into two classes: human and natural. Although, the probabilities of some of these failure events are extremely low, the possibility of occurrences cannot be neglected in a comprehensive performance assessment of the potential repository site. In this discussion, concentration is placed on one of the human causes of possible breaching of the containment and subsequent failure, namely containment breach which may be attributed to potential exploration and exploitation of natural resources of the host geologic medium. In order to be able to estimate, through mathematical modeling, the adverse consequences of postulated human intrusion on repository performance, scenarios must be constructed, scenario probabilities assessed and expected consequences determined.

Note that regulations specify certain mitigating measures to protect against inadvertent human intrusion. Following the decommissioning of a repository and sealing of the drifts, the site and selected subsurface mineral rights in an up to 10 km wide buffer zone (5 km in EPA 40 CFR Part 191) bordering the repository will be maintained by the government to exclude exploration/exploitation of minerals which might affect geologic repository performance. Multiple, permanent records must be preserved for at least several centuries as per 10 CFR Part 60. EPA rule, 40 CFR Part 191, specifies that institutional controls are to be considered active for only 100 years after closure. Also, permanent markers will be placed to warn of the potential hazard associated with drilling operations. Site and regional monitoring is expected to continue indefinitely, and permanent records will be maintained of the temperature in the ground as well as in the aquifers around the waste burial area and of the levels of the radioactivity in air and in surface and ground water. Figure 4-3 shows the relationship between "regulatory" time periods, repository periods, repository temperature, and radionuclide activity for 10^6 years after closure.

It is a rather difficult task to anticipate over a period of 10,000 years, all possible events likely to disrupt or nullify the mitigating measures which will be implemented at the repository site subsequent to permanent closure of the repository. Nevertheless, it can be argued that records can be lost through a major natural disaster, wars, or political/social upheavals. In this context, even the complete collapse of our major civilization could be postulated.

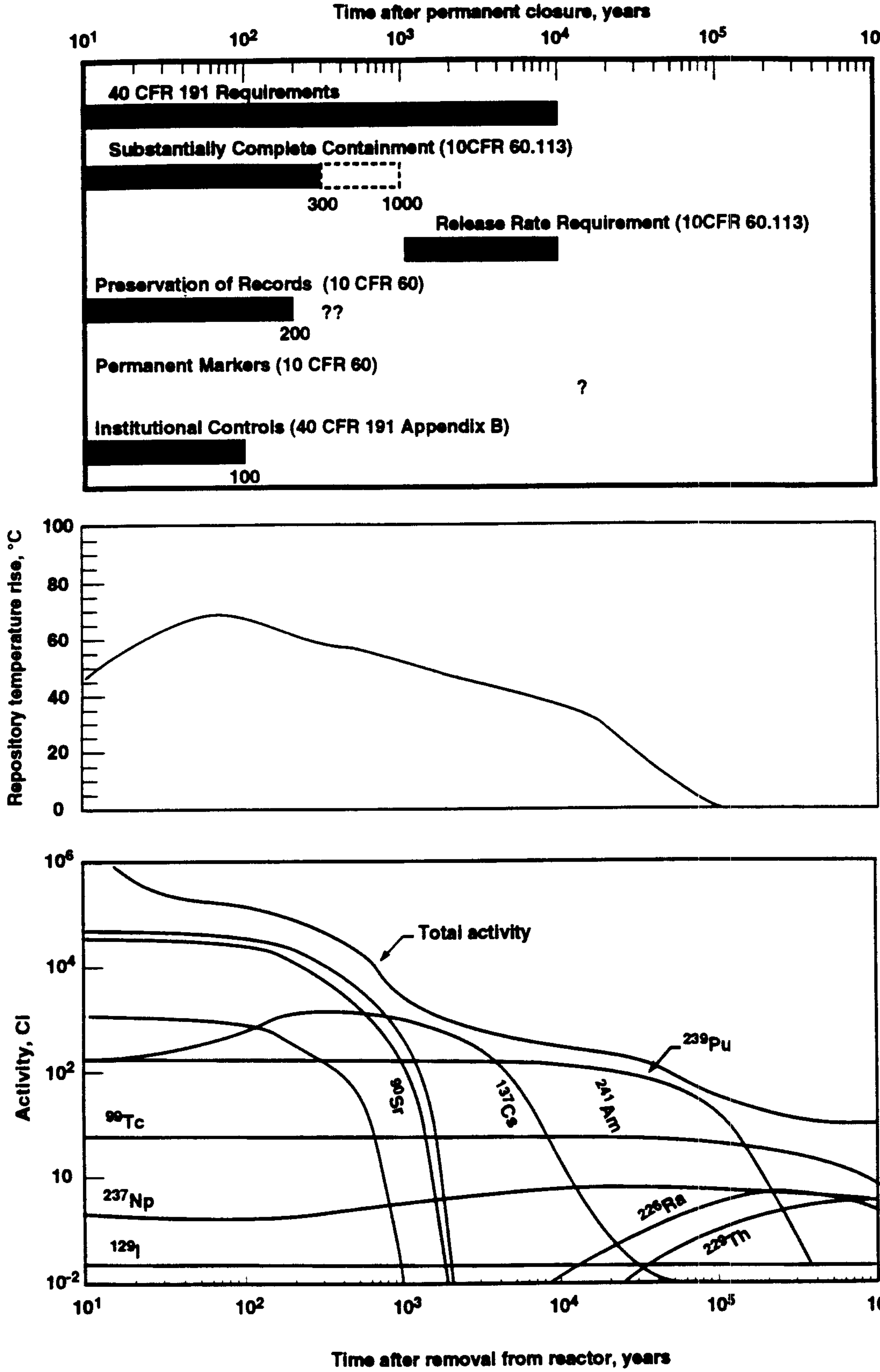


Figure 4-3. Relationship of "regulatory" time frames, repository temperature, and radionuclide activity for 10^6 years after closure (after I.S.Roxburgh, 1987).

On the other hand, such loss of records and markers would not appear to present serious problems because the repository would remain inaccessible to a civilization that did not possess the technology for drilling several hundreds of meters in search of natural underground resources. Therefore, in what follows it is assumed that whatever takes place with regard to our civilization, that present day or better technology will be prevalent in future human intrusion scenarios

4.2.6.2 Potential Human-Intrusion Scenarios

Long term scenario analyses pertaining to human intrusion in a HLW repository in the post closure period are concerned with:

- Identification of events on and around the repository that may affect the release rates of radionuclides or toxic gases from the canisters and their subsequent migration from the repository horizon to the accessible environment and the biosphere

- Estimation of the probability of release occurrence

- Estimation of long-term stability of engineered barriers

- Estimation of consequences on radionuclide release water-pathways perturbed by such events disregarding other natural causes

- Estimation of consequences on radionuclide release water-pathways perturbed by such events considering other natural causes.

Scenario analyses are performed within the framework of technical analyses, including performance assessment investigations and require the usage of mathematical models (i.e., deterministic and probabilistic) designed to cope with the different geophysical-geochemical-geohydrological current and anticipated processes encountered in the repository environment.

In the event where exploratory drilling were to take place randomly over the repository area, and assuming that the drill directly intersects a canister, some radioactive material could be brought up to the surface by the drilling mud or rock debris. In such a case the drillers may or may not detect the radioactive material depending upon the sophistication of their detection methods. This scenario arises because, during the end of the drilling operation, the cuttings and drilling fluids are usually disposed in the immediate vicinity of the drilling site, hence would present an immediate health hazard to workers at the drilling operation and to local residents. However, if dumped in a nearby landfill, the long term potential risk of groundwater contamination from a landfill would then prevail.

Rickertsen and Alexander (1989) list the following possible human actions that may interfere with the undisturbed functioning of the repository:

- Drilling
- Ground water withdrawal
- Injection
- Irrigation
- Military activities
- Mining

- Recharge
- Underground storage

All of these actions would presumably require some sort of drilling or excavation activity. This list is not specific to the proposed Yucca Mountain site. However, further definition of such scenarios to a level of detail sufficient for modeling does require consideration of the specific site under investigation. As stated in Section 2.3.2, it is assumed that these human activities occur on the site because knowledge about the repository is lost to future generations. It is also assumed that any of these activities will occur in two phases: the exploration phase and development and production phases. In the exploration phase, future generations will likely recognize the special conditions (e.g., radioactivity) in the repository horizon and stop further action. Such considerations may help establish a (conservative) upper bound on human-induced disturbance for performance assessment. Such an upper limit is stated as a guidance by EPA in 40 CFR Part 191; NRC, however, may or may not adopt this guidance in its implementation of 40 CFR Part 191.

EPA (40 CFR Part 191, Appendix B) guidance states that the likelihood of inadvertent and intermittent drilling need not be taken to be greater than 30 boreholes per square kilometer of repository area per 10,000 years for geologic repositories in proximity to sedimentary rock formations, or more than 3 boreholes per square kilometer per 10,000 years for repositories in other geologic formations. Further, EPA guidance in Appendix B of 40 CFR Part 191 states that the consequences of such inadvertent drilling need not be assumed to be more severe than:

> "(1) Direct release to the land surface of all the ground water in the repository horizon that would promptly flow through the newly created boreholes to the surface due to natural lithostatic pressure — or (if pumping would be required to raise water to the surface) release of 200 cubic meters of ground water pumped to the surface if that much water is readily available to be pumped, and
>
> (2) Creation of a ground water flow path with a permeability typical of a borehole filled by a soil or gravel that would normally settle into an open hole over time—not the permeability of a carefully sealed borehole."

In a letter to EPA (NRC, 1990a), NRC staff commented on the above aspect of Working Draft Number 2 of EPA standards which were undergoing revision. The staff recommended that EPA reevaluate the technical basis underlying the guidance on intrusion frequency and severity. It was NRC's understanding that EPA limited its consideration to oil exploration when the likely number of drillholes was set in the guidance. NRC believes that exploration for other natural resources may take different forms than EPA guidance suggests. EPA guidance which is based on the oil-industry practices may not be representative of other exploratory drilling practices — including numbers, depth, extent and sealing methods and requirements for boreholes.

It is assumed that the potential HLW repository at the Yucca Mountain, Nevada site will be located at a depth of 350 m below the earth surface in the unsaturated zone, where the water table is at approximately 600 m depth. The repository horizon has been selected because it is known to have hydrogeological formation properties which are favorable for radioactive waste isolation. Low precipitation rates recorded in the past at the repository site, if continued in the future, will tend to keep the geological formations, above and immediately below the repository horizon, under partially saturated conditions. Such conditions will tend to inhibit the movement of water through the host rock and the repository. Note, however, that given the probable occurrence of various possible natural events such as impact of meteorites, volcanism, faulting, and erosion, the present hydrogeological, geomechanical and geochemical characteristics of the repository site and its man-made structures are not likely to remain unaltered.

Drilling boreholes in the geologic media of interest may result from the exploration for natural resources: minerals, precious metals, gas or oil, geothermal and groundwater. Figure 4-4 is a cartoon illustrating plausible human-intrusion activities which might affect the performance objectives at the Yucca Mountain proposed geologic repository. Based on available data indicating the existence of such resources, it may be stated that the drilling of boreholes in the course of exploration is a function of the perceived value of the natural resource and is not a random process.

4.2.6.3 Occurrence of Human-Intrusion Scenarios: Probabilistic Analysis

Because of the rather speculative nature of the human intrusion scenarios, no firm probabilistic model for assigning probabilities exits. Two approaches have been discussed in the literature:

- Poissonian models
- Markovian models

In the Poisson model, the probability of drilling a borehole is described by a Poisson distribution. The main characteristic of the Poisson distribution is that the probability of drilling a borehole is not affected by the knowledge of previously existing boreholes. In this formulation, the probability of drilling a bore hole between time t and $t + \delta t$ is taken to be $r\,\delta t$, where r is the average rate of drilling per unit time. The probability that a total of k, $[N(t) = k]$, boreholes will be drilled in time t is then given by a single parameter distribution:

$$P[N(t) = k] = \frac{e^{-t} r^{k}}{k!} \qquad (4\text{-}1)$$

The Poisson model of Eqn. (4-1) can be easily generalized by either taking the rate parameter, r, to be time dependent [i.e., r = r(t)]; or by considering r itself as random. The latter consideration gives rise to compound Poisson processes.

In a recent performance assessment exercise conducted by NRC (NRC, 1992), the Poissonian probability model for drilling combined with EPA guidance on upper limit of 30 boreholes per square kilometers of repository area led to an estimate of probability of hitting a waste container of ≈ 1 in 10,000 years. In their estimate, repository area was assumed to be 5.1 km^2. Preliminary estimates of the probability of a drill (6 cm diameter) intersecting a canister varied between 0.00518 and 0.0025 (see Campbell et al, 1978) for a vertically emplaced canister and was 0.01139 for a horizontally emplaced one.

Obviously, the above is an extremely simple treatment of a difficult subject. The rate, r, of drilling should actually be a function of the perceived economic value of the natural resources. Also, the location of drill holes is not explicitly considered in this model.

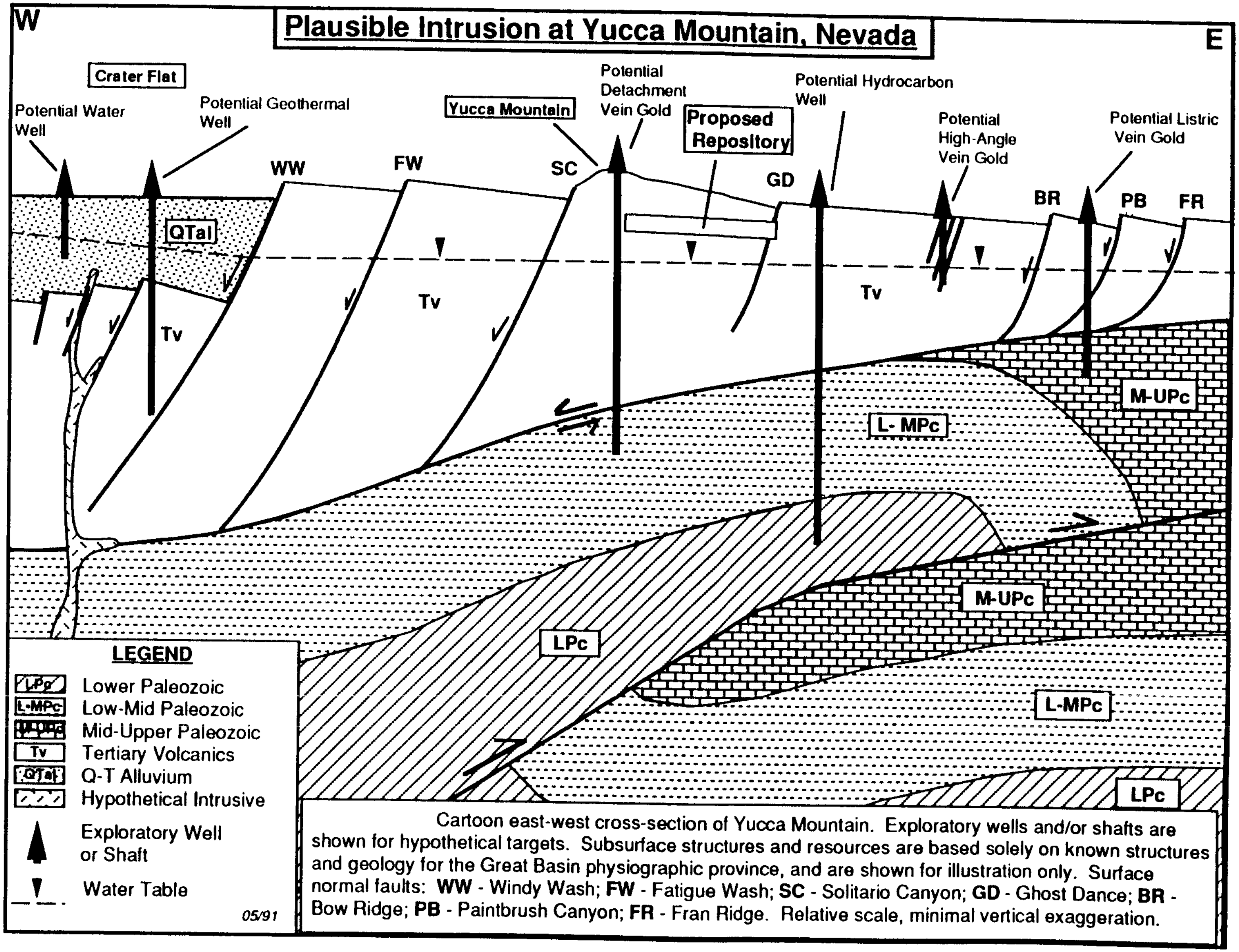


Figure 4-4. Plausible Inadvertent Human Intrusion at Proposed Repository at Yucca Mountain, Nevada

The two- and three-state Markov model is discussed by Woo (1989). The three states in the model are:

- State 0 — information on site radiological hazard is available and regulations are enforced
- State 1 — information on site radiological hazard is available but access controls have lapsed
- State 2 — information on site radiological hazards is not available [and regulatory control has ended].

Initially, the repository system starts in State 0. The probability that the state will change from a ($a = 0,1,2$) to b ($b = 0,1,2$) in time δt is $Q(a,b)\ \delta t$.

The complete state transition probability matrix can then be written as:

$$\begin{bmatrix} 1-Q(0,1)\delta t-Q(0,2)\delta t & Q(0,1)\delta t & Q(0,2)\delta t \\ Q(1,0)\delta t & 1-Q(1,0)\delta t-Q(1,2)\delta t & Q(1,2)\delta t \\ Q(2,0)\delta t & Q(2,1)\delta t & 1-Q(2,0)\delta t-Q(2,1)\delta t \end{bmatrix} \tag{4-2}$$

Given the six transition probabilities, $Q(a,b)$, $a = 0,1,2$; $b = 0,1,2$; the time the system would spend in each state can be estimated by standard Markovian theory. Woo (1989) discusses some philosophical underpinnings for estimating these transition probabilities. He argues that no human intrusion will occur in State 0, the rate (say r) of intrusion will be the highest in State 2, and the rate in State 1 can then be $c\ r$ where $c < 1$.

Whittingham (1989) discusses the sociological approach (in contrast to scientific) where a broad range of scenarios are placed in their historical and societal context for predicting the future. He stresses an event tree approach for estimating probabilities of various possibilities such as the event that post-closure controls will fail. Such an approach is fraught with problems as it would require projection of human development into the distant future. An event-tree approach is also discussed by Chapman and Jowett (1989) who construct the tree based on the assumption that future humans will undertake geophysical and geological exploration and that they will be able to detect an anomaly due to the presence of the repository.

CNWRA and NRC staff recognize that it is possible to develop conceptual models for most human intrusion scenarios that can disrupt a repository. So long as the conceptual models are fully described, it is possible to derive accurate probabilities for events within a given scenario. For example, the probability of drilling a borehole through a waste canister can be very accurately described given the area of the repository, the combined cross-sectional area of all canisters, and the area of the borehole. But such a derived probability is of little value given that the frequency of onsite drilling during the next 10,000 years is unknown and unknowable. However, an understanding of the scenarios that may be more likely to release radionuclides can help in the design of more effective warning markers and engineered barriers. In this regard, the applicant will especially need to consider future development of natural resources at the site.

Interestingly, none of the approaches in the literature link, directly, the future economic worth of natural resources to the probability of occurrence of human-intrusion scenarios. It seems that once a site is selected (based on the determination that the present and the near future worth of natural resources is such that the site is suitable for development as a repository) the probabilities are assigned on an ad hoc basis to the human intrusion scenarios.

4.2.7 Summary of Regulatory Compliance Methods

This regulatory requirement, concerning PAC - Presence of Naturally Occurring Materials [10 CFR 60.122(c)(17)] focuses on the characterization of any identified or undiscovered naturally occurring materials within the proposed site relative to the surrounding region (geologic setting). Naturally occurring materials beyond the site must also be considered in making the resource value comparisons to other areas within the geologic setting as required by 10 CFR 60.122(c)(17)(ii). Additionally, this PAC requires that a determination be made regarding the current or potential feasibility of economic extraction of identified or undiscovered naturally occurring materials in the foreseeable future. The presence of this PAC should be determined not only for naturally occurring materials within the site but also for those naturally occurring materials beyond the site whose exploration or exploitation could affect isolation within the controlled area.

The determination of the presence of any naturally occurring material or the determination that future generations are likely to perceive the proposed repository site as a target for exploration or exploitation of naturally occurring materials should be used to structure human intrusion scenarios (e.g., Raney, 1990b) which are to be considered in an overall system performance assessment. Such exploration/exploitation activities must be considered when:

- Assessing the potential for human intrusion within and adjacent to the site
- Evaluating the consequences of such intrusion on the capability of the proposed geologic repository to isolate wastes

The proposed Yucca Mountain site is located in a natural resources-rich geologic setting that includes current gold production and exploration for hydrocarbons. Gold has been mined in the site vicinity at Bare Mountain (16 kilometers to the west for over a century (Nevada Bureau of Mines & Geology, 1984, p. 1) and at Wahmonie (28 kilometers to the east (Raney, 1990a)). Interest in gold exploration and exploitation in the site vicinity continues as five new mines and prospects have been located within 48 kilometers of the proposed repository site between January 1988 and July 1990 (Raney, 1990a). In addition, oil exploration was conducted at three separate sites during 1991 within 25 kilometers of the proposed Yucca Mountain repository site (State of Nevada/Department of Minerals, 1990). No exploitable hydrocarbon resources were encountered. The hydrocarbon exploration holes were plugged and abandoned (Nevada Oil Reporter, 1991, p. 1). Finally, private exploration for natural resources north and east of the site has been highly restricted for more than 40 years by the presence of weapons testing ranges (including nuclear weapons). These restricted-entry areas include the Nellis Air Force Range and the NTS. Based on the historical record (DOE, 1988; Miller, 1989; Nevada Bureau of Mines & Geology, 1990; Petzet, 1991), it is highly likely that exploration for precious metals and hydrocarbons in the vicinity will continue into the foreseeable future.

Groundwater, however, is the only natural resource known to exist beneath and adjacent to the proposed site (DOE, 1988). Groundwater is a potentially exploitable naturally occurring material which might engender direct intrusion into the proposed repository. As such it should be addressed in determining compliance with 10 CFR 60.122(c)(17) for longterm future inadvertent human intrusion considerations. However, the potential for foreseeable human activity (such as mining activities, military action or extensive irrigation) to adversely affect the groundwater flow system should be addressed under another PAC -- Human Activity and Groundwater [10 CFR 60.122(c)(2)]. Future inadvertent human intrusion, with respect to all naturally-occurring materials (including groundwater) will be evaluated from the overall system performance perspective in the consideration of 10 CFR 60.112.

To summarize, the following statements and assumptions have been made in in this section:

- Proposed Yucca Mountain site is located in a natural resources-rich geologic setting that includes current gold production, exploration for hydrocarbons, and exploitation of groundwater resources

- Groundwater is the only natural resource currently known to exist beneath and adjacent to the proposed site

- With respect to groundwater, the potentially adverse condition 10 CFR 60.122(c)(17) may be shown to exist

- Although there is no known direct evidence of viable deposits of precious metals or hydrocarbons beneath or immediately adjacent to the proposed site, the mineral-rich local environment may yet encourage the exploration of Yucca Mountain and its environs based upon the perception that viable resources might be present

- Based on the historical record, it is likely that exploration for precious metals will continue into the foreseeable future

- Although future human activities and their effects cannot be reliably predicted, it is possible to identify and evaluate a reasonable range of natural resources-related exploration and exploitation scenarios

- Determination of the effect of inadvertent human intrusion will be evaluated as part of the determination of complaince with the overall system performance objectives in 10 CFR 60.112

In order to comply with 10 CFR 60.122(c)(17) the applicant should specifically:

- Provide information to determine whether and to what degree the potentially adverse condition is present

- Provide information to determine the degree to which the PAC is present, but undetected

- Assure the sufficiency of the lateral and vertical extent of data collection

- Evaluate the information presented in the first and second bullets with assumptions and analysis methods that adequately describe the presence of the PAC and ranges of relevant parameters

The applicant while addressing naturally occurring materials, should include within its considerations the following:

- Appropriateness of the methods to the problem (i.e., foreseeable economics, comparison of areas, and undetected resources)

- Limitations of resource evaluations

- Types and levels of uncertainty in the analyses

- Means and methods of verification of the analyses (see Singer and Mosier, 1981). If expert judgement has been used extensively to evaluate resource presence and future value, the applicant should present the assumptions and methods used in arriving at and supporting its conclusions.

The applicant should confirm that it has fully considered the most recent exploration and exploitation activities within the geologic setting that are appropriate for the analysis (assessment to include timeframe up to the time of submittal of LA). The naturally occurring materials study should confirm that the current industry and government projections of natural resources potential within the region have been included within the applicant's considerations. If the applicant determines that naturally occurring materials (whether identified or undiscovered) are present within the site, it should demonstrate that it has adequately considered whether: (i) economic extraction of such materials is currently feasible or potentially feasible during the foreseeable future, and (ii) such materials have greater gross value or net value than the average for other areas of similar size that are representative of and located within the geologic setting.

4.3 COMPLIANCE WITH REGULATORY LANGUAGE IN PAC — EVIDENCE OF SUBSURFACE MINING

The information in this section is a product of a CNWRA study of the regulation and presents CNWRA approaches to satisfying the intent of the regulation. The regulatory language of 10 CFR 60.122(c)(18) is as follows:

"(18) Evidence of subsurface mining for resources within the site[2]."

This regulatory requirement, concerning a PAC, focuses on DOE's demonstration, through appropriate investigations, of the presence of (or conversely, the absence of) subsurface mining for natural resources within the site. In addition, such investigations are to include the area outside of the site if the presence of the PAC could affect isolation within the controlled area. These investigations are necessary because the existence of undiscovered mining activities could have important implications on the radiological safety and waste isolation potential of a candidate site. Such implications might include:

- Creation of preferential pathways for infiltrating waters or for released gaseous radionuclides

[2]The meaning of the terms "evidence of" and "within the site" were discussed in Section 2.4. Definitions of Selected Phrases Concerning Natural Resources, earlier.

- Shortening of flow paths and potential radionuclide transport pathways through the unsaturated zone below the repository horizon.

As a post-closure consideration for another regulatory requirement (i.e., 10 CFR 60.122(c)(17) — Presence of Naturally Occurring Materials), the presence of existing subsurface mining may be perceived by future explorationists as evidence of mineralization which might encourage new exploration at the site.

The scope of this regulatory requirement is limited to the consideration of evidence for supporting or negating existing (presite-characterization) natural resources-related subsurface mining. This includes mineral prospects (lode claims) and mills (including reduction works) as well (see DOE, 1988, p. 1-255). This regulatory requirement does not include direct consideration of shafts, boreholes and other excavations resulting from DOE's site characterization activities. However, it is recognized that the presence of such site characterization excavations may increase the likelihood that future explorationists will investigate the area for natural resources. Concerns that such site characterization excavations may become pathways possibly compromising the ability of the repository to meet the performance objectives should be considered under the design criteria for the Geologic Repository Operations Area (10 CFR 60.134 — Design of Seals for Shafts and Boreholes).

The rule requires the applicant to examine the proposed site (and the region beyond the site, as appropriate) and examine appropriate documents (including mining claims, historical and other maps, and air photos) to determine if any subsurface mining for resources has occurred there. Based on the collected information, one must either demonstrate that the PAC is not present or is to provide information to determine to what degree the PAC is present, or present, but undetected.

All appropriate information necessary for NRC staff to review the evidence supporting the absence of (or conversely, the presence of) existing subsurface mining for resources within the site (and beyond the site, if considered necessary) should be presented in the LA. The information in DOE LA should be presented in a manner such that the assumptions, data, and logic leading to a demonstration of compliance with the requirement are clear and do not require NRC to make extensive analyses and literature searches. The report should contain any controversial information and appropriate alternative interpretations and models which have been adequately described and considered.

DOE should either resolve all NRC staff objections to the LA that apply to this requirement or provide all the information requested in Section 1.6 of NRC (1990b) for unresolved objections. DOE should provide sufficient information to ensure that the evaluation of the effect of any unresolved objections, both individually and in combinations with others, has not:

- Impeded NRC's ability to conduct a meaningful and timely review

- Impeded the Commission's ability to make a decision regarding construction authorization within the three-year statutory period.

The LA should, as a minimum, provide adequate data and analyses in the LA to allow NRC to determine compliance with 10 CFR 60.122(c)(18). Specifically, the LA should:

- Provide information to determine whether and to what degree the PAC is present

- Provide information to determine to what degree the PAC is present, but undetected

- Assure the sufficiency of the lateral and vertical extent of data collection

- Evaluate the information presented under the first two listed items, with assumptions and analysis methods that adequately describe the presence of the PAC and ranges of relevant parameters

NRC relative to the PAC — Evidence of Subsurface Mining is expected to be very interested in the following:

- Evidence that the applicant has fully considered the most recent information regarding the existence of past subsurface mining-related activities that are appropriate for the analysis; and

- Evidence that regional investigations for past subsurface mining activities, which may have been limited to a 10 kilometer distance from the perimeter drift outline (DOE, 1988), are sufficient to assure that adequate information has been acquired to fully consider the presence, or absence, of such subsurface mining activities.

DOE indicates, in its 1988 Site Characterization Plan (SCP), that its investigations relative to this subject are complete (DOE, 1988, p. 1-353). Accordingly, DOE has determined that no additional investigations are planned. However, in its SCP, DOE has not provided the bases underlying its decision to limit its existing subsurface mining investigations to the area within 10 kilometers of the perimeter drift outline. If the controlled area is defined by DOE at its maximum extent of 10 kilometers from the outer boundary of the underground facility DOE must still investigate subsurface mining which is located more than 10 kilometers from the geologic repository operations area if such mining might affect waste isolation.

To summarize, the following statements and assumptions have been made in this discussion of PAC — Evidence of Subsurface Mining — 10 CFR 60.122(c)(18):

- Proposed Yucca Mountain site is located in a natural resources-rich geologic setting that has experienced exploration/exploitation of precious metals and other valuable resources.

- Regulatory requirement is limited to the consideration of evidence for supporting or negating existing (presite-characterization) subsurface mining.

- Boreholes, shafts and other site characterization-related activities (which may be perceived by some as constituting evidence of subsurface mining) should be considered by DOE under other regulatory requirements (i.e., 10 CFR 60.134).

4.4 COMPLIANCE WITH REGULATORY LANGUAGE IN PAC — EVIDENCE OF DRILLING

The information in this section is the product of a CNWRA study of the regulation and presents CNWRA approaches to satisfying the intent of the regulation. The regulatory language of 10 CFR 60.122(c)(19) is as follows:

"(19) Evidence of drilling for any purpose within the site[3]."

This regulatory requirement, concerning a PAC, focuses on the demonstration, through appropriate investigations, of the presence of (or conversely, the absence of) boreholes drilled for any purpose within the site. In addition, such investigations are to include the area outside of the site if the presence of the PAC could affect isolation within the controlled area. Safety implications potentially arising as a result of drillholes might include:

- Adverse effects on the groundwater flow system
- The creation of preferential pathways for infiltrating waters or for released gaseous radionuclides
- The shortening of flow paths and potential radionuclide transport pathways through the unsaturated zone below the repository horizon.

Presite-characterization drillholes, as well as those drilled for site characterization purposes, may be perceived by future explorationists as evidence of mineralization, thus, encouraging new exploration. Such drillholes constitute a post-closure consideration of the regulatory requirement for naturally occurring materials [10 CFR 60.122(c)(17)]. This perception may result in natural resources-related exploration activities (including boreholes) that may affect isolation within the controlled area. DOE is expected to evaluate such effects under the regulatory requirement for the overall system performance objective after permanent closure (10 CFR 60.112).

The scope of this regulatory requirement is limited to the consideration of evidence supporting or negating existing (presite-characterization) drilling for any purpose. This regulatory requirement does not include consideration of boreholes resulting from DOE's site characterization activities. However, the staff recognizes that the presence of such boreholes may increase the likelihood that future explorationists will investigate the area for natural resources. CNWRA and NRC staff concerns that such site characterization excavations may become pathways, possibly compromising the ability of the repository to meet the performance objectives, are to be considered under the design criteria for the Geologic Repository Operations Area (see 10 CFR 60.134 — Design of Seals for Shafts and Boreholes).

In order to satisfy the requirement PAC — Evidence of Drilling, DOE should:

- Examine the proposed site (and the region beyond the site, as appropriate), to determine if drilling for any purpose has occurred there
- Examine appropriate documents (including mining claims, historical and other maps, and air photos) for suggestions of drilling locations.

Any information concerning drilling at the site should be factored into the overall system performance assessment.

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[3]The meaning of the terms "evidence of" and "within the site" are discussed in Section 1.4 Definitions, earlier.

The study should fully consider the most recent information regarding the existence of past drilling associated with mining-related activities as well as drilling for other purposes (such as groundwater, irrigation and scientific purposes) that are appropriate for the analysis. DOE's regional investigations for past drilling activities, which may have been limited to a 10-kilometer distance from the perimeter drift outline, should be sufficient to assure that adequate information has been acquired to fully consider the impact (if any) of such drillholes (if such exist) on meeting the overall system performance objective (10 CFR 60.112).

DOE indicates in its 1988 SCP that its investigations relative to this regulatory requirement are complete (DOE, 1988, p. 1-353). As such, DOE has determined that no additional investigations are planned to further address this subject. However, in its SCP, DOE has not provided the bases underlying its decision to limit its existing drillholes investigations to the area within 10 kilometers of the perimeter drift outline. If the controlled area is defined by DOE at its maximum extent of 10 kilometers from the outer boundary of the underground facility, then DOE's investigations of drilling activities greater than 10 kilometers from the geologic repository operations area would have to be presented in the LA in order to satisfy the requirement that the PAC "outside the controlled area" be investigated only if it might affect waste isolation.

To summarize, the following statements and assumptions have been made in this discussion of the PAC Evidence of Drilling — 10 CFR 60.122(c)(19):

- Proposed Yucca Mountain site is located in a natural resources-rich geologic setting that has included exploration/exploitation of precious metals and other valuable resources.

- In addition to natural resources-related exploratory boreholes, this regulatory requirement is limited to the consideration of evidence for supporting or negating existing (presite-characterization) holes drilled for any purpose, including those drilled for either scientific or military purposes.

- Boreholes drilled for site characterization-related activities and their effect on the performance objectives are to be considered by the staff under other regulatory requirements (i.e., 10 CFR 60.134 and 10 CFR 60.112).

5 CONCLUSIONS

5.1 SUMMARY OF THE REQUIREMENTS OF THE EXISTING RULE

The regulatory requirements dealing with natural resources are identified as PAC — Human Activity and Groundwater contained in 10 CFR 60.122(c)(2), Presence of Naturally Occurring Materials contained in 10 CFR 60.122(c)(17), Evidence of Subsurface Mining in 10 CFR 60.122(c)(18), Evidence of Drilling contained in 10 CFR 60.122(c)(19), and the 10 CFR 60.21(c)(13) portion of the SAR. When considered in aggregate with the applicable performance objects of 10 CFR 60.112 and 60.113 and the favorable conditions of 10 CFR 60.122(b), these requirements comprise the regulatory needs related to natural resources with which the applicant must demonstrate compliance in a geologic repository LA.

The language of the PAC requires the following:

- Investigation and evaluation of conditions dealing with future human activity which might adversely affect the ground water flow system [10 CFR 60.122(c)(2)]

- Investigation and evaluation of the adverse effects on the performance objectives which might arise from the exploration for or exploitation of naturally occurring materials [10 CFR 60.122(c)(17)]

- Investigation and evaluation of the effect on the performance objectives of the implications from past mining [10 CFR 60.122(c)(18)] and/or drilling activity [10 CFR 60.122(c)(19)]

The ultimate basis for consideration of each of these four PACs is the potential effect on performance of the repository in the context of meeting the overall system and subsystem requirements. Engineered remedies which would be included in engineering designs and compensation for a given PAC by a combination of favorable conditions or characteristics are mitigating factors. Reporting and evaluation of the results of these natural resource related investigations and evaluations are to be presented in the SAR [10 CFR 60.21(c)(13)]. The conclusions found in this section and the suggested methods for demonstrating compliance by an applicant are the product of the CNWRA and represent only one approach to resolving the issues discussed.

5.1.1 PAC — Human Activity and Groundwater

PAC 10 CFR 60.122(c)(2) concerns an evaluation of the potential effects of human activity on the groundwater flow system. Groundwater exists beneath the site, the controlled area and nearby, in quantities sufficient to encourage current commercial use in mining operations within 15 kilometers of the site. Local groundwater is used for activities at the Nevada Test Site (NTS) (including the now defunct Nuclear Rocket Development Area). DOE uses local groundwater for site characterization activities at the proposed repository site. The search for, and exploitation of local groundwater resources in the vicinity of the high-level waste repository could potentially affect the groundwater flow system. The effects of groundwater withdrawal on the ability of the repository to meet performance objectives both currently, and in the future, must be investigated and evaluated. Effects of human activity affecting groundwater on the pre-waste-emplacement groundwater travel time sub-system performance requirements of 10 CFR 60.113(a)(2) should be evaluated. This evaluation should include the likelihood of use of groundwater for additional commercial or governmental activities (e.g. mining or an increase in activity at NTS) as well as use in an urban environment (e.g. residential drinking water) or agricultural environments (e,g. irrigation). The final consideration should always be a determination of the likelihood and extent of the effect of human activities affecting the groundwater system which may affect the attainment of the overall and subsystem performance objectives.

A discussion of the result of the investigations and evaluations should be a part of the SAR which is a part of the LA.

5.1.2 PAC — Presence of Naturally Occurring Materials

The main regulatory requirement dealing with natural resource evaluation to determine the effects of inadvertent human intrusion for resources on the proposed repository is the PAC — Presence of Naturally Occurring Materials [10 CFR 60.122(c)(17)]. The regulatory language and logical relationships of required considerations of this PAC are complicated and include eight different sub-considerations which have been identified within the language. These eight sub-considerations are as follows:

- Identified materials for which economic extraction is currently feasible
- Identified materials for which economic extraction is potentially feasible during the foreseeable future
- Undiscovered materials for which economic extraction is currently feasible
- Undiscovered materials for which economic extraction is potentially feasible during the foreseeable future
- Identified materials that have a greater gross value than the average for other areas of similar size that are representative of and located within the geologic setting
- Identified materials that have a greater net value than the average for other areas of similar size that are representative of and located within the geologic setting
- Undiscovered materials that have a greater gross value than the average for other areas of similar size that are representative of and located within the geologic setting
- Undiscovered materials that have a greater net value than the average for other areas of similar size that are representative of and located within the geologic setting

The goal of any evaluation of a PAC should be to determine if its presence has potentially compromising effects on attainment of the performance objectives. Performance assessment in 40 CFR Part 191 is defined as:

> "... an analysis that: (1) identifies the processes and events that might affect the disposal system; (2) examines the effects of these processes and events on the performance of the disposal system; and (3) estimates the cumulative releases of

radionuclides considering the associated uncertainties, caused by all significant processes and events" (EPA, 1987, p. 11).

A necessary extension of the presence of naturally occurring materials in any of the eight possible configurations is the investigation of the effect of inadvertent human intrusion associated with naturally occurring materials on the attainment of the performance objectives. This implicit requirement for determining the effect of future inadvertent human intrusion caused by the perception or discovery of naturally occurring materials at a given site is not explicitly written within 10 CFR Part 60. In addition, it is only implicitly included within EPA performance requirements in 40 CFR Part 191 for an NRC regulated high-level waste repository. The regulatory language of 40 CFR Part 191 states that the facility shall be designed to "provide a reasonable expectation, based upon performance assessments" that releases of radionuclides will be within established limits (EPA, 1987, p. 11). The guidance contained in Appendix B of 40 CFR Part 191, however, does explicitly give specific scenarios which may be construed to be applicable considerations of inadvertent human intrusion into a geologic repository which are driven by exploration/exploitation of natural resources.

Inadvertent human intrusion for resources is alluded to in Section 191.14 of 40 CFR Part 191 which is prefaced by the statement "... these provisions do not apply to facilities regulated by the Commission (see 10 CFR Part 60 for comparable provisions applicable to facilities regulated by the Commission)." Section 191.14 of 40 CFR Part 191 (EPA, 1987, p. 11) states the following.

> "(e) Places where there has been mining for resources, or where there is a reasonable expectation of exploration for scarce or easily accessible resources, or where there is a significant concentration of any material that is not widely available from other sources, should be avoided in selecting disposal sites. Resources to be considered shall include minerals, petroleum, or natural gas, valuable geologic formations, and ground waters that are either irreplaceable because there is no reasonable alternative source of drinking water available for substantial populations or that are vital to the preservation of unique and sensitive ecosystems. Such places shall not be used for disposal of wastes covered by this part unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future."

It is not until Appendix B — Guidance for Implementation of Subpart B, that inadvertent human intrusion is explicitly mentioned in EPA rule. Inadvertent human intrusion is discussed in two sections as follows: (1) "Consideration of Inadvertent Human Intrusion into Geologic Repositories" and (2) "Frequency and Severity of Inadvertent Human Intrusion into Geologic Repositories"(EPA, 1987, p.16). Interestingly, this information is presented only as guidance and "the implementing agencies are not bound to follow this guidance" (EPA, 1987, p.15).

The language of 10 CFR 60.122 (a)(2) and 10 CFR 60.122(c) specifies how the PAC in 10 CFR 60.122(c)(17) (or any other PAC) must be considered. The rule requires that adequate investigation and evaluation of naturally occurring materials (or any other PAC) be accomplished in order to factor this information into an assessment of the ability of the proposed repository to meet the performance objectives. The objectives are mandated by EPA in 40 CFR Part 191, and captured by NRC in 10 CFR 60.112 — Overall Performance Objectives and are augmented by the sub-system performance objectives in 10 CFR 60.113.

The applicant is required to present the results of its analyses (investigations and evaluations) to NRC in the SAR which is a part of the LA.

5.1.3 PAC — Evidence of Subsurface Mining

PAC 10 CFR 60.122(c)(18) is stated very simply: it requires the applicant to determine if there has been any subsurface mining for resources at the site or nearby (included only if the nearby mining might affect the performance objectives). The applicant is to determine if the evidence for such mining indicates that performance objectives are currently, or will in the future be, compromised. All existing evidence of subsurface mining for resources at the time of license application (including site-characterization mining albeit not for resources) should be considered. The considerations of the applicant are as follows:

- Determine if existing mining (if present) in the controlled area and nearby environs (if that existing mining might have an effect upon the performance objectives) is sufficient to cause the repository not to be capable of meeting the required performance objectives.

- Determine if the presence of past mining indicates that the site and nearby areas are a likely target for future mining activity which might cause the performance objectives to be compromised. The investigation should determine if the evidence of site characterization-caused mining will influence the likelihood of the site being explored in the future. Future exploration could cause inadvertent human intrusion into the repository. Determination the likely effects of such inadvertent human intrusion in the overall system performance assessment is the primary consideration.

A thorough study should investigate and evaluate the implications of past subsurface mining for resources and translate the implications into an evaluation of repository performance. The report of the results of this analysis will be in the SAR which is a part of the LA.

5.1.4 PAC — Evidence of Drilling

PAC 10 CFR 60.122(c)(19) requires a determination if there has been any drilling at the site or nearby (only if such nearby drilling might have an adverse effect on performance objectives). The applicant is to determine if the evidence for such drilling indicates that performance objectives are currently, or will in the future be, compromised. All evidence of drilling existing at the time of license application (including site-characterization drilling) should be considered. The considerations of the applicant are as follows:

- Determine if the existing and planned drilling in the controlled area and nearby environs is sufficient to cause the repository to not be able to meet the required performance objectives.

- Determine if the presence of past drilling (not including site characterization activities) indicates that the site and nearby environs are likely targets for future drilling which might cause performance objectives to be breached. Future exploration could cause inadvertent human intrusion into the repository. The study should determine the likely effects of such inadvertent human intrusion in the overall system performance assessment.

A thorough study should investigate and evaluate the implications of past drilling and translate the implications into an evaluation of performance objectives. The report of the evaluation will be in the SAR which is a part of the LA.

5.2 REGULATORY BASES FOR THE EXISTING RULE REQUIREMENTS PERTAINING TO NATURAL RESOURCES

The existing regulations dealing with natural resources and associated subsurface mining, drilling, and water use were intended to ensure that the resources which might contribute to future inadvertent human intrusion at a proposed repository site were considered thoroughly and evaluated in the context of the performance objectives. Intentional human intrusion into the repository is not specifically regulated by 10 CFR Part 60. NRC in the Staff Analysis of Public Comment ...(NRC, 1983, p. 134) has expressed the belief that a reasonable measure to discourage people from intruding into a geologic repository is "directing site selection toward sites having little resource value...". A section on Human Intrusion from the Federal Register states the following:

> "... the problem of human intrusions, intentional or inadvertent moots much of the previous discussions since there is no way to reasonably limit the variety of conceivable human activities which might compromise a forgotten repository. The only logical recourse, since engineering against human intrusion is impossible practically, is to avoid targets, i.e., sites which may invite such intrusion. Mineral resources, water resources, interesting geologic or hydrologic features are sure to attract the developer or the explorer. Shallow repositories would more easily be intruded upon than deep ones. Therefore, what is needed are site suitability criteria which would lead toward uninteresting sites of little resource value, and design criteria which would yield designs that present minimal 'targets'" [45 Fed. Reg. 31395 (1980)].

Additionally, the Commission "anticipates that a high standard of engineering will be necessary—not only to compensate for geologic uncertainties at even the best reasonably available sites, but perhaps also to mitigate the consequences of unanticipated processes and events (including potential intrusion) during the years when the fission product inventories remain high" [48 Fed. Reg. 28204 (1983)]. The Commission view is that;

> "...while the passive control measures it is requiring will reduce significantly the likelihood of inadvertent intrusion into a geologic repository, occasional penetration of the geologic repository over the period of isolation can not be ruled out, and some provision should be made in the final rule for consideration of intrusion should these measures fail. Its objective is to provide a means for evaluating events that are reasonably of concern, while at the same time excluding speculative scenarios that are inherently implausible. ...it will grant a license if it is satisfied that the risk to the health and safety of future generations is not unreasonable" [48 Fed. Reg. 28199 (1983)].

NRC staff commented on the need to consider the perceived as well as proven resources at a site as follows:

"A location perceived as likely to have resources that would attract intrusion normally would be classed as having resources of greater value than the average for other locations in the geologic setting. This would be a potentially adverse condition" (NRC, 1983, p. 138).

"In summary, the Commission has retained the principle that highly speculative intrusion scenarios should not be allowed to become the driving force in license reviews, but has introduced some flexibility to permit consideration of intrusion on a case-by-case basis where circumstances warrant" [48 Fed. Reg. 28200 (1983)].

5.3 APPROACHES TO EVALUATING NATURAL RESOURCES

The Commission has placed specific regulations in the rule to cause natural resource driven inadvertent human intrusion into a geologic repository to be studied. The language of the regulation requires the applicant to demonstrate that consequences of inadvertent human intrusion be proven not to compromise the performance objectives delimited for the proposed geologic repository. The regulation [10 CFR 60.122(c)(17)] contains very specific language on the means to be used by the applicant to consider natural resources. The regulation requires that the applicant use economic valuations of naturally occurring materials, for the present and future, and analogous comparison areas in the geologic setting to determine the relative present worth of identified and undiscovered materials at a given repository site. Additional guidance on the prospective analyses of the applicant is provided in the description of the contents of the SAR. In 10 CFR 60.21(c)(13), in the description of the contents of the SAR, the Commission requests the use of reasonable inference in evaluating undiscovered resources. Second, the Commission specifies the considerations to be used when determining net value of the resources (namely, development, extraction, and marketing costs). Third, the acceptable descriptors for natural resources without current markets (namely, physical factors such as tonnage, or other amount, grade, and quality) are requested in the regulatory language.

When objectively assessing the occurrence of natural resources at a given site, in order to determine the likelihood of future intrusion and its effect upon the stated performance objectives, it is suggested that each of the specific regulatory requirements are not a unique (and hence the only) means of demonstrating compliance with the intent of the regulation. There may be other means acceptable to NRC to satisfy the intent of the regulation (i.e., to determine the effect of future inadvertent human intrusion upon the performance objectives) than just the demonstrations called for in the current language of the regulation in 10 CFR Part 60.

One reasonable approach to satisfying the intent of the regulation, other than that currently specified within the regulatory language, would be to conduct a study of a given proposed repository site from a "resource explorationist" point-of-view. Specifically, the applicant could use exploration philosophy and techniques to evaluate the mineral resources of the site and nearby areas. The "explorationist" approach would be implemented in stages. The first stage would involve a comparison between features of genetic models for resource concentration and deposit formation from the geologic setting, with models developed for the local geologic environment and history at the site. Because the presence or absence of a given resource is highly dependent on the characteristics of the individual site, a point-by-point comparison between the site and other areas of the geologic setting should not be the focus of this exercise. Rather, the generic models developed for the various producing districts within the geologic setting should be used as guides to identify important features in the formation of these deposit types that are present or absent at the proposed repository site and nearby. If the comparison indicates that key characteristics of a given resource type are missing at or nearby the site, then the potential for this resource is downgraded, and the likelihood of its presence having an adverse affect on the performance of the site is lessened. If, however, comparisons at this stage are favorable for a given resource, then additional studies should be accomplished by the applicant for further natural resource target appraisal and target definition as deemed appropriate.

If indications of natural resource potential remain positive after economic forecasting, and a decision is made to proceed with the proposed repository, then exploration/exploitation scenarios of probable human intrusion, given the presence of a natural resource, should be developed. These scenarios should be restricted to determining the effect of the exploitation of the targets defined at the preceding stages on the ability of the repository to meet performance objectives related to waste isolation. The evaluations should consider the size of the resource based on the economics of production, the physical operation itself, and estimates of the likelihood of inadvertent breaching of the repository during the lifetime of the given operation. Only the economics of the foreseeable future should be considered in these exploitation scenarios, and only reasonable estimates of technological advances (or retreats) should be incorporated.

Since the ability of a given repository to control the release of radioactive waste at levels below EPA standard is the goal of a licensing evaluation, it is obvious that scenarios dealing with inadvertent human intrusion resulting from a perception of resources at a given site must be evaluated whether resources are currently known to be at a site or not. A thorough investigation and evaluation should include a series of scenarios in its repository performance assessment that "test" the site given various stages of natural resource perception. The stages are envisioned to include the types of activities shown in Figure 3-20, earlier. Table 5-1 is CNWRA assignment of expectation to each of the generic types of intrusions which might occur at a given site using Yucca Mountain as an example. Based upon the types of materials likely to be considered in future intrusion scenarios at a given site, a thorough investigation should generate "normal" exploration and exploitation scenarios which would be used to define the types, sizes and quantities of drillhole, drifts, and or other intrusions at a given location. The "resource perception" based scenarios would be generated on a site specific basis to include those likely resources and their expected mode of occurrence in the geologic setting particularly at and nearby a proposed repository site. Earlier described literature and analytical work should be used in evaluation of probable resource perception and subsequent activities of future generations at a given site.

If initial site investigation studies result in positive indications for one or more resources, additional studies are necessary to further evaluate the resource potential of the site. Initial studies will have indicated areas that merit further study and will act to focus subsequent efforts. Subsequent efforts may include more systematic and dense surface sampling and additional geochemical analysis to define targets for an exploratory drilling program with the express purpose of testing for natural resources. Again, it is emphasized, the purpose of the initial study is not to develop and exploit natural resources at the site, but rather to provide data so that a decision determining how the increased potential for resources at the site (as indicated by aggregate of positive results from the additional studies) will affect the ability of the site to meet the performance objectives. Any site characterization program which includes drilling or surface sampling, for whatever purposes, should consider the acquisition of mineral samples as a part of the ongoing data acquisition process.

Table 5-1. Expectation of Inadvertent Human Intrusion Within the Controlled Area or Near the Controlled Area During Next 10,000 Years at the Yucca Mountain Site

Nature of Inadvertent Human Intrusion	Minerals⁺ Exp	Minerals⁺ Pro	Hydro-carbons	Ground-water	Geo-thermal*	Coal
Borehole/excavation finishes within rock above repository horizon	5	2	1	1	3	1
Borehole finishes within repository host rock horizon	2	2	1	1	2	1
Borehole finishes within rock between repository host rock horizon and water table	2	2	1	1	2	1
Borehole finishes below water table in underlying aquifer	2	2	1	5	2	1
Borehole finishes beneath underlying aquifer	1	1	2	1	2	1

1 Not expected (Assigned Probability 0)
2 Low probability
3 Moderate probability
4 High probability
5 Expected (Assigned Probability 1)

$^{+}$Exp = exploratory
Pro = production

*Assumes "natural" heat only but is problematic since the heat generated by an intact repository may be misconstrued as a natural geothermal anomaly particularly during the first few hundred years after emplacement when fission inventories and heat generation remain high. Inadvertent human intrusion could result from the misinterpretation of a local geothermal heat anomaly as "natural" rather than high-level waste repository-induced, thus causing the likelihood assignment to be nearer to "5 Expected" or a probability of 1.

If additional studies (drilling, surface sampling, water sampling, etc.) identify potential targets, it then becomes feasible to perform an economic forecast for a given resource using the available information. The study should consider the economics of developing and producing the estimated reserves at the site using estimates of production technology in the foreseeable future (probably not more than 50 years hence). The resulting findings would indicate the level of resources presence at the site. If the economics appear unfavorable, then the likelihood of future human intrusion (given reasonable estimates of technological advances) related to compromise of the performance objectives should be downgraded. The study would then evaluate the likelihood of exploration/exploitation programs at the site to find and/or utilize the perceived resources, assigning probabilities to the likelihood of each step in the exploration/exploitation process which might affect some facet of the performance objectives. The next step would be to factor the probabilities of exploration/exploitation into the performance assessment scenarios being developed for the particular site. The final evaluatory step would be to run the performance assessment model(s) to determine if the impact of inadvertent human intrusion on the site characteristics would cause performance objectives of the site to be compromised.

An optional approach to determining the likelihood and extent of inadvertent human intrusion for naturally occurring materials at a proposed repository site in the absence of discovered resources, would be to use the "explorationist" approach discussed earlier. By using an "explorationist" approach one would not be confronted with the difficult requirement to deal with undiscovered deposits economically, in the present and in the future, in every case, and would preclude the need to identify and individually study the "comparison areas" (as discussed earlier) for economic value. It is probable that the results of human intrusion performance assessment scenarios generated by either an explorationist approach or by a strict adherence to the language of the regulation would be very similar. Because of the great uncertainty in predicting human activity including economic systems more than a few decades into the future, the impact of strictly adhering to the language of the regulation would be to compound the uncertainty with the projection of future economic conditions in addition to the uncertainty of predicting inadvertent human intrusion scenarios themselves. By evaluating the site as an "explorationist" would, removal of much of the uncertainty involved in the economic manipulations which are required by adherence to the strict language of the regulation occurs. In any event, the applicant is expected to establish a rational approach to the consideration of future intrusion which is built on the identified or perceived presence of natural resources at the proposed repository site. Based on dialogue with the NRC and other interested parties, DOE in the LA is expected to satisfy the intent of the Commission in its formulation of the natural resource related language of the requirements of 10 CFR Part 60.

5.4 CNWRA ASSESSMENT OF INTENT OF COMMISSION IN CONSIDERING NATURAL RESOURCES AT A PROPOSED REPOSITORY SITE

The potentially adverse conditions as presented in an "Advanced Notice of Rulemaking" in May, 1980 included the following:

"60.122 Siting Requirements

(a) General Requirements
(a)(8) The Department shall perform a resource assessment for the region within 100 km of the site using available information. The Department shall include estimates of both known and undiscovered deposits of all resources that

(i) have been or are being exploited or
(ii) have not been exploited but are exploitable under present technology and market conditions. The Department shall estimate undiscovered deposits by reasonable inference based on geologic and geophysical information. The Department shall estimate both gross and net value of resource deposits. The estimate of net value shall take into account development, extraction, and marketing costs.

(b) Potentially adverse conditions
(b)(1) Potentially adverse human activities
(i) There is or has been conventional or in situ subsurface mining for resources.
(ii) Except holes drilled for investigations of the geologic repository, there is or has been drilling for whatever purpose to depths below the lower limit of the accessible environment.
(iii) There are resources which are economically exploitable using existing technology under present market conditions.
(iii) Based on a resource assessment there are resources that have either higher gross value or net value than the average for other areas of similar size in the region in which the geologic repository is located.
(vii) There is an indication that present or reasonably anticipatable human activities can significantly affect the hydrogeologic framework. Human activities include ground-water withdrawals,..." [45 Fed. Reg. 31401 (1980)].

Although the language is modified and moved within the final version of 10 CFR Part 60, the essence of the language of 1980 is contained within the current regulation. The relationship of the adverse conditions regarding natural resources to some future violation of the repository performance objectives due to inadvertent human intrusion was not stated within the regulation in the 1980 draft and remains unstated within the current regulation. The current (and originally proposed) language places significant constraints on the investigations and analyses to be used by the applicant. The language provides almost prescriptive means and methods to accomplish the investigations and evaluations of the natural resources themselves. At the same time, however, the regulation provides no guidance on the more perplexing problems of how to generate intrusion scenarios based on natural resource information and how to evaluate the probabilities and potential effects of such inadvertent human intrusion upon the various performance objectives. Interestingly, the requirements (evaluations) as they are now stated within the context of 60.122(c)(17) totally depend upon bottom line economic assessments for their realization.

There is significant discussion in the various Statements of Consideration and "Staff Analysis of Public Comments..." (NRC, 1983) on the intention of NRC to use 10 CFR 60.122(c)(17) as a test of the likelihood and impact of unintentional (inadvertent) human intrusion into a geologic repository during the regulatory period of interest. The means to accomplish the desired investigations and evaluations which are discussed within the text of PAC 60.122(c)(17) — Presence of Naturally Occurring Materials and 60.21(c)(13), SAR, are very precise. The preciseness may result in too much emphasis being placed on the physical state of resources at the site and too little emphasis being placed upon the cause and effect relationship between the presence of naturally occurring materials (actual or perceived), the likelihood and nature of intrusion for such materials, and the consequences of the plausible inadvertent human intrusion scenarios which might occur at any time within the regulatory life of the repository.

NRC desires to allow the applicant reasonable latitude in conducting the investigations and evaluations necessary to provide reasonable assurance to the Commission that the performance objectives of a proposed geologic repository for high-level radioactive waste will not be compromised as a result of inadvertent human intrusion into or near the site for naturally occurring materials. The apparent intent of the Commission can be presented as a simple direct restatement of the PAC dealing with naturally occurring materials as follows:

> The intent of the Commission in crafting the language of the naturally occurring materials PAC was for the applicant to demonstrate that the potential for inadvertent human intrusion resulting from the exploration for or the exploitation of inferred or discovered naturally occurring materials, which are currently resources or may become resources due to credible projected changes in economic or technologic factors, has been investigated and evaluated. The results of the investigation should be an evaluation which is a recognizable part of the overall system performance assessment which responds to the language of 10 CFR 60.112 and EPA rule 40 CFR Part 191.

This clarification of the intent of the current regulatory language links the potential for naturally occurring materials with likely exploration/exploitation. This CNWRA statement of NRC intent further strengthens the cause/effect relationship between the perceived presence of natural resources and future inadvertent human intrusion at a geologic repository.

The following quotations from the Federal Register demonstrate that the intent of the Commission in crafting the PAC — Presence of Naturally Occurring Materials [10 CFR 60.122(c)(17)] was to tie together naturally occurring materials and inadvertent human intrusion.

- "The Commission observed, in the preamble of the proposed rule, that everything that is reasonable should be done to discourage people from intruding into the geologic repository. Those measures which its (sic) believed to be reasonable included directing site selection to areas having little resource value and marking and documentation of the site" [48 Fed. Reg. 28199 (1983)].

- "The Commission considers it necessary to clarify its position and, in doing so, allows for examination of intrusion under appropriate bounding conditions" [48 Fed. Reg. 28199 (1983)].

- "...the Commission is of the view that while the passive control measures it is requiring will reduce significantly the likelihood of inadvertent intrusion into a geologic repository, occasional penetration of the geologic repository over the period of isolation cannot be ruled out, and some provision should be made in the final rule for consideration of intrusion should these measures fail. Its objective is to provide a means for evaluating events that are reasonably of concern, while at the same time excluding speculative scenarios that are inherently implausible" [48 Fed. Reg. 28199 (1983)].

- "Consistent with the references to resources in the requirements for the content of the safety analysis report Section 60.21(c)(13), the presence on [sic] naturally occurring materials for which economic extraction is currently feasible or potentially feasible during the foreseeable future may give rise to a potentially adverse condition" [48 Fed. Reg. 28212 (1983)].

- "Consistent with its previously stated views, it [the Commission] thinks that the selection of a site with no foreseeably valuable resources could so reduce the likelihood of intrusion, as to reduce, or eliminate any further need for it to be considered" [48 Fed. Reg. 28199 (1983)].

- "In summary, the Commission has retained the principle that highly speculative intrusion scenarios should not be allowed to become the driving force in license reviews, but has introduced some flexibility to permit consideration of intrusion on a case-by-case basis" [48 Fed. Reg. 28200 (1983)].

Consideration of naturally occurring materials includes both identified (discovered) and undiscovered (inferred) materials. Conditions are to be evaluated based on "credible" projections. In order to accomplish an adequate investigation of the PAC and subsequent evaluation of effect on performance objectives the Commission should allow the applicant to determine the means to accomplish the investigations/evaluations without relying on the constraints imposed by the explicit regulatory language in the natural resource related requirements. The applicant should be free to use the methods which it determines will provide the Commission with the required "reasonable assurance" that the performance objectives would not be compromised by inadvertent human intrusion for naturally occurring materials in the regulatory future of the repository. The Commission should not rely only on the fiscal-oriented language in 10 CFR 60.122(c)(17) and 10 CFR 60.21(c)(13) for compliance with performance objectives related to inadvertent human intrusion. The current regulatory language includes "gross or net value for other areas of similar size" and "currently feasible or potentially feasible during the foreseeable future" which depend on economic extraction for their determination. Economically based analyses should not be the only allowable means afforded the applicant to discriminate the likelihood and extent of inadvertent human intrusion related to naturally occurring materials and its effect on repository performance.

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APPENDIX A

REPORT TO
CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES

A METHODOLOGY FOR ASSESSING GROUND WATER RESOURCES AS A POTENTIAL SOURCE OF HUMAN INTRUSION

by

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1.0 INTRODUCTION

1.1 TASK ASSIGNMENT

The Nuclear Regulatory Commission (NRC) Staff has requested support from the Center for Nuclear Waste Regulatory Analyses (the Center) in the development of a Staff Technical Position on Natural Resources Assessment Methods. The Center was directed to identify the attributes of acceptable methodologies for the assessment of natural resources of a proposed high-level waste repository site, with particular consideration being given to a site with a geologic setting similar to that of the Yucca Mountain site in the southern Basin and Range physiographic province.

As part of the overall natural resource assessment initiative, the Center has directed Adrian Brown Consultants (ABC) to prepare three technical reports addressing specific aspects of the assessment of ground water potential. The topics to be addressed and their status are as follows:

- **Ground water classification with respect to the Individual and Ground Water Protection requirements of 40 CFR Part 191.** This report, cited in the references as ABC, 1989a, was submitted to the Center on November 9, 1989.

- **Identification of ground water resource assessment methodologies.** This is the topic of this technical report. The draft of this technical report, cited in the references as ABC, 1989b, was submitted to the Center on November 27, 1989.

- **Projections of regional ground water needs in southern Nevada.** This topical report, cited in the references as ABC, 1989c, was submitted to the Center on December 27, 1989.

1.2 REGULATORY BACKGROUND

1.2.1 Relevant Portions of 10 CFR Part 60

Regulatory matters related to water resources issues are found in two portions of Part 60: Subpart B, addressing Licenses, and Subpart E, addressing Technical Criteria. The principal regulatory citations are as follows:

60.21 Content of Application

(a) An application shall consist of general information and a Safety Analysis Report. An environmental report shall be prepared in accordance with Part 51 of this chapter and shall accompany the application. ...

(c) - The Safety Analysis Report shall include:

...

(1) (i) (The description of the site)...In addition, where subsurface conditions outside the controlled area may affect isolation within the controlled area, the description (of the site) shall include such information with respect to the subsurface conditions outside the controlled area to the extent that such information is relevant and material. The detailed information in this paragraph shall include:

...

(D) the hydrogeologic properties and conditions.

...

(13) An identification and evaluation of the natural resources of the geologic setting, including estimates as to undiscovered deposits, the exploitation of which could affect the ability of the geologic repository to isolate radioactive wastes. Undiscovered deposits of resources shall be estimated by reasonable inference based on geologic and geophysical evidence. This evaluation of resources shall be conducted for the site and for areas of similar size that are representative of and are within the geologic setting. For natural resources with current markets the resources shall be assessed, with estimates provided of both gross and net value. The estimate of net value shall take into account current development,

extraction and marketing costs. For natural resources without current markets, but which would be marketable given projected changes in economic or technological factors, the resources shall be described by physical factors such as tonnage or other amount, grade and quality.

60.122 Siting Criteria

(c) Potentially Adverse Conditions ...

(2) Potential for foreseeable human activity to adversely affect the ground water flow system, such as ground water withdrawal...

(17) The presence of naturally occurring materials, whether identified or undiscovered, within the site, in such a form that:

(i) Economic extraction is currently feasible or potentially feasible in the foreseeable future; or (ii) Such materials have greater gross or net value than the average for other areas of similar size that are representative of and located within the geologic setting.

Additional references to the environmental report, its updates, and National Environmental Policy Act (NEPA) evaluations consistent with the requirements of 40 CFR Part 51 are found in Sections 60.24, 60.31, and 60.41. These citations are not included in this report, as they place no additional requirements on the DOE beyond those implicit in Section 60.21, the Atomic Energy Act, as amended, and the Nuclear Waste Policy Act, as amended.

1.2.2 Discussion

The natural-resource evaluations of Part 60 fall into two categories: those associated with demonstrating compliance with NEPA requirements and those associated with demonstrating compliance with the waste-isolation requirements of Part 60 (and, by reference, 40 CFR Part 191). While much, and perhaps all, of the data related to ground water resources at and near the Yucca Mountain site will be applicable to both styles of evaluation, the analysis of the data for these two purposes will be quite different. The NEPA evaluation will look at ground water as a component of the "human environment" and assess the impact of the geologic repository program on that environment. In contrast, the

Part 60 evaluation will focus on the potential effects of exploitation of ground water on the performance of the geologic repository.

The former is a style of both procedural and substantive analysis that, after 20 years of experience at thousands of sites, is well established in methodology (though almost never devoid of either complexities or controversy in execution). The latter is a strictly technical evaluation (albeit in a specific public-policy environment). While Part 60, addressing the disposal of high-level radioactive waste, applies the technical analysis to a specific problem that has not been dealt with to date, the impact analysis itself poses no general technical issues that have not been addressed in other contexts many times over the last fifty or more years. In essence, the fundamental technical issue is how the exploitation of water in one location may affect the performance of another part of a hydrologic system. This style of analysis is performed routinely in evaluating potential interference effects from new wells on existing well fields and water rights (and analogously for petroleum and geothermal reservoirs), in assessing the impacts of mine or construction dewatering programs and the hydrogeologic impacts of reservoirs, in designing ground water restoration projects, deep-well injection systems, and major tunneling programs, and in a variety of other geotechnical and geohydrologic applications. Thus, it is considered that there is a very significant body of knowledge that can be applied to describing the attributes of an analysis of hydrologic impacts on performance.

1.3 GENERAL STATEMENT OF PROBLEM AND APPROACH

Based on our understanding of the task assignment and the current NRC Staff concerns, we consider that the evaluation of ground water with respect to future impacts on the repository is the critical issue for analysis at this time. That is, the following discussion will evaluate techniques that could be used to assess the likelihood of human intrusion associated with ground water exploration or exploitation, either directly (i.e., by drilling into the repository) or indirectly (i.e., by adversely affecting the hydrologic performance of the geologic repository). After presenting the concepts on a step-by-step basis, the methodology will be illustrated with examples drawn from a site like the Yucca Mountain Site, Nevada. This paper will not evaluate the NEPA aspects of the ground water resources.

The technical approach proposed by this report is as follows:

1. Define a conceptual geologic repository system, identifying the hydrologically functional parts of the system.

2. Define one or more undesired states (or events) of the system. (This can be viewed as the converse of defining positive performance measures for the system.)

3. Identify all credible pathways in which the undesired event can occur.

4. Identify the data necessary to assess the likelihood that each pathway is "complete".

5. Identify the data necessary to quantify the probability of the undesired event.

As applied to a hydrologic problem, NRC reviewers will recognize steps 1-3 as the basic steps of a Fault Tree Analysis (NUREG 0492). Steps 4 and 5 are related to aspects of scenario analysis and screening (e.g., NUREG/CR-1667 and NUREG/CR-2452, 1982), or they can be considered part of the fault-tree quantification process (e.g., Breeding et al., 1984). It has been pointed out by a reviewer that use of the term "pathway" creates some ambiguity in the application of fault-tree analysis to ground water flow. In terms of the methodology as applied in this paper, "pathway" refers to a logically complete pathway to an undesired event or state of the system. The macroscopic, physical movement of water through the flow system will be referred to generally as a "flow path" or, in a more restricted, technical sense as a "streamline". Note that because the phenomenon under consideration involves the flow of water, it is not possible to entirely separate these two concepts. A logically complete "pathway" must include appropriate consideration of the physical basis of flow. In addition, a complete "pathway" also will involve additional, external factors (e.g., the presence of a well or borehole in the target area) that do not necessarily affect the physics of the flow of water, but rather define initial or boundary conditions that permit the formulation of a well posed problem. In general, context will make it quite clear whether one is discussing the logic of the methodology or the hydraulics of ground water flow.

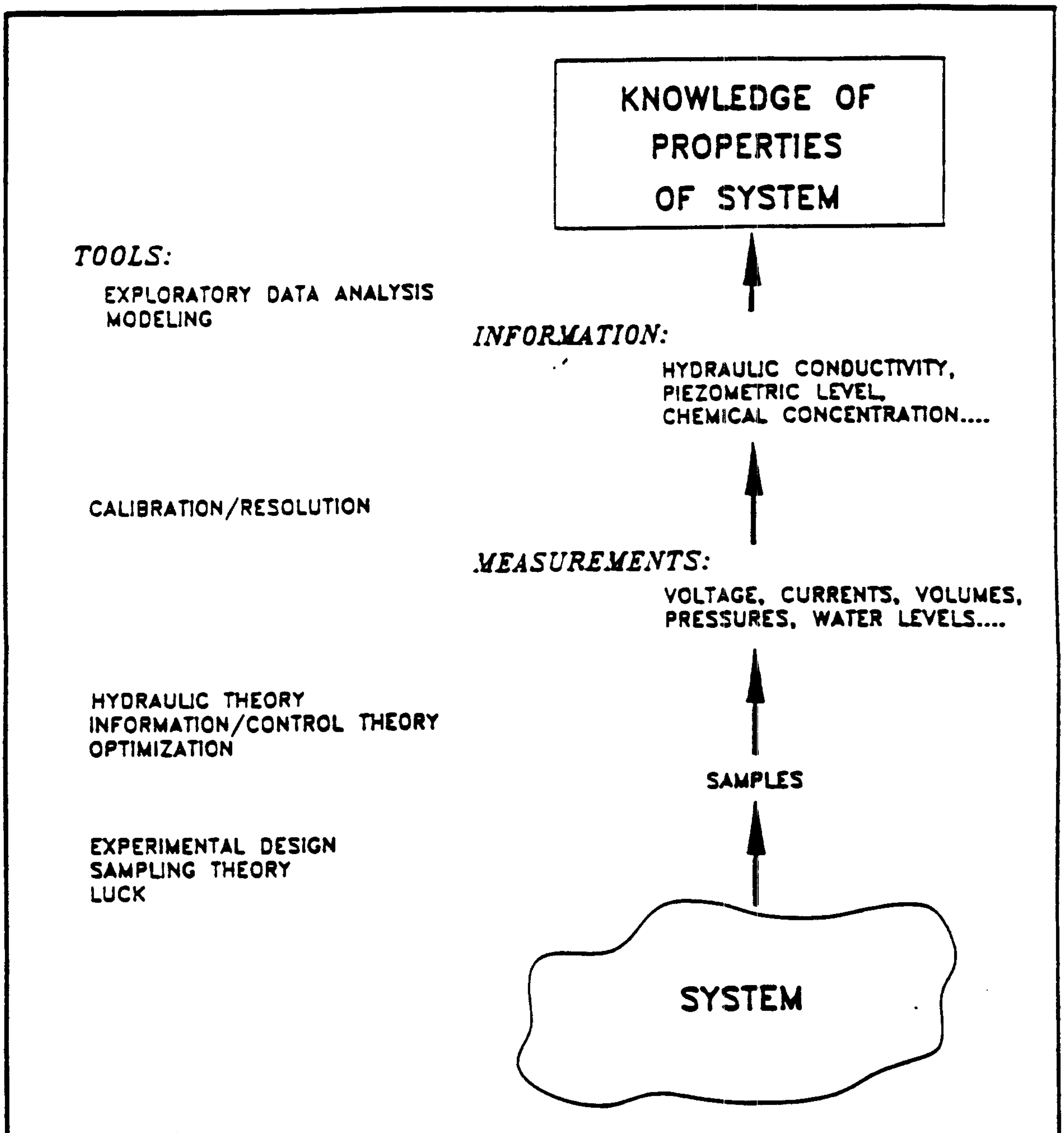
In this methodology, the existence of a complete logical pathway to an undesired state of the system is considered to define the "consequence", and the estimation of the probability of that undesired state is the end-point of the quantification. This is not to say that this would be the end-point of the performance assessment process that would be required by DOE, which, clearly, would have to assess the impact of the human intrusion on system and subsystem performance against the performance objectives of 10 CFR Part 60. However, the methodology proposed potentially allows a simplification of the total-system analysis by externally performing a detailed analysis of one group of scenarios, the output from which could be used as input to a more idealized system evaluation.

2.0 GENERAL REVIEW OF METHODS AND PROCEDURES FOR EVALUATION OF GROUND WATER RESOURCE

Whether intentionally designed to be so or not, all applications of natural resource evaluation can be viewed in terms of an analytical process such as that illustrated schematically in Figure 1. (Figure 1 is modified from Sharaf et al. (1986), who applied the concept to exploratory data analysis in analytical chemistry. However, the principles and the basic steps in the process have very general applicability.)

The goal of the generalized analytical process is to learn something specific about the properties or behavior of the system of concern. Given a system, from which are available a collection of objects (called samples) characterized by a set of measurements made on each object, the goal is to find and/or predict a property of the objects that is not directly measurable itself (Sharaf et al., 1986). To give a concrete example for a geohydrologic analysis, testing in a borehole (including completed wells or piezometers) constitutes sampling the hydraulic system. These samples are characterized by direct measurements of hydraulic responses (for example, drawdown as a function of time and distance from a pumping well) and appropriately derived physical properties of the aquifer (e.g., hydraulic conductivity). As necessary, boundary conditions for system performance are measured (e.g., hydraulic head at specific points long a boundary), estimated (e.g., infiltration across the phreatic surface), or inferred (e.g., a major fault considered by the analyst to be a no-flow boundary). From the analysis of the characteristics of the samples, using the boundary conditions and a physical flow model, we wish to assess the aquifer yield of a given confined aquifer (where some criterion for "unacceptable" decline in piezometric level has been predetermined to provide a criterion for aquifer yield).

A wide range of methods exists for assessing natural resources in general (e.g., Singer and Mosier, 1981), including formal and informal, deterministic and probabilistic approaches. It is likely that there are several approaches that would yield satisfactory results with respect to evaluating water resources at a site such as Yucca Mountain, even with particular respect to the issues of potential human intrusion. However, as with many matters, vague questions lead to vague (or otherwise unuseful) answers (Belknap and Steel, 1976), and the first step in determining potentially useful assessment methodologies is to determine how to state the



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THE ANALYTICAL PROCESS

Modified From Sharaf et al., 1986

Figure 1

problem clearly. This requires identifying who will use the product, how it will be used, and what are acceptable forms of the product; in short, the question, as well as the answer, must be formulated relative to a specific knowledge situation (Hempel, 1965; van Fraasen, 1980; Salmon, 1984). For the purpose of this review, we will make the following fundamental assumptions:

- o The end user is the NRC Licensing Staff.
- o The product will be used to assess the likelihood of human intrusion of the geologic repository due to exploration for or exploitation of ground water.
- o The methodology should encompass an analysis of ground water resources that, when fully implemented on the basis of data collected during site characterization, is capable of quantifying the likelihood of human intrusion.

2.1 RESOURCE ASSESSMENT METHODS FOR GROUND WATER - GENERAL APPROACHES

Two gross styles of resource assessment can be defined - extrapolation and analogy. In water resource assessments, it is typical to employ aspects of both. Most hydrologists as well as non-technical persons with practical experience begin any water resource evaluation by identifying aspects of the environment that, based on their previous knowledge and experience, are most likely to lead them to a source of water that will meet their needs. Thus, based on vast common experience, most aquifers will be located in unconsolidated sediments, high-permeability sedimentary rocks (e.g., sandstone; karstic carbonates), or fractured, porous volcanic rocks. Furthermore, in general, ground water will be located closer to ground surface near topographic lows than near topographic highs. That is, one does not, in general, look for ground water in topographically elevated terrain when there is topographically low terrain available for exploration, all else being equal. While there are physical reasons for both these initial "guesses" - permeability and porosity considerations for the former and energetic considerations for the latter - most, if not all aquifer explorations would begin on the basis of analogy, not theoretical analysis.

Having identified one or more hypothetical targets, the exploration would typically move to the collection of data. The nature of the data collection depends on the state of knowledge, technical sophistication, and resources (of time and money) of the explorer. On the one hand, a local water user may simply elect to start drilling, based on an extrapolation of water-bearing potential from neighbors and the identification of a reasonable target on his property.

On the other hand, a resources institution, such as the U.S. Geological Survey or the World Bank, may undertake a very extensive exploration program that includes aspects of both analogy and extrapolation to refine estimates of total resource, long-term use potential, or other matters of large-scale spatial and temporal concern. Such a program, might involve some or all of the following techniques:

- o Surface geological methods, including review of available maps, reports or other data; remote sensing ranging from black and white aerial photography to advanced forms of satellite-based image analysis; and site-specific geologic and hydrogeologic field mapping (e.g., Meinzer, 1932; Ray, 1960; Toth, 1966; Freeze, 1969; Walton, 1970; Bowden and Pruit, 1975; Avery, 1977; Todd, 1980).

- o Subsurface geologic and hydrogeologic methods, including test-drilling and aquifer tests (e.g., Kruseman and de Ritter, 1970; Walton, 1970; Johnson Division, 1972; Todd, 1980).

- o Surface geophysical testing, including seismic, gravimetric, and electro-magnetic methods (e.g., Zohdy et al., 1984).

- o Borehole geophysical testing, including electrical, nuclear, acoustic, and various physical techniques (e.g., Keys and MacCary, 1983).

Overviews of these techniques and additional references can be found in Office of Water Data Coordination (1977) and classic general texts such as Freeze and Cherry (1979), Todd (1980), and Walton (1970).

Such activities typically will draw an analogy between the known presence of ground water in some specific location(s) and the existence of specific geologic features or physical measurements of the property of a system, and then seek to extrapolate that inference to other areas or depths by identifying analogous features or responses in areas where water resources have not yet been developed.

For example, a terrain analysis project using aerial photography might identify ranch wells in terrace deposits along ephemeral streams in an arid environment. The analyst might then proceed to map terrace deposits as potential targets for domestic well exploration across his study area. Similarly, a geophysicist might work with a suite of borehole logging techniques to identify potentially productive water-bearing zones. Based on an analogy between physical (including nuclear and electromagnetic) response of the logging tool(s) and lithologic and hydrologic characteristics of subsurface materials, the geophysicist will identify favorable prospects for ground water. Then, based on these analogies, perhaps supported by extrapolation of geophysical information from controlled, correlated water-producing zones, the geophysicist would identify new locations or depth intervals as targets for additional testing (e.g., piezometer tests; water quality analysis) or even direct exploitation.

Having identified and generally characterized an aquifer, ground water resource evaluations may move on to quantifying the ability to exploit the aquifer, largely through a process of analogy between physical characteristics and instrumental responses. In general, this stage will require the collection of data on the physical extent of the aquifer (e.g., its saturated thickness and lateral extent) at the scale of concern and its hydraulic parameters such as hydraulic conductivity and storage coefficient (or transformed equivalents of these two parameters; see Freeze and Cherry, 1979, Chapter 2). Methods for evaluating hydraulic parameters at scales from laboratory-scale permeability tests to large scale pumping tests are presented in numerous classic papers and reference works and will not be detailed here. Major sources for hydraulic analyses for a wide variety of spatial scales, aquifer geometries, extraction scenarios, and hydrogeologic conditions (e.g., confined, unconfined, and leaky aquifers) include: Kruseman and de Ridder (1970); Walton, (1970); Stallman (1971); Freeze and Cherry (1979); Lohman (1979); Todd (1980).

Finally, impacts of potential water-resource exploitation schemes on aquifers can be predicted using either analytical, numerical or analog methods to evaluate a mathematical model of a ground water system. The initial modeling exercise is, by definition, a matter of analogy: the analyst draws an analogy between his analytical framework (model) and the manner in which the real physical system will respond. As with other ground water evaluation tools, analytical and numerical models may be used in impact assessments fundamentally as an extrapolation technique, using a mathematical analog of the ground water flow system calibrated to one set of spatial and temporal data to predict hydrologic responses at different locations and/or times.

The choice of modeling technique may depend on the level of detail in which predictions are needed, resources of the modeler, or personal preference. With the ready availability of digital computers, numerical simulations of aquifer yield and other hydrologic impacts have rapidly become a standard tool for ground water resource evaluations - particularly for the computationally complex matter of evaluating heterogeneous aquifers with irregular boundaries -, though analytical and physical analog models still have valid uses, particularly in designing, constraining, and bounding detailed numerical simulations.

Overviews of modeling methods can be found in general texts such as Freeze and Cherry (1979), more advanced materials such as Bear (1972), and specialized volumes on modeling such as Prickett (1975), Mercer and Faust (1981) or Wang and Anderson (1982). All of these authors include extensive bibliographies related not only to ground water modeling, but also to the fundamental physical and mathematical assumptions and techniques on which the various modeling approaches are based.

2.2 DISCUSSION WITH RESPECT TO YUCCA MOUNTAIN

There are two significant factors with respect to the pragmatic application of the generalized methods outlined in Section 2.1:

- There are identified water resources near the controlled zone for a potential geologic repository at Yucca Mountain(ABC, 1989a; DOE, 1988). Thus, a de novo water-resource evaluation, such as might be undertaken to assess the potential for undiscovered metallic minerals, is not required or appropriate. Instead, further evaluation should be directed at compiling the economic analysis required by 10 CFR 60.21(c)(13) and then proceeding to the technical evaluation of the likelihood of exploitation leading to adverse effects on repository performance. This second style of evaluation will be dealt with in Section 3 below.

- Because of the required long-term (>10,000 years) performance of the geologic barrier, it is not reasonable to evaluate the human intrusion potential associated with ground water (or any other resource for that matter) solely on the basis of current technology. It is clear that with current technology a water resource can be identified and evaluated - at least with respect to its potential usefulness as an exploitable resource -, as the resource has been identified and water resources in this and many other environments are routinely analyzed for a variety of purposes. Additionally, it can be assumed that if the technology of water-resource evaluations improves at some point in the future, then it would also be possible to find and evaluate ground water at Yucca Mountain. However, a different style of analysis may be needed if one assumes that over the course of 10,000 years, the knowledge of our current water-resource technology is lost. Aspects of the evaluation of water-resource exploitation on repository performance under this final scenario will also be addressed in Section 3 below.

3.0 METHODOLOGY FOR ASSESSING GROUND WATER RESOURCES AS A POTENTIAL SOURCE OF HUMAN INTRUSION

The general technical approach for assessing ground water exploitation as a potential source of adverse impact on the performance of a geologic repository was outlined in Section 1.3 above. For convenience, this "fault-tree" approach is repeated here:

1. Define a conceptual geologic repository system, identifying the hydrologically functional parts of the system.

2. Define one or more undesired states (events) of the system.

3. Identify all credible pathways that can lead to the undesired state.

4. Identify the data necessary to assess the likelihood that each pathway is "complete".

5. Identify the data necessary to quantify the probability of the undesired event.

The following section will develop the basic concepts of this approach and then illustrate the use of this methodology for a site similar to the proposed geologic repository at Yucca Mountain. In general, the source of data used in the examples is the Site Characterization Plan (SCP) for the Yucca Mountain site (DOE, 1988) or documents cited in the SCP. It is emphasized here that the examples, using data for a "real" site, are only that: examples, or exercises of the methodology. The Yucca Mountain site is currently undergoing site characterization in accordance with the Nuclear Waste Policy Act, as amended, and conclusions in this paper are not to be interpreted as pre-decisional judgments on the merits of the Yucca Mountain site for licensing.

3.1 DEFINITION OF A CONCEPTUAL GEOLOGIC SYSTEM

3.1.1 Concepts

The analytical process begins by defining a conceptual model of the geologic repository system as it applies to issues of human intrusion via ground water development. The approach used here defines a conceptual model in a particular fashion:

> A conceptual model identifies the minimum features of the real system of concern that are needed to qualitatively determine the relevant behavior of the system.

Specific aspects of this definition require some elaboration:

a. A conceptual model should be a concept, that is an abstraction. This implies that not everything in the model must be precisely known. However, the concept must include the relevant, functional features of the real system. No aspect of the system that is important to determining the relevant system behavior at the desired level of detail should be missing from the model.

b. A conceptual model should be a model. That is, it should be an analog of the real system and it should be capable of simulating the behavior of the real system when its input parameters and conditions are specified.

c. A conceptual model should be use oriented. That is, the model may relate to only one aspect of the real system in order to keep it relevant to the specific problem of interest. This implies that multiple conceptual models of the same geologic repository system may be needed in order to address the qualitative behavior of different aspects of the repository system or to answer different questions about a single aspect.

d. A conceptual model should be minimal. That is, the model should not contain any factors that are unnecessary for the use to which the model is put. In addition, the model should not contain any aspects that can be deduced or reasonably inferred from an analysis using other information provided by the model.

e. A conceptual model is the basis for constructing analog, analytical or numerical models in which numerical values are assigned to model parameters and conditions and quantitative results are obtained.

f. A conceptual model is an hypothesis, capable of being tested, not an established fact. The conceptualization of the system may change as knowledge of site conditions increases, and, if the changes involve functional aspects of the conceptual model, problems may need to be reanalyzed in light of the new conceptualization.

In general, the statement of a conceptual model of the system will have the following:

1. Site to be described (e.g., geographic location; geologic or hydrogeologic units; location of the repository with respect to ground surface, hydrogeologic units, and zone(s) of saturation);

2. Objective of the analysis, identifying processes to be modeled (e.g., drilling; ground water flow);

3. Key assumptions (e.g., Darcy flow; continuous porous medium);

4. Description of the system (which may be, at least in part, pictorial), including some or all of the following:

    a. representative unit framework (combination or separation of hydrostratigraphic layers);
    b. estimates or locations and amounts of recharge and discharge;
    c. ground water flow patterns;
    d. locations of hydrologic stresses and indications of how the system responds to stress;
    e. locations and nature of boundary conditions.

3.1.2 Example - Yucca Mountain Site

The example site is a geologic repository located in unsaturated, fractured volcanic rocks in the interior of a Basin-and-Range upfaulted block. The objective of the modeling is to assess human intrusion due to ground water exploration or exploitation. Events and processes to be modeled include drilling for groundwater within the area of concern and potential migration of radionuclides from the geologic repository to the accessible environment via the drilling itself or subsequent use of boreholes or wells .

Key assumptions include:

1. Motion of all fluids in the system follows the Navier-Stokes equations. In particular, flow of water (i.e., the aqueous phase) can be described by Darcy's law and that flow will occur along streamlines;

2. The geologic barrier responds as a continuous medium to flow,

which may be either through a porous matrix or along fractures, or both.

3. Boreholes or wells located within the controlled zone define the location of the accessible environment at that point.

4. Exploration for ground water typically ceases at the first exploitable unit.

Figure 2, from Montazer and Wilson (1984), shows a conceptual flow regime for the Yucca Mountain site under baseline conditions. This pictorial conceptualization forms the description of the system for the purpose of the examples in this paper. The model has the following functional attributes:

- o There is a geologic repository located in the Topopah Springs welded unit at about 1,000 feet below ground surface.

- o The geologic repository is located in the unsaturated zone. The hydraulic gradient in the unsaturated zone is vertical downwards; if there are localized perched zones, they are expected to have a lateral gradient parallel to dip, that is to the east (i.e., down-dip at Yucca Mountain).

- o The water table is located in the Crater Flat unit and Calico Hills nonwelded unit below the repository and in the Topopah Springs welded unit to the southeast of the repository location. That is, the hydraulic gradient in the saturated zone is to the southeast at the scale of Yucca Mountain itself, and the first aquifer is unconfined.

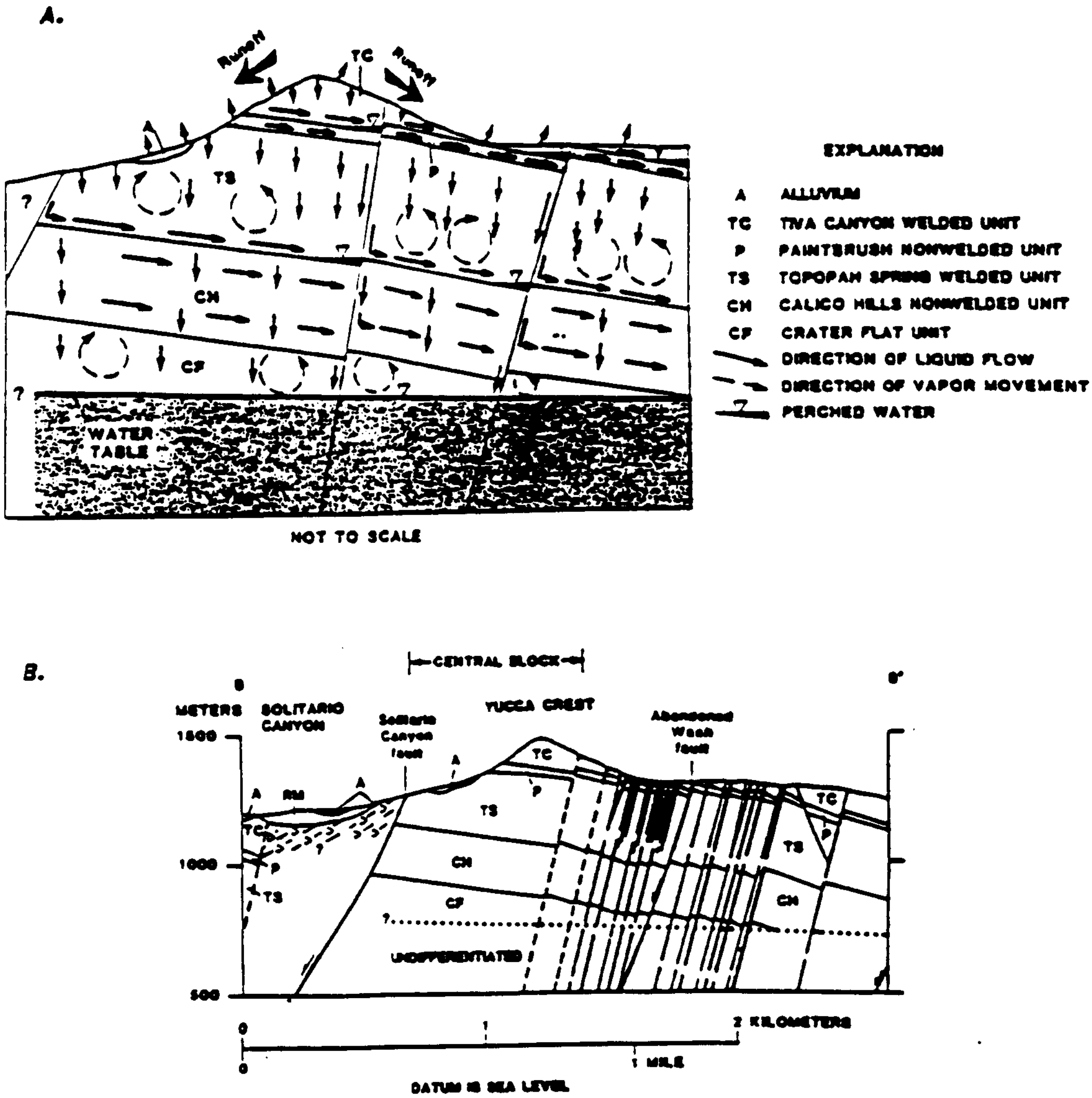

Figure 2

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A. GENERALIZED YUCCA MOUNTAIN FLOW REGIME

B. HYDROGEOLOGIC SECTION ACROSS YUCCA MOUNTAIN

(After Montazer & Wilson, 1984)

3.2 UNDESIRED STATES OF THE SYSTEM WITH RESPECT TO GROUND WATER EXPLOITATION

3.2.1 Concepts

Because the issue to be addressed is adverse impacts on repository performance, two undesired states can be defined:

1. Direct human intrusion into the repository.

2. Changes in the physical system that would accelerate the movement of radionuclides from the repository to the accessible environment.

3.2.2 Discussion

The two undesired states are generic; no discussion of a site-specific examples is needed. However, some discussion of the two states is appropriate.

Direct human intrusion into the repository is defined as an undesired state for the obvious reason that such intrusion defeats the principal purpose of the geologic repository, namely long-term isolation of the waste from the biosphere. More concretely, such intrusion would have the capability of directly or indirectly exposing people to waste materials (e.g., through excavation of contaminated wastes by the drilling apparatus or by allowing vapor-phase contaminants, such as C-14 in carbon dioxide, direct access to the surface) and would certainly short circuit the geologic barrier with respect to potential flow paths from the repository to the accessible environment.

Indirect effects on repository performance due to changes in the functional definition of a site (i.e., the location of the accessible environment) and/or physical flow and transport rates and processes are also conceptually possible. Indeed, some of these matters are dealt with among the "potentially adverse conditions" listed in 10 CFR 60.122(c). The following sections will discuss conceptual and analytical approaches to passive and active versions of indirect effects and provide illustrations using data from the Yucca Mountain site.

3.3 PATHWAYS TO UNDESIRED STATES

For the defined undesired states, there are only a limited number of credible pathways associated with ground water. These are identified and discussed below. Information needed to assess the probabilities of events that could lead to these states are presented in Sections 3.4 and 3.5 below.

3.3.1 Concepts

Direct Human Intrusion

Direct human intrusion during exploration for ground water would require that a drill hole or a dug well extend from the ground surface to the repository horizon within the perimeter of the underground facility. For a variety of practical reasons, water exploration and exploitation wells are always essentially vertical.

Indirect, Adverse Effects on Waste Isolation

Three styles of credible adverse-impact pathways associated with ground water exploration or exploitation can be postulated.

1. An open borehole or well exists in the unsaturated zone between the repository and the lateral limit of the accessible environment. Such an open hole would define the location of the accessible environment, per the definitions of 10 CFR 60.2 and 40 CFR Part 191. The adverse technical effect on repository performance due to the existence of the borehole alone is that the length of the flow path from the repository to the accessible environment is shortened from the hypothetical maximum of 5 km. For a geologic repository located in the unsaturated zone, analysis of the pathway would require consideration of vapor-phase transport of radionuclides, as well as of aqueous-phase transport in the saturated zone beneath the repository, as the potential flow paths may differ significantly.

2. An open borehole or well exists to the water table between the repository and the accessible environment. Such an open borehole or well would define the location of the accessible environment, per 10 CFR 60.2. The adverse effect on repository performance due to the existence of the borehole

alone is that the length of the flow path is shortened from the hypothetical maximum of 5 km. Shorter flow paths in the saturated zone imply shorter travel times to and higher radionuclide concentrations (and therefore activities) at the accessible environment, all else being equal. (Shorter flow paths and travel times increase the radionuclide concentrations because there is less radioactive decay and less mass of in-situ substrate on which radionuclide attenuation may occur. Also, dispersion of solutes is considered by most modern analysts to be a function of flow path length, taken either in a distance or a temporal metric (e.g., Gelhar et al., 1979; Schwartz, 1977; and a very voluminous literature during the entire 1980's). Thus, shorter flow paths suggest that there will be less dispersion and therefore less dilution of radionuclides. As discussed in TTI (1986), dispersion does not affect potential for compliance with the EPA cumulative release requirements except under extraordinary and unlikely circumstances, but it could affect a demonstration of compliance with the Individual Protection requirements.)

3. A pumping well completed in the saturated zone is located so that exploitation of the water resource changes the saturated flow system in a manner that decreases the flow time and increases the concentration (and therefore activity) of dissolved radionuclides at the accessible environment. This pathway does not require that the borehole be located at less than 5 kilometers from the controlled area, as it is conceivable for the hydraulic effects of a pumping well to extend across the 5 km limit. (A similar pathway could be defined for an injection well, but this is not considered here, as injection of fluids is incompatible with ground water resource development.)

3.2.2 Discussion

The three types of pathway to undesired states are generic; no discussion of a site-specific examples is needed. However, some discussion of the pathways is appropriate.

A passive borehole completed in the unsaturated zone, Case 1 above, is significant only if there is transport of radionuclides in the unsaturated zone. In theory, there are mechanisms for mass transfer across the potentiometric surface from the saturated to the unsaturated zone. In practice, these are not likely to be quantitatively significant except for species that are present in the vapor phase across the range of temperature, pressure and fugacity of the gas of concern in the flow system (i.e., unless a separate vapor phase exists in the repository or exsolves from solution along a flow path). Assuming containment is adequate to permit radioactive decay of noble gases initially present in the cladding, only C-14 reporting to $CO_{2(v)}$ is likely to qualify for additional analysis with respect to this scenario. While a detailed analysis is beyond the scope of this report, an initial evaluation of potential processes indicates mass transfer of radionuclides from the liquid phase across the potentiometric surface to and through the unsaturated zone is likely to be negligible. Therefore, the passive borehole completed in the unsaturated zone is considered to be a credible pathway only for a repository located in the unsaturated zone.

However, not all transport of radionuclides from an unsaturated zone repository need be via vapor-phase transport. Depending on a variety of source-term, physical, and energetic factors, transport from an unsaturated-zone repository could be (1) entirely along flow paths through the unsaturated zone; (2) along flow paths that are partly in the unsaturated zone and partly in the saturated zone that must exist somewhere below the repository interval; or (3) along separate flow paths in both the unsaturated and the saturated systems. Case 2 above contemplates this approach: the open borehole completed in the saturated zone (or, equivalently, a well that is completed across unsaturated as well as saturated intervals) is capable of intercepting radionuclides along any conceptual flow path, regardless of the phase of the transporting medium. That is, the portion of the open interval above the saturated zone would intercept vapor-phase flow, and the portion of the open interval below the water table would intercept aqueous phase flow (assuming, of course, that the borehole intersects a flow path; see Section 3.5 below).

A pumping well is conceptually different from a passive borehole. A passive boreholes changes the limits of the flow domain for the purpose of analysis but does not affect the physics of ground water flow or radionuclide transport. In contrast, the change in pressure at a pumping well will change the distribution of potential energy (i.e., change the hydraulic gradient of the aqueous phase) in the flow system. For an assumption of Darcy flow and a continuous medium, a change in gradient implies a change in specific discharge (and average linear velocity) along any given streamline. If the hydraulic stress is applied in a direction not parallel to the original streamline, a new streamline (that is, a new direction of flow across a new cross-sectional area) may develop with specific discharge (and average linear velocity) which may be different than those of the unstressed streamline, depending on the magnitude of the stress and the intrinsic physical properties of the fluid and solid phases. Depending on the direction and magnitude of the changes to the energy field, such changes could either increase or decrease the travel time and cumulative release of radionuclides to the accessible environment compared to the baseline (unstressed) case. To reach an undesired state - i.e., accelerated movement from the repository to the accessible environment - the only circumstance of concern is that the pumping well increases the hydraulic gradient between the repository and the accessible environment, as this is the only pumping-induced change that can increase specific discharge.

3.4 DATA NEEDS FOR IDENTIFYING A COMPLETE PATHWAY

3.4.1 Concepts

Evaluation of the water resource scenarios with respect to risk of adverse impact on a geologic repository must begin by evaluating the credibility of the proposed pathways. If a pathway is not logically complete for some reason, then there is no likelihood that its component events or processes could adversely affect repository performance.

Direct Intrusion Pathway

To be considered complete, a direct intrusion pathway requires the following components:

1. A target source of ground water at or below the repository location.

2. A technology capable of excavating or drilling to the target (not the repository) depth.

The data needs associated with these two components include:

1. **Evidence for the existence of an aquifer that suits a particular need at or below the repository location.** Such evidence depends initially on the performance measure(s) selected for the water use, and then on the ability and opportunity to develop the geologic and hydrologic data necessary to quantify a water resource against that performance measure.

For example, the performance measures for a single family well might be a set such as the following:

- Water within 1,000 feet of ground surface. (Rationale: Except in extraordinary situations, domestic wells are typically less than a few hundred feet deep and almost never more than 1,000 feet deep because of cost);

- Water of less than 1,000 mg/l total dissolved solids. (Rationale: While the EPA assumes that treatment is technically feasible up to 10,000 mg/l, single families typically do not have access to water-treatment systems. The EPA Secondary Standard for total dissolved solids is 500 mg/l from public water supplies. Waters above 1,000 mg/l TDS are typically so saline as to be distasteful.)

- A water source capable of continuously yielding 400 gallons per day. (Rationale: Based on a 100 gallon per day per capita rural domestic use in the Western U.S. in 1980 (Solley et al., 1988), 400 gallons per day is a minimum estimate for a family of 4, excluding any need for consumptive use of water for any type of agriculture.)

(**Note**: ABC understands that these illustrative criteria are more restrictive than the criteria provided by the definition of a "significant source of ground water" in 40 CFR 191.15. Less restrictive criteria could also be established, for example, based on a hypothetical high demand/high value assumption, such as for industrial or irrigation use. The assumptions are made solely to provide a concrete set of conditions to illustrate the methodology.)

The specific data needed to address these performance measures would be derived from the sorts of ground water evaluations addressed in Section 2.1 above. Alternative performance measures would increase or decrease the amount of data necessary and the cost of producing it, but would not change the fundamental styles of data necessary to produce evidence for a target.

2. **Evidence for the existence of a suitable excavation technology**. This evidence may be either a demonstration that such technology exists (or is likely to exist during the time frame of concern), or a set of data that can be used to assess the technical feasibility of such drilling or excavation.

Indirect, Adverse-Effects Pathway

The evaluation of the completeness of the two passive, open-borehole pathways requires the same information as the direct intrusion pathway: evidence for a target and evidence for technical feasibility of drilling.

Evaluation of the remote pumping scenario involves evidence for a target and for feasibility of drilling, plus evidence that pumping could have an adverse effect on radionuclide transport. If a person or society is assumed to have the capability of identifying and quantifying a target and of physically reaching the target at depths of up to 1,000 feet, it is also necessary to develop information about the physical relationship of pumpage from the target aquifer to the transport system of the geologic repository. That is, one must establish that there is physical continuity of flow between the repository and the pumping well.

3.4.2 Examples - Yucca Mountain

Direct Intrusion Pathway

The evaluation of the completeness of the direct intrusion pathway can be illustrated for a site such as the Yucca Mountain site and the single-family water supply scenario as follows:

- Against the target component, the pathway is not complete because there is not a target aquifer within 1,000 feet of the ground surface at the location of the repository.

- Against the excavation-feasibility component, several levels of evaluations can be made. To be a complete pathway, there must be a presumption that society possesses drilling technology approximately equivalent (or superior) to our own, as no hand-dug well through solid rock to 1,000 feet is feasible. Thus, the pathway is potentially complete, but only for the assumption of 20th-Century-level drilling technology.

Indirect, Adverse-Effects Pathway

The evaluation of the completeness of the indirect, adverse-effects pathway can be illustrated by considering Figure 2. Imagine that water is identified in a shallow alluvial aquifer in Solitario Canyon, west of the repository. Such a target might be easy to identify, quantify and develop, but it is not in continuity with the ground water flow system that could potentially affect the repository performance. Thus, the set of complete pathways for indirect effects on the Yucca Mountain repository does not include all possible ground water targets that meet a given need, but rather those target aquifers that are in hydraulic communication with the repository or a flow path from the repository to the accessible environment. Specifically, the target aquifers potentially include only the Calico Hills and Crater Flats units within or to the east of the controlled zone and the Topopah Springs unit to the east of the controlled zone. Whether exploitation of these aquifers would be expected actually to affect repository performance requires a probabilistic evaluation of specific hydraulic scenarios, to be discussed further below.

3.5 DATA NEEDS FOR EVALUATING LIKELIHOOD OF ADVERSE HUMAN IMPACTS DUE TO GROUND WATER EXPLOITATION

3.5.1 Concepts

Direct Intrusion Pathway

Assuming that it can be established that there is a credibly complete pathway for direct human intrusion, it is necessary to develop information that can be used to establish the probability of direct intrusion. That is, the formulation for likelihood of human intrusions is a conditional probability of a form such as:

> "What is the probability of human intrusion given drilling?" Schematically, this might be represented by: **P(HI/D)**, where the symbols have their intuitive meaning from the interrogative sentence above.

Conceptually, the conditional formulation requires a means of evaluating the probability of drilling and the probability of drilling intersecting the repository. There is no body of knowledge extant concerning the population distributions germane to this issue, so a classical analysis is not possible. One could take a frankly subjective approach to both issues, depending exclusively on "expert judgment" to assign probabilities. Alternatively, one could use available data on both density of drilling and parameters defining the target to condition the subjective analysis. This approach is preferred by the author, as discussed and illustrated below. (Note that great precision in estimating probabilities using this empirical approach, while arithmetically possible, is neither realistic nor necessary. To maintain a sense of perspective, calculations of probability estimates are truncated at one significant figure in this report. Use of more than one significant figure in estimating such probabilities is considered highly unrealistic by the author, but the methodology would allow the arithmetic to be done to whatever computational standard is chosen by the analyst. In this report, values are given interchangeably in decimal and scientific notation (e.g., .004 = 4 E-3), though scientific notation is used exclusively for values less than .001 to avoid difficulty in reading decimal places.)

Taking a sort of Bayesian approach, one could estimate a prior probability of drilling given knowledge that a water resource exists, based on current probabilities of drilling at another scale in the region, and then compute the conjunctive probability of both drilling and direct intrusion (**P(HI.D)**). Given that only unintentional intrusion is appropriate for an analysis of ground water, drilling for ground water and intersection of the target zone can be considered independent. Therefore, the calculation of the joint probability is just the product of the two independent probabilities. For this problem, the computation devolves to the determining the expected value of number of drill holes in the target area, or the product of the drilling density estimate times the area of the target.

Different estimates of drilling density could be developed based on different assumptions about the size of the area to be considered and on the nature of the water resource to be exploited. Tradeoffs between these (and potentially other factors) may have to be made by the analyst in developing his estimate of prior probability of drilling. For example, the analyst may want to concentrate his data base on a specific radial distance from a site in order to minimize geologic or hydrologic variability of settings, but also to consider only deep wells, for example bedrock wells. If, however, there are no deep wells in the initial area considered, the analyst must decide between assigning a drilling density of 0 or expanding his area of analysis in order to obtain a non-zero estimate. The choices must be left to the analyst, but it might be well as a matter of practice for the analyst to look at (and document) a range of assumptions in order to test the sensitivity of the estimate of potential intrusion to uncertainties in the prior estimate of drilling density.

Indirect, Adverse-Effects Pathways

Passive Pathway (Open Borehole)

The approach to assessing the passive (i.e., open borehole) probabilities begins with the same analysis as the direct intrusion scenario. That is, one identifies a target (which in this case is the entire controlled area; see Section 3.3), establishes some basis for modeling the probability of drilling, and computes an expected value for "number of boreholes" intersecting the target area.

This is a maximum estimate for these scenarios because the existence of a hole does not completely define the logical pathway. In addition, the borehole must intersect a fluid flow path carrying radionuclides. Evaluation of mechanisms for transfer of radionuclides from the repository system to the borehole involve release and transport scenarios such as those developed by Sandia National Laboratories for other NRC performance assessment studies. As such, these other factors are outside the scope of this paper and will not be pursued here; the reader is referred to NUREG/CR-2452 (1982) for discussions of these matters.

However, one can assert that, by definition, the probability of release and transport scenarios providing radionuclides to a controlled-area borehole is less than or equal to 1. In fact, it seems reasonable that for the passive borehole pathway, the probability approaches the ratio of the cross-sectional area of the borehole that is perpendicular to flow to the cross-sectional area of flow along a stream line from the repository to the accessible environment. Lateral and vertical flow paths from the repository to the borehole should be considered for completeness and because the ratios of cross-sectional areas may be substantially different.

Finally, if the drilling of the well is an independent event (i.e., intrusion is inadvertent), then the estimate of probability of both drilling into the target area and intersecting flow is the product of the two separate estimates.

Active Pathway (Pumping Well)

A similar approach can be used for the evaluation of the active borehole (pumping scenario), though it is harder to quantify based on simple bounding calculations. First, one would establish a conceptual model for the interference by assessing how pumping could adversely affect performance. As discussed in Section 3.3

above, the only credible effect is that pumping could increase the hydraulic gradient in the saturated zone along a flow path from the repository to the accessible environment. For this to occur, the pumping well must be completed in a unit that is in hydraulic communication with a portion of the saturated system directly below the repository. Furthermore, the pumping well must also be located downgradient of the repository, because if it were upgradient or even significantly across gradient, pumping would decrease the effective hydraulic gradient along the streamline, and thus lengthen flow times. That is, assuming that the pumping effects are superimposed on a flow field with a distinguishable baseline lateral hydraulic gradient, for pumping to adversely affect performance requires that the well be located in perhaps a 60 compass-degree sector downgradient of the repository. This acts to significantly constrain the target area. (However, note that in a continuous flow system with very little or no lateral hydraulic gradient, such as the flow system in the vicinity of the Reference Repository Location at the erstwhile Hanford Site, the restriction-of-sector approach would not apply, as it is not possible to define "downgradient". In this type of setting, any perturbation in the energy field that is in continuity with the repository location has the potential to affect flow directions and specific discharges and, therefore, radionuclide concentrations and cumulative fluxes.)

Additionally, there is, for any given set of aquifer conditions and pumping assumptions, an effective limit to the radial distance at which pumping at any reasonable rate would cause enough change in hydraulic head to affect the hydraulic gradient. The effect of pumping on hydraulic head in space is mathematically related through the diffusion equation to hydraulic conductivity and specific storage and the rate of change in head at a point in time (e.g., Freeze and Cherry (1979), Equation A2.19, p. 533; the Freeze and Cherry analysis is based on Jacob (1950).). Therefore, hydraulic gradient changes cannot be determined generically or from first principles alone. This calculation has to be done for real, site-specific data on an aquifer and detailed assumptions of pumping.

3.5.2 Examples - Yucca Mountain Site

Direct Intrusion Pathway

To assess the likelihood of direct intrusion, one needs an estimate of the size of the target area and the likelihood of drilling. Based on an underground facility with a lateral area of 1380 acres (DOE, 1988), the target area for direct intrusion at Yucca Mountain is 5.6 square kilometers. To assess the likelihood of drilling in the vicinity of the site, one could begin with available data on total drilling density (in holes per square kilometer) in basins near the proposed site. For example, based on compilations of data in DOE (1988), there are 397 water wells drilled in the Amargosa Desert (Basin 230) plus an additional 17 wells in the portion of the Ash Meadows Basin (Basin 227) within the Nevada Test Site. Based on a total area of 110,000 square kilometers in these two basins, this is a frequency of .004 wells per square kilometer. Thus, if that regional drilling density (which has developed over less than 100 years) is a reasonable first estimate for the target area over the next 10,000 years, one could estimate **P(HI.D)** as:

(.004 wells/sq. km) * 5.6 sq. km = 2.24 E-2 = .02

potential "intrusions" in the target area. Because this estimate is less than, but perhaps not much-less (the mathematical construct, "<<") than 1, this seems to indicate that human intrusion is a reasonably probable event.

However, as discussed above, not all water well drilling in the region is reasonably ascribable to drilling that might occur in the target area. That is, one should preanalyze the drilling data to develop a density that relates more closely to the conceptualization of the actual event to be estimated. For example, of the 414 wells in the total drilling database, only 5 are completed in fractured volcanic rock. Therefore, a more reasonable estimate for drilling density would be 5 E-5 wells per square kilometer, and the estimate of direct intrusions would be:

(5 E-5 wells/sq. km) * 5.6 sq. km = 2.8 E-4 = 3 E-4

potential intrusions in the target area. This is still an overestimate because drilling for water on the height of land is not reasonable when adjacent lowlands are equally or more accessible, as can be seen from reviewing data on the actual locations of water wells with respect to topography in the region. Without formally evaluating the effect of this additional mitigation factor, it is clear that the expected number of water wells that would invade the repository is nearly four orders of magnitude less than 1, which indicates that there is a very low probability of direct human intrusion due to drilling for ground water.

Indirect, Adverse-Effects Pathways

Passive Pathway (Open Borehole)

For the Yucca Mountain site, a repository with a lateral area of 5.6 square kilometers has an effective radius of 1.34 kilometers. Thus the controlled zone has an effective radius of 6.34 kilometers (representing a 5 kilometer buffer around the repository) and an area of 126.3 square kilometers. Using the DOE (1988) data for density of drilling to fractured tuff for water (5 E-5 wells/sq. km), the expected number of boreholes completed in the Topopah Springs inside the controlled area would be:

(5 E-5 wells/sq. km) * 126.3 sq. km = 6.3 E-3 = 6 E-3

potential intrusions into the target area.

In order to illustrate the process of calculating a probability of adverse impact, first, consider lateral flow from a repository that intersects a vertical borehole. The maximum value a cross-sectional area of flow could have (neglecting dispersion because of the streamline concept) is the maximum lateral dimension of a repository emplacement panel times the vertical dimension of that emplacement panel. Based on current design concepts (DOE, 1988), the maximum lateral dimension of an emplacement panel is 980 m, and the median thickness of the lower nonlithophysal zone of the Topopah Springs (the proposed repository emplacement unit) is about 42 m. Thus, the cross-sectional flow area is estimated to be approximately 4.12 E+4 meters squared. Assuming a moderate-diameter water well, with a diameter of about 0.3 m (12 inches), drilled through the 42 m thick emplacement unit, the maximum surface area of the well perpendicular to flow would be one-half the surface area of the borehole across that interval, or about 6.3 square meters. This suggests that the probability of lateral flow from the repository intersecting a single borehole that is <u>assumed to exist</u> is approximated by the ratio of the two areas:

(6.3 sq. m) / (4.12 E+4 sq. m) = 1.53 E-4 = 2 E-4.

If the drilling of the well is independent (i.e., intrusion is inadvertent), then the estimate of probability of both drilling and intersection of lateral flow is the product of the two estimates, or:

$$6 \text{ E-3} * 2 \text{ E-4} = 1.2 \text{ E-6} = 1 \text{ E-6}$$

human intrusions that intersect a lateral streamline from the repository toward the accessible environment in a passive (open) borehole or well.

If the borehole were completed above the repository (i.e., were oriented perpendicular to the total lateral cross section of the repository), the basal area of the borehole would be .07 square m (radius = .15 m), and the maximum cross-sectional area of flow from the repository would be 5.6 E+6 square m (5.6 square kilometers). In this case probability of intersection assuming a borehole would be given by the ratio of the two areas:

$$(.07 \text{ sq. m}) / (5.6 \text{ E+6 sq. m}) = 1.26 \text{ E-8} = 1 \text{ E-8}.$$

The probability that a passive borehole would both exist and serve as a locus for transfer of radionuclides to the accessible environment is

$$6 \text{ E-3} * 1 \text{ E-8} = 6 \text{ E-11},$$

or a vanishingly small likelihood.

Active Pathway (Pumping Well)

As identified in Section 3.1.2 above, the first exploitable bedrock aquifer downgradient of the repository at Yucca Mountain is unconfined. Although the pumping analysis would need to be performed in detail by the analyst, it can be stated that there are very few real-world examples where pumping from a single, small to moderate capacity well (approximately 400 gallons per day for the single-family domestic well considered in this analysis) produces drawdowns in a water-table aquifer of more than a meter at radial distance in excess of one kilometer. To be extremely conservative for the purpose of this example, assume that the radial distance of concern extends for 10 kilometers from the center of the repository. Then, the target area is about 52.4 square kilometers (1/6 of the area of a circle with radius 10 km), and for a drilling density of 5 E-5 tuff wells per square kilometer, the expected number of wells in the target area is 3 E-3. Again, the estimated number of wells potentially affecting the repository performance is much less than 1, indicating that there is little likelihood of ground water pumping adversely affecting the performance of the repository.

4.0 SUMMARY AND CONCLUSIONS

This paper develops and illustrates a methodology for incorporating information on ground water resources into an evaluation of potential for human intrusion. The approach assumes that the user of the methodology will be the NRC Staff and that the methodology must be suitable for licensing assessments. ABC recognizes that alternative approaches may also be suitable for such analyses, and this approach is presented for consideration by the NRC Staff as the basis for one methodology that the Staff would find acceptable by an applicant in performing the ground water resource evaluations.

The EPA Standard (40 CFR Part 191) contemplates a probabilistic approach to assessing long-term repository performance. Therefore, the methodology set out here assumes the need to develop a probabilistic assessment. The approach is based on a Fault-Tree Methodology, such as has been developed and applied in probabilistic assessments of power reactors and other industrial facilities. The assessment methodology has five basic steps:

1. Define a conceptual geologic repository system, identifying the hydrologically functional parts of the system.

2. Define one or more undesired states (or events) of the system.

3. Identify all credible pathways in which the undesired event can occur.

4. Identify the data necessary to assess the likelihood that each pathway is complete.

5. Identify the data necessary to quantify the probability of the undesired event.

The ABC methodology begins by establishing a conceptual model that includes the minimum features of the real geohydrologic system necessary to qualitatively determine the relevant behavior of the system. For the purpose of this evaluation, the relevant behavior includes (1) drilling or excavating into the functional part(s) of the flow and transport system and (2) transport of radionuclides from the repository to the accessible environment.

Undesired events include both direct human intrusion during ground water exploration and indirect human intrusion associated with shortening the flow path or adversely affecting the hydraulic gradient of the saturated flow system.

Credible pathways associated with ground water exploration and exploitation are defined on the basis of (1) an identifiable water resource and (2) the existence of a drilling technology capable of exploiting such a resource.

Finally, the data needed to quantify the likelihood of human intrusion are defined in terms of a conditional probability structure, and the report shows that a Bayesian-style analysis using current data to assess the conjunctive probability of drilling and intrusion can be applied.

The ABC methodology is illustrated with examples and discussion based on a repository environment and design like that of the Yucca Mountain site, Nevada. Note that, because a ground water resource has already been defined for the vicinity of the Yucca Mountain site, there is no need to develop a new methodology for determining a hidden natural resource at this specific potential repository location. Evaluations of the NEPA and those economic aspects of ground water resources required by 10 CFR Part 60 can proceed based on current information. ABC, 1989c addresses projections of regional ground water needs in southern Nevada. In the more generic case, the approaches described in Section 2.0 of this report could be applied to identification and quantification of ground water as a natural resource, and the approaches illustrated in ABC, 1989c could be applied along with the physical resource data to assess likelihood of ground water development at other potential repository sites.

To illustrate the potential application of the methodology, the paper utilizes the following:

- A conceptual geologic model of a repository in fractured, unsaturated volcanic rock in an uplifted Basin-and-Range fault block, drawn from the DOE conceptual model of a geologic repository located at Yucca Mountain.

- Drilling and other hydrogeologic information from the defined ground water basins near Yucca Mountain and selected information on the geology and geohydrology of the Yucca Mountain site. It is recognized that these data, drawn from DOE (1988) are preliminary and that the Yucca Mountain site is currently undergoing site characterization as required by the Nuclear Waste Policy Act, as amended. The specific data are used only to exercise the methodology and provide examples of the style of calculation appropriate to the methodology.

Specific pre-decisional judgments on licenseability of the site are not to be drawn from these examples.

- A test water-exploitation case based on assumptions suitable for a rural, single-family domestic well. As with the use of site-specific data, this assumption is for illustrative purposes only, and the full exercise of the methodology by the licensee or the NRC Staff would require assessment of other exploration and exploitation scenarios.

For the example considered, it is determined that data are available to indicate that at least one pathway is complete and that other pathways are possible under certain assumptions. Design parameters for the Yucca Mountain repository and Part 60 definitions of the controlled zone are used to define potential targets for both direct and indirect intrusion scenarios. Data on completion of water wells in a 110,000 acre area of two designated ground water basins near the site are used to estimate drilling densities. Based on this outline analysis and the data selected for the examples, there is a very low probability that ground water exploration or exploitation under credible assumptions would lead to adverse effects on long-term repository performance for a site like the Yucca Mountain site. For any given set of drilling density assumptions, the maximum probability of impact, based on this methodology, will likely be for the active, indirect (pumping scenario) pathway, because the target area for this scenario (i.e., the area of influence of a pumping well) will often, perhaps always be the greatest of the possible range of target areas.

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APPENDIX B

REPORT TO
CENTER FOR NUCLEAR WASTE
REGULATORY ANALYSES

WATER RESOURCES IN SOUTHERN NEVADA

by

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155 South Madison Street
Suite #302
Denver, Colorado 80209

December 20, 1989
891220BB.NW2

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1.0 INTRODUCTION

1.1 TASK ASSIGNMENT

The Nuclear Regulatory Commission (NRC) Staff has requested support from the Center for Nuclear Waste Regulatory Analyses (Center) in the development of a Staff Technical Position on Natural Resources Assessment Methods. The Center was directed to identify the attributes of acceptable methodologies for the assessment of natural resources of a proposed high-level waster repository site, with particular consideration being given to a site with a geologic setting similar to that of the Yucca Mountain site in the southern Basin and Range physiographic province.

As part of the overall natural resource assessment initiative, the Center has directed Adrian Brown Consultants to prepare three technical reports addressing specific aspects of the assessment of ground water potential. The topics to be addressed and their status are as follows:

- **Ground water classification with respect to the Individual and Ground Water Protection requirements of 40 CFR Part 191**. This report was submitted to the Center on November 9, 1989.

- **Projections of regional ground water needs in southern Nevada**. This is the topic of this technical report.

- **Identification of ground water resource assessment methodologies**. This report was submitted to the Center on December 6, 1989.

This second task entails a review of available information on long-term projections of regional groundwater needs in southern Nevada. The following is a review of water resources in southern Nevada and the current and projected water demands on these resources. The area considered for this report is shown on Figure 1.

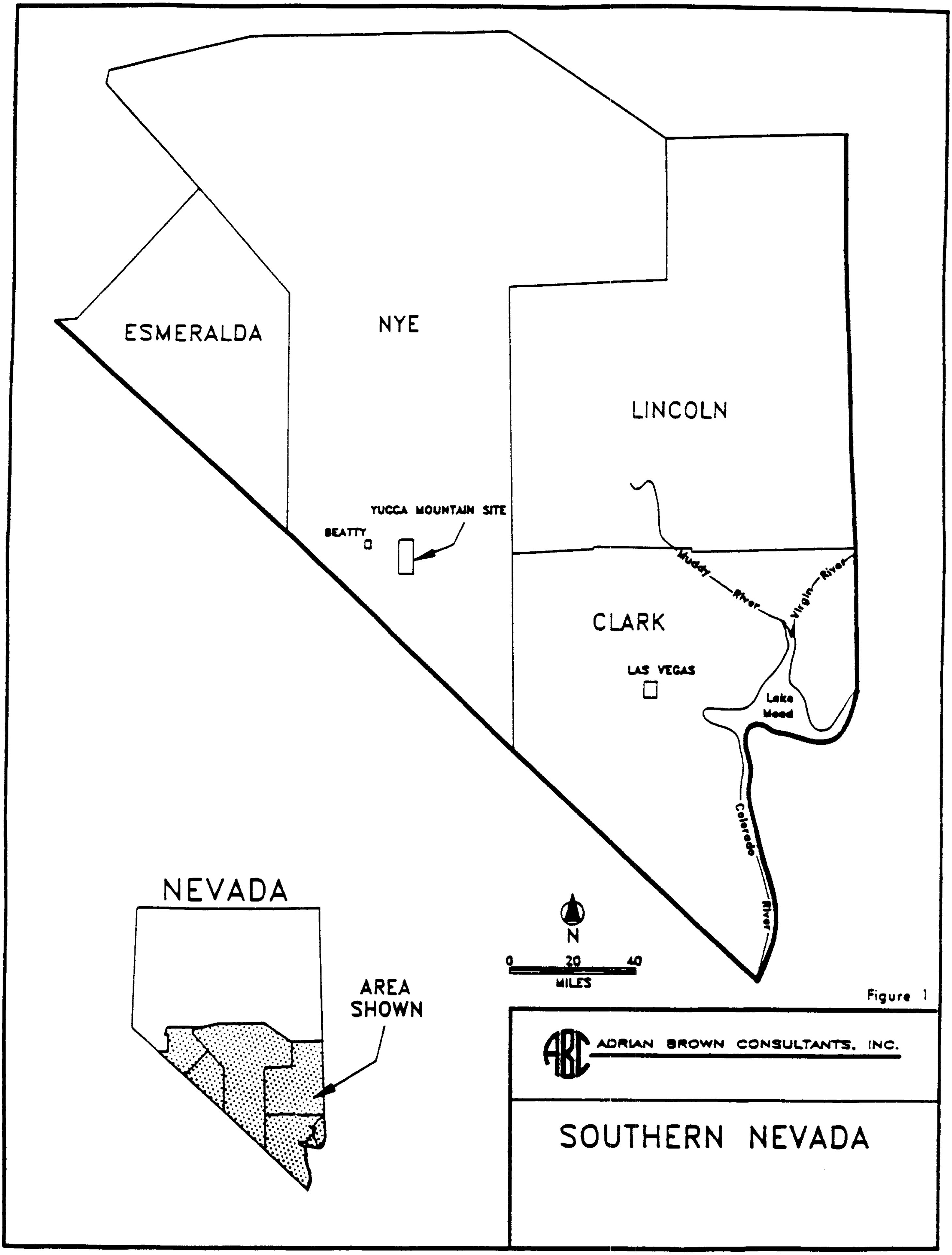

Figure 1

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SOUTHERN NEVADA

1.2 LIMITATIONS ON PROJECTIONS

The state economists' have projected current population growth to the year 2010. For resource and economic planning, a 20-year prediction is felt to be reasonably accurate. Planning beyond a 20-year time frame introduces large uncertainties and is not felt to be necessary for Nevada's economic and resource planning purposes. Predictions made in 1970 for 1990 are rapidly being exceeded due to unanticipated growth in the State, particularly in the Las Vegas metropolitan area. This report looks at the current water resources and uses and water-use projections based on the 20-year predictions.

2.0 RELATIONSHIP TO THE NUCLEAR REGULATORY COMMISSION REGULATIONS

The Nuclear Regulatory Commission (NRC) regulations relevant to this report can be found within 10 CFR Part 60, Subparts B and E. Subpart B pertains to the actual documentation which must be submitted to the NRC for licensing of a high-level nuclear waste repository (HLWR). Subpart E is required in order to establish performance objectives and site and design criteria which will support, if satisfied, the licensing of an HLWR. Portions of these regulations relevant to this report are given below:

> 60.21(c) The Safety Analysis Report shall include: ... (13) an identification and evaluation of the natural resources of the geologic setting ...
>
> 60.122(c) The following conditions are potentially adverse conditions if they are characteristic of the controlled area or may affect isolation within the controlled area.
>
>> (2) Potential for foreseeable human activity to adversely affect the groundwater flow system, such as groundwater withdrawal, extensive irrigation ... or construction of large scale surface water impoundments.
>>
>> (17) The presence of naturally occurring materials ... within the site, in such form that: (i) Economic extraction is currently feasible or potentially feasible during the foreseeable future...

Although the data needs for each regulatory requirement are similar, the objective of each is logically different. Section 60.21(c) is concerned with the potential impacts of the repository on the natural resources whereas for Section 60.122(c), this objective is reversed. Section 60.122(c) is concerned with the potential impacts of development and exploitation of natural resources on the repository performance. This report addresses occurrence of water resources in the state and the potential for exploitation of these resources in the near future.

3.0 WATER RESOURCES AVAILABLE IN SOUTHERN NEVADA

Present water supply sources available in Southern Nevada include groundwater from the several extensive shallow alluvial aquifers, groundwater from generally deep carbonate aquifers, Colorado River water, and limited surface water exclusive of main stem Colorado River water. These sources are discussed below.

3.1 GROUNDWATER RESOURCES

Although Nevada, and particularly southern Nevada, has a dearth of surface streams accessible for water supply, an abundant water supply is available for one time use from groundwater in storage in all of the valleys where it is conceivable a need would exist. The exception to this is the Las Vegas metropolitan area. A study conducted by Montgomery Engineers (State of Nevada, 1971) concluded the only area with a significant water deficiency (present and future) in southern Nevada would be in the Las Vegas Metropolitan area.

The extent to which groundwater in storage is exploited is largely limited by the state's water policy. State policy is usually based on population growth and designated usage. The State Engineer's current policy is based on a "safe yield" concept (e.g. Todd, 1959). This construct limits water rights to the estimated perennial yield. When the perennial yield of a basin is fully appropriated, the basin becomes "designated" by the State Engineer and no new water rights will be issued. Several designated groundwater basins exist in southern Nevada, as shown on Figure 2. For these designated basins, the groundwater withdrawn may still exceed the safe yield if the State Engineer determines exploitation is necessary for the common good. This provides some flexibility within Nevada's current water policy. Alternative water policies are discussed in Section 4.2.2.

Estimates of available groundwater in the southern portions of Clark, Esmeralda, Nye, and Lincoln counties are given in Table 1.[1]

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[1] *Values in Table 1 are approximate and may be in error by as much as thirty percent (State of Nevada, 1982).*

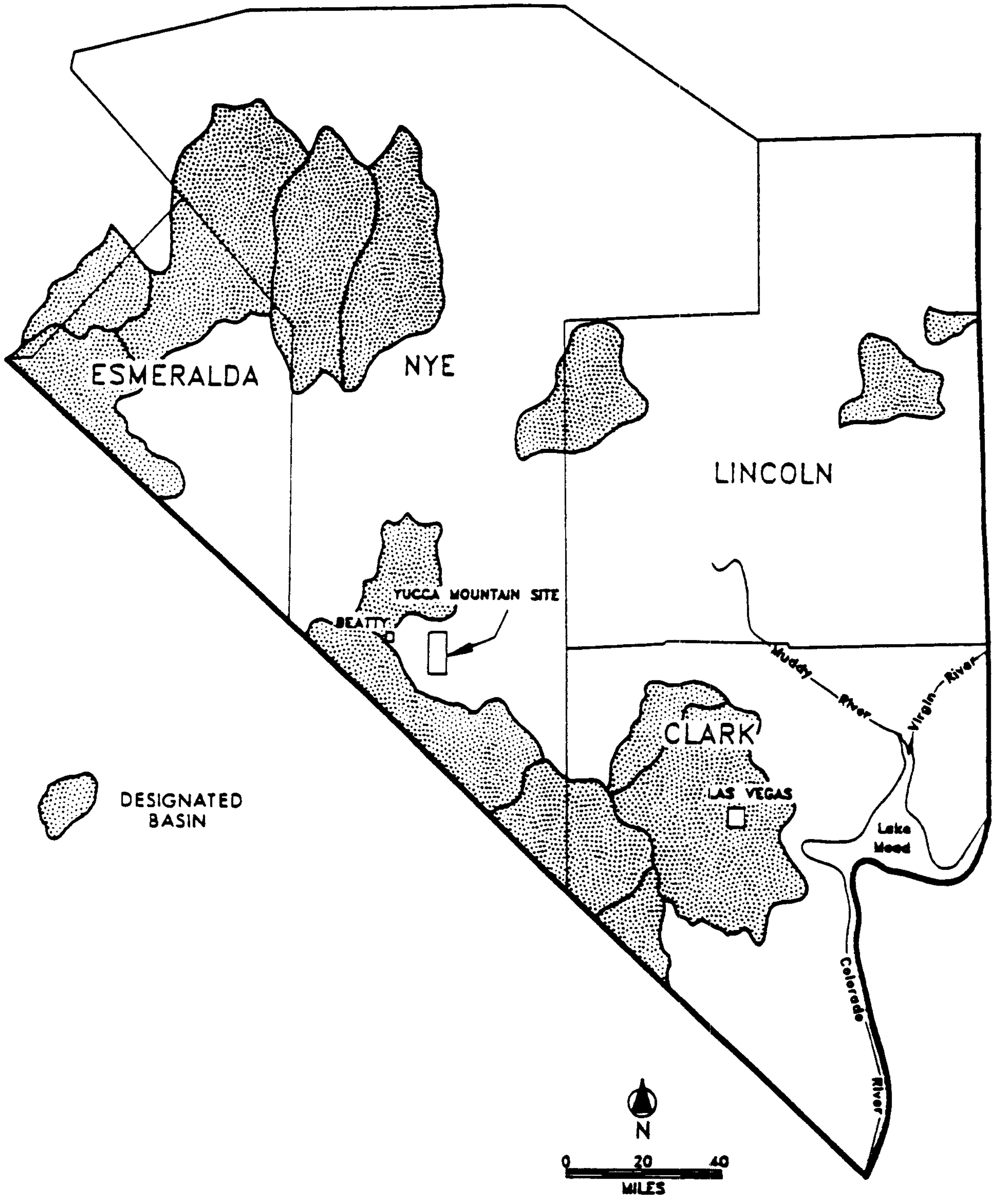

Figure 2

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DESIGNATED GROUNDWATER BASINS IN SOUTHERN NEVADA

Table 1. Groundwater Availability by County

County Name	Perennial Yield (acre-feet/year)	Water in Storage (acre-feet)
Clark	203,625	17,856,350
Esmeralda	67,350	4,225,300
Lincoln	168,050	21,628,350
Nye	214,350	28,741,350
TOTAL	653,375	72,451,350

(State of Nevada, 1982)

Perennial yield estimates are, in general, for the shallowest aquifer (i.e., alluvial aquifer). Storage estimates are defined by the water in storage in the upper 100 feet of saturation. As shown in Figure 3, perennial yield and storage estimates (Table 1) are not available for all hydrographic basins in Esmeralda, Lincoln, and Nye counties. Based on the current safe yield concept, all of the perennial yield is subject to use. The data in Table 1 show that groundwater recharge (perennial yield) is limited. As is also shown in Table 1, a considerable amount of groundwater in storage is easily available, but only for one-time use. Based on today's (1990) southern Nevada population (740,000) and a per capita consumption of 475 gallons per day (State of Nevada, 1971), this amount of water in storage (excluding perennial yield) could sustain the current population until 2200. If we were to assume a per capita usage of 780 gallons per day (Table 2) based on ABC's calculation, water in storage (excluding perennial yield) could only sustain the current population until 2100.

Table 2. Current Water Use by County

County Name	Population (1985)	Per Capita Usage (1985) (gallons/day/person)
Clark	570,000	490
Esmeralda	1,400	26,000
Lincoln	4,200	16,000
Nye	15,000	5,300
	weighted average =	780

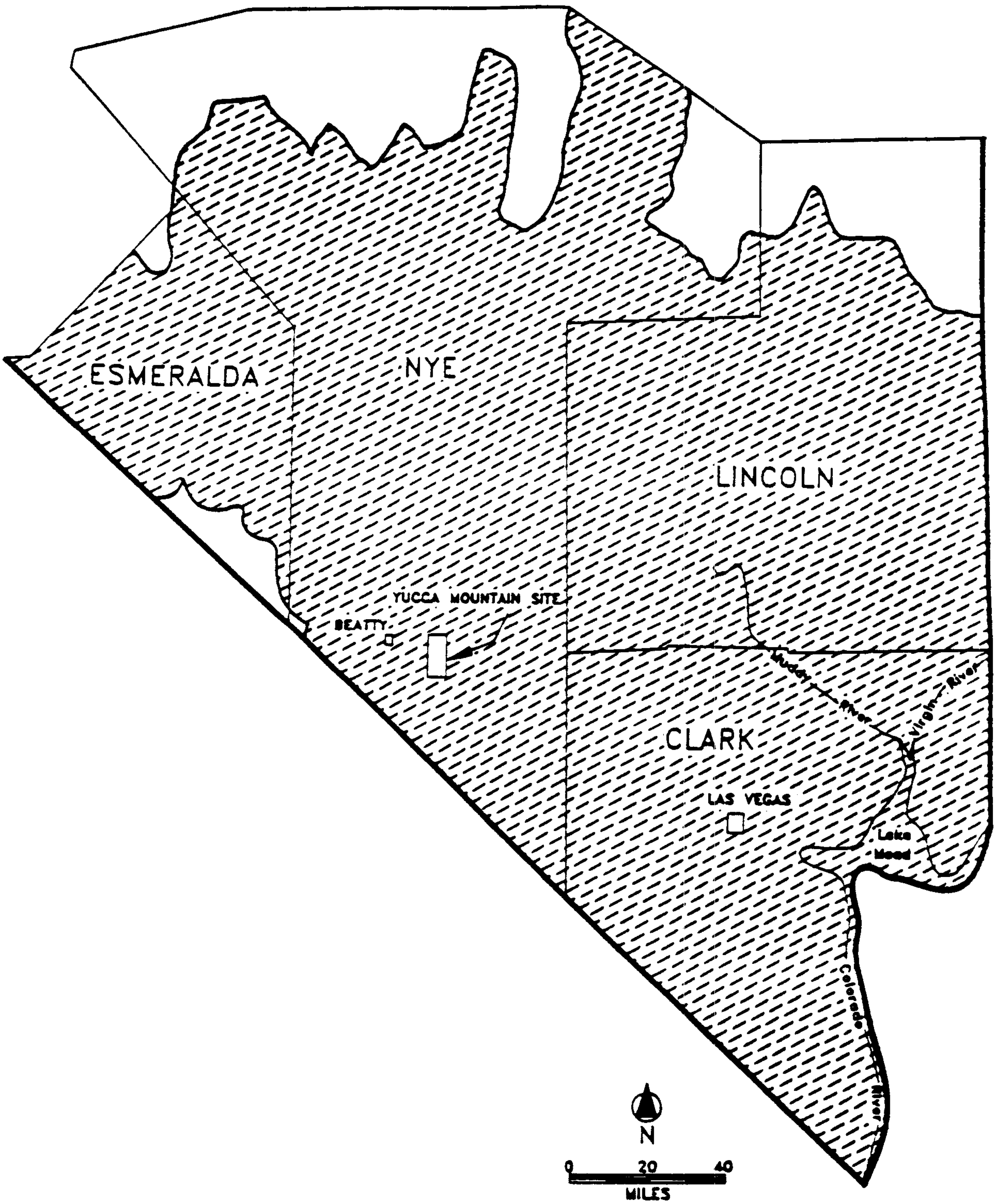

Figure 3

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AREAS INCLUDED IN AVAILABLE GROUNDWATER ESTIMATES (Table 1)

To date, all groundwater developed in the Las Vegas Valley has come from the alluvial aquifers. Carbonate bedrock underlies the saturated valley-fill of many Nevada hydrographic basins. According to Mifflin (1968) and State of Nevada (1982), little is known in many of these basins regarding the quantity, quality and interconnectivity of the deep carbonate aquifers; however, it is believed a considerable amount of water could be mined from these aquifers. In most places, the carbonate aquifers are at great depth (735-4000 feet), but in a few places (e.g., parts of the Nevada Test Site and the localized areas of the Amargosa Desert) these aquifers are relatively shallow and are utilized for water supply (Winograd, 1975). Saturated thickness for these carbonate aquifers is known to range from a few hundred to several thousand feet thick in southern Nevada (Mifflin, 1968). Due to the great depth of the carbonate aquifers in some areas (including the Las Vegas basin), widespread use of water from these deep aquifers is not currently considered economic (State of Nevada, 1982).

3.2 SURFACE WATER RESOURCES

Historically, southern Nevada has depended heavily on the Colorado River for its water supply. Current surface water rights under the Colorado River Compact limit the availability of water from the Colorado River to Nevada at 300,000 acre-feet per year (Wallen, personal communication, 1989). Based on actions of the compact and litigation such as Arizona v. California (e.g., U.S. 546, 1963; 439 U.S. 419, 1979; 460 U.S. 605, 1983)[2] there exists the threat of reallocation of these surface water rights which could potentially reduce Nevada's Colorado River allocation and increase the need for exploitation of the state's groundwater resources.

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[2] *Note that reallocation issues exist not only between the various States, but also between the States and the Indian Tribes on the lower Colorado. For example, Justice Black's 1963 majority opinion awarded five lower basin Tribes (representing only about 3,500 people) more than 10% of the entire annual lower basin share of the Colorado River, or about three times the entire amount granted to Nevada. Note that the new Indian allocations, determined on the basis of the Report of the Special Master, Simon H. Rifkind (Arizona v. California, 54, 265, 1960), are to be subtracted from the States in which the reservations are located, and that these Winters rights are considered senior to all other rights in the lower basin.*

Due to southern Nevada's arid climate, there are very few perennial streams other than the Colorado River. Although the streams are dry nearly all of the year, they may carry a significant volume of water after a heavy thunderstorm. Tables 3 and 4 summarize stream and lake data pertinent to Nevada's southern counties. This compilation indicates only 72 streams and 58 water bodies total in Clark, Esmeralda, Lincoln, and Nye counties. Known spring discharge data, given in Table 5, is assumed to be a part of the data given in Tables 3 and 4. The spring outflow may exceed the stream flow due to the arid climate and rapid evapotranspiration (U.S. Department of Energy, 1988).

Of the five streams listed in Clark County, one is the Colorado River and two are direct tributaries to the Colorado River (Virgin River and Muddy River - Figure 1). The reported stream flow for Clark County is data collected from the two tributaries at their exit points into Lake Mead (State of Nevada, 1982). Upstream from Lake Mead, water from the tributaries contributes to agricultural, domestic and industrial water supply systems.

Table 3. Stream Inventory by County

County Name	No.	Total Length (miles)	Stream Flow (ac-ft/yr)
Clark	5	69.0	92,000
Esmeralda	9	50.3	55,200
Lincoln	11	91.2	NA[3]
Nye	47	281.4	18,400

(Walstrom, 1973)

[3] *NA = data not available*

Table 4. Lake, Reservoir and Pond Inventory by County

County Name	No.	Total Volume (acre-feet)
Clark	7	4,153
Esmeralda	5	32,700[4]
Lincoln	18	33,581
Nye	28	7,012

(Walstrom, 1973)

Table 5. Larger and Better-Known Springs of Southern Nevada

County Name	No.	Spring Flow (ac-ft/yr)
Clark	8+	39,000
Esmeralda	12	2,900
Lincoln	10+	36,000
Nye	31+	64,000

(State of Nevada, 1982)

Of the seven water bodies listed for Clark County in Table 4, one is Lake Mead and another is Lake Mojave. The water volumes reported excluded these lakes since they are part of the Colorado River appropriations. Evidently, excluding the Colorado River resources, surface water is a very limited resource.

Stream flows of 76.2 cubic feet per second (55,200 acre-feet/year) are reported in Esmeralda County. Flows were surveyed in June (when spring runoff is occurring) in the White Mountains; one would expect the stream flow volume to decrease considerably if reported on a per annum basis. Unfortunately, no actual water volumes are recorded for the five water bodies reported in Esmeralda County, but surveys of average depth and surface area allow for an estimate of the water volume on the surface in the county. One might assume that the stream flow would be near a peak during Spring runoff, and that a surface water volume of about 32,700 acre-feet/year would be available for consumptive use.

[4] *Represents water-body capacity, not actual volume*

Lincoln County reports 91.2 miles of streams. Stream flows were not reported, but the State reports spring flows of 36,000 acre-feet/year in Lincoln County (Table 5). The county has several mountain ranges with large topographic relief, two flood control projects, and several reservoirs. If one were to assume three times the water volume reported in the county's lakes, reservoirs, and ponds (33,581 acre-feet/year), flows would run about 100,000 acre-feet/year. A stream flow of as much as 100,000 acre-feet/year may be a bit high, but is not unreasonable.

Nye County is the largest county in southern Nevada with respect to surface area. Several mountain ranges in the northern part of the county account for a number of the streams and miles reported. However, stream flows and lake, reservoir and pond volumes indicate the aridity of the region. The county has claim to numerous springs (Table 5), but much of the spring outflow is lost to evapotranspiration. No stream flows are reported with a greater than 5 cubic feet per second (3600 acre-feet/year) flow, the highest spring discharge recorded is 15 cubic feet per second (11,000 acre-feet/year), and the total water-body volume is quite small. However a large percentage (about 70%) of the water body data did not report volumes. One might assume some part of the total spring and stream flows (say, 50,000 acre-feet per year) is available for consumptive use.

Although there is high uncertainty in the surface water data collected (based on methodology, missing data, etc.), it would be reasonable to assume 200,000 to 250,000 acre-feet per year of surface water exclusive of the Colorado River is available in southern Nevada for water supply. In 1985 only about 120,000 acre-feet per year of this flow was being utilized. Based on a population of 740,000 and an expected water demand of .87 acre-feet per person per year (780 gallons/day, see Table 2), the surface-water resources of the four county area (excluding the Colorado River) are only sufficient for about 130 days.

4.0 CURRENT AND PROJECTED WATER USE

The following estimates of current and projected water use are based on hydrologic data collected by the State Engineer and population estimates and forecasts compiled by the Nevada State Demographer. Figure 4 shows the estimated population trends by county to 2010. As shown, Clark and Nye counties expect considerable growth in the next 20 years and beyond. Lincoln and Esmeralda counties expect some limited growth. As always, large uncertainties are persistent in population forecasts, based on economic policies at both the state and federal levels (e.g. Nevada will continue to urge industry growth, gaming will continue to be legal in Nevada, the national economy will continue to grow, etc.). Predictions of water usage are based on population trends, current land irrigation, and proposed industrial growth.

4.1 CURRENT WATER USAGE BY COUNTY

The most recent available (1985) water usage data are summarized in Figure 5. Data are not given for electric power consumption in counties other than Clark. Water demand for 1985 based on surface and ground water is given in Figure 6. Based on 1985 data, Table 2 gives water use per capita by county. As shown in Table 2, the higher concentration of population (i.e., Clark County) produces a decrease in per capita consumption. The current economic expansion occurring in southern Nevada, specifically Clark and Nye counties, is based on light industrial/commercial development for which less water per capita is necessary. Arid agricultural regions such as Esmeralda and Lincoln counties require high per capita water demand, specifically for irrigation needs.

4.2 PROJECTED WATER DEMAND BY COUNTY

Figure 7 shows projected water usage (surface and groundwater) for Clark, Nye, Esmeralda, and Lincoln counties. The maximum available estimates delineated on Figure 7 are derived from perennial yields and the surface water assumptions discussed in Section 3.2; groundwater resources in storage are not included. As can be seen

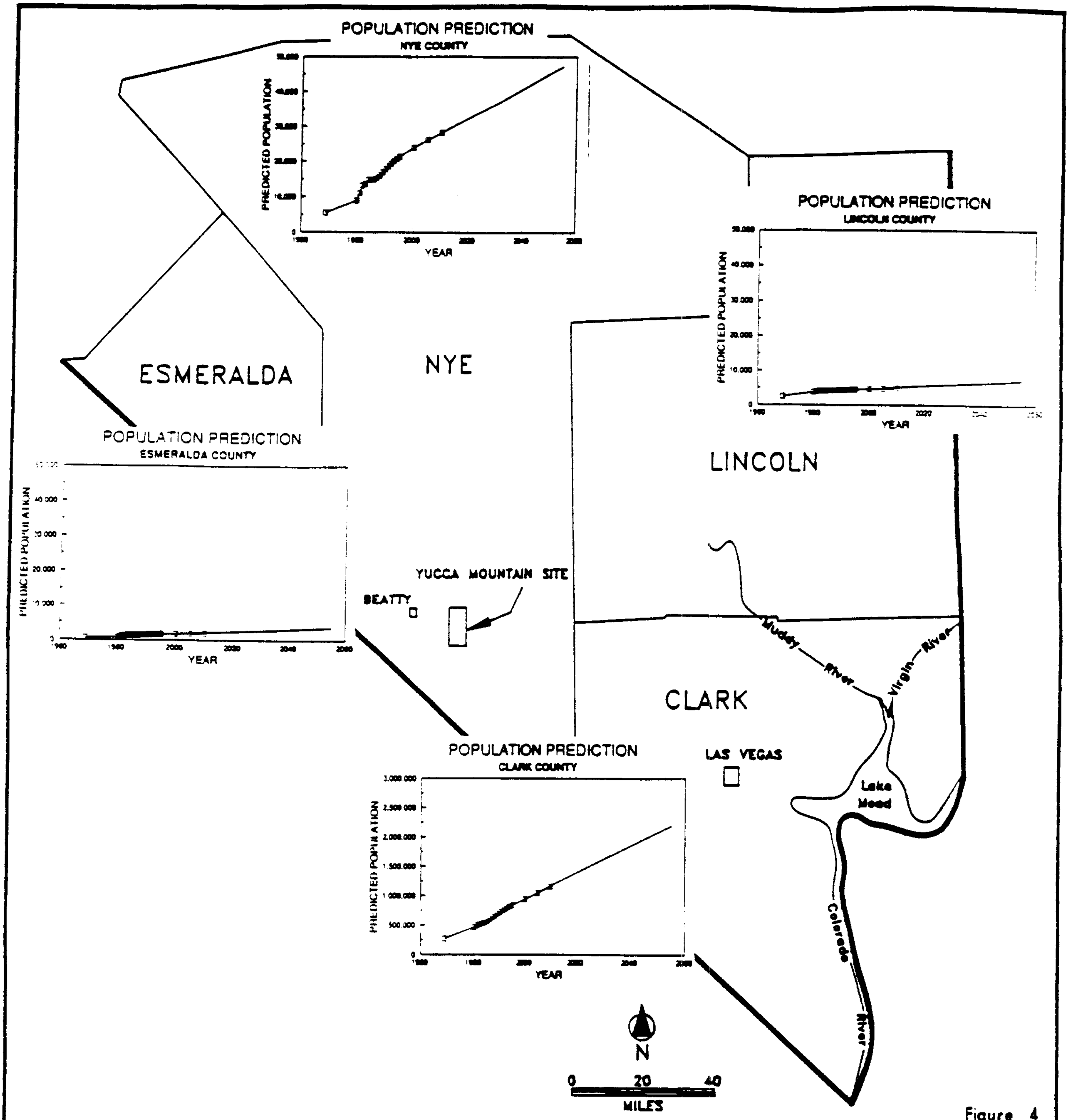

Figure 4

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ESTIMATED POPULATION TRENDS

Figure 5. Water Demands (1985) Based on Use

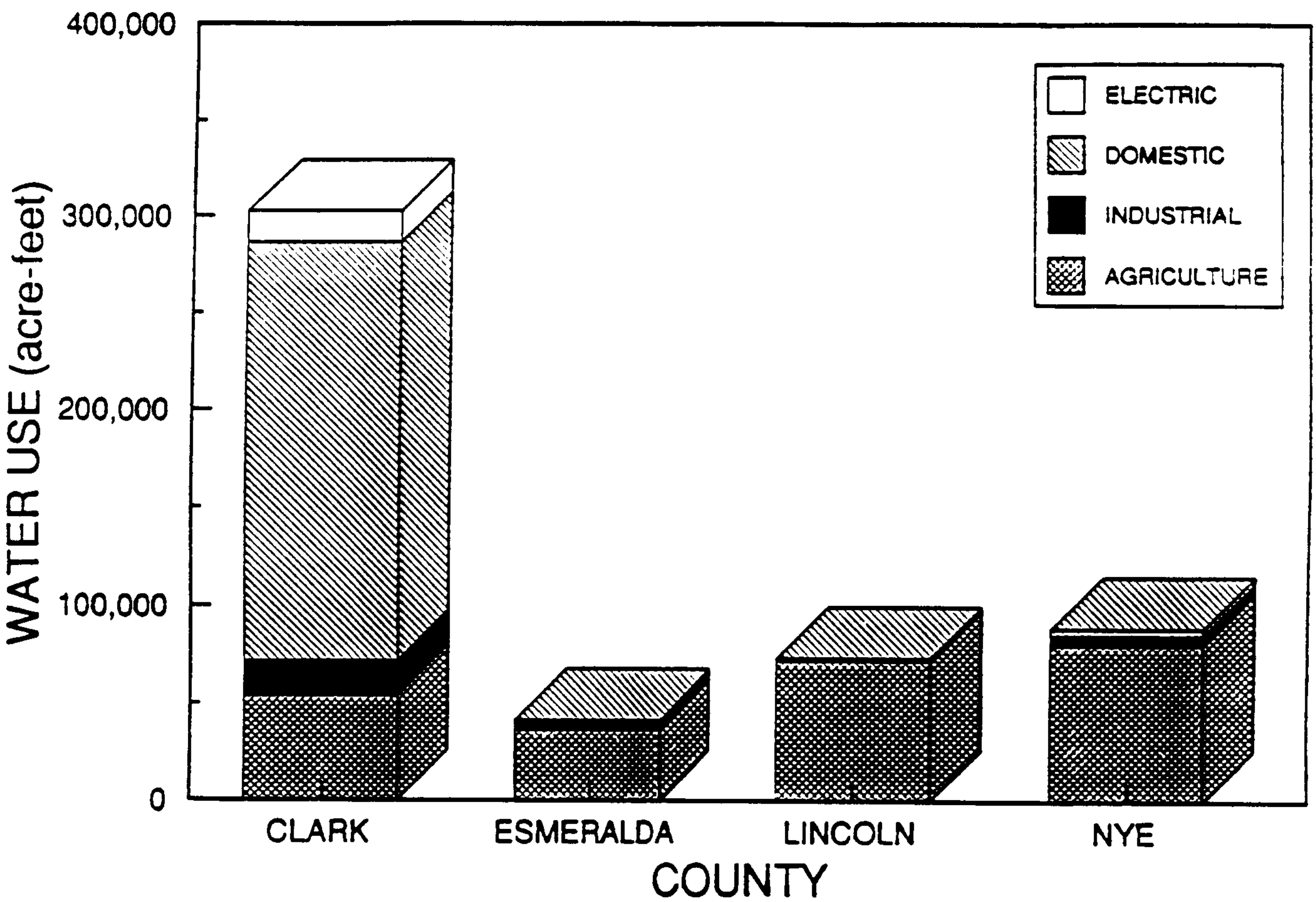
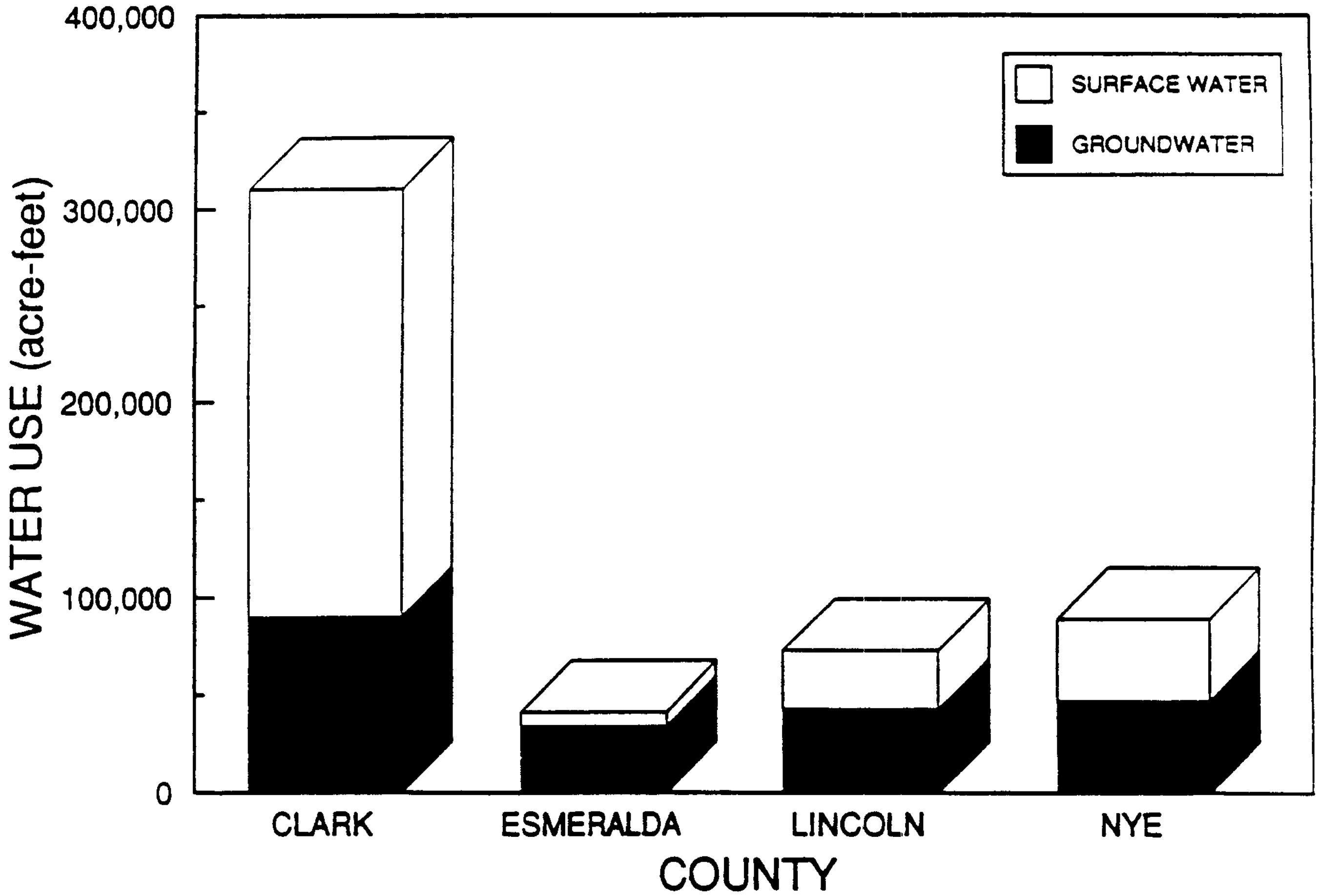


Figure 6. Water Demands (1985) By Source



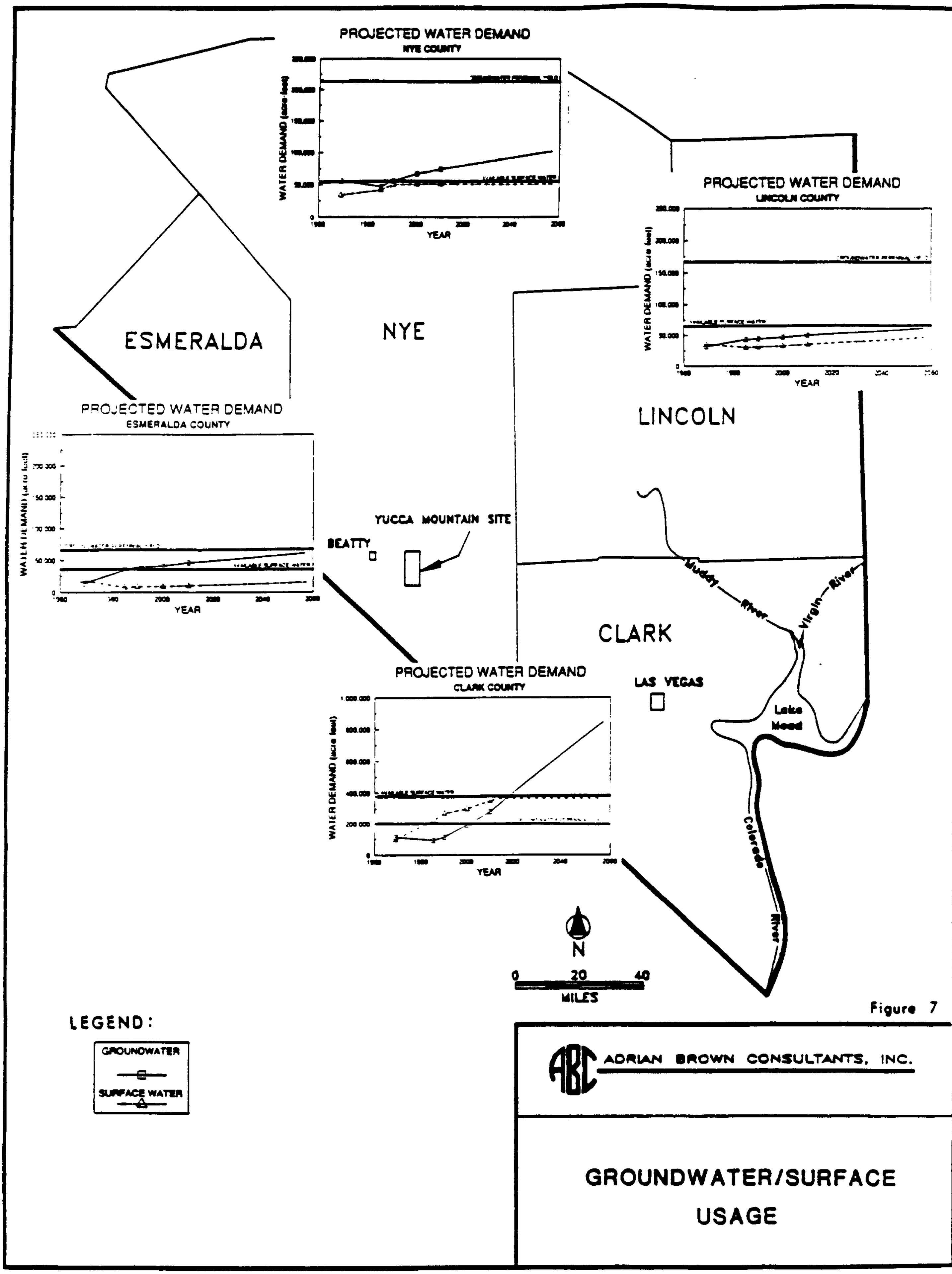


Figure 7

GROUNDWATER/SURFACE USAGE

from this figure, the only area anticipating significant water deficiencies in the future is Clark County. A breakdown of projected usage by county is given in Tables 6-9 and Figure 8. Based on expected growth of industrial/commercial ventures in Clark and Nye counties and the minimal economic growth occurring in agriculture nationwide, irrigation needs are assumed to remain essentially constant in Clark and Nye counties. However, based on the limited population growth in Lincoln and Esmeralda counties, it was assumed for projection estimates that agricultural expansion will continue in these counties. Domestic, industrial, and electric power water supply projections are directly dependent on the overall population growth of the region.

Table 6. Clark County Projections

YEAR	1969[5]	1985[6]	1990[7]	2000[7]	2010[7]
POPULATION	270,000	570,000	720,000	940,000	1,200,000
AGRICULTURE					
Wells	10,000	14,000	18,000	23,000	29,000
Streams & Springs	53,000	40,000	51,000	51,000	66,000
DOMESTIC					
Wells	82,000	55,000	69,000	120,000	200,000
Streams & Springs	19,000	160,000	200,000	230,000	260,000
COMMERCIAL, MINING AND INDUSTRIAL					
Wells	14,000	8,400	11,000	26,000	31,000
Streams & Springs	20,000	8,900	11,000	11,000	15,000
ELECTRIC POWER					
Wells	1,500	8,400	11,000	17,000	22,000
Streams & Springs	3,700	8,000	10,000	10,000	13,000
TOTAL WITHDRAWAL					
Wells	110,000	90,000	110,000	190,000	280,000
Streams & Springs	96,000	220,000	270,000	300,000	350,000

[5] *Data from State of Nevada, 1971a.*

[6] *Data compiled by USGS, 1989 (unpublished, on file at ABC office and Nevada State Engineer's office)*

[7] *Projection by ABC, this report.*

Table 7. Esmeralda County Projections

YEAR	1969[5]	1985[6]	1990[7]	2000[7]	2010[7]
POPULATION	600	1,400	1,600	1,700	1,900
AGRICULTURE					
Wells	6,000	29,000	33,000	35,000	39,000
Streams & Springs	18,000	7,300	8,300	8,900	10,000
DOMESTIC					
Wells	80	240	240	240	240
Streams & Springs	25				
COMMERCIAL, MINING AND INDUSTRIAL					
Wells	7,000	4,800	5,500	5,800	6,500
Streams & Springs	40	56	64	68	76
ELECTRIC POWER					
Wells					
Streams & Springs	400				
TOTAL WITHDRAWAL					
Wells	13,000	34,000	39,000	41,000	46,000
Streams & Springs	18,000	7,400	8,400	8,900	10,000

Table 8. Lincoln County Projections

YEAR	1969[5]	1985[6]	1990[7]	2000[7]	2010[7]
POPULATION	2,500	4,200	4,300	4,600	4,900
AGRICULTURE					
Wells	30,000	42,000	43,000	46,000	49,000
Streams & Springs	35,000	30,000	31,000	33,000	35,000
DOMESTIC					
Wells	680	1,000	1,000	1,100	1,200
Streams & Springs	170	22	23	24	26
COMMERCIAL, MINING AND INDUSTRIAL					
Wells	1,000	240	240	240	240
Streams & Springs					
ELECTRIC POWER					
Wells					
Streams & Springs					
TOTAL WITHDRAWAL					
Wells	32,000	43,000	44,000	47,000	50,000
Streams & Springs	35,000	30,000	31,000	33,000	35,000

Table 9. Nye County Projections

YEAR	1969[5]	1985[6]	1990[7]	2000[7]	2010[7]
POPULATION	5,500	15,000	18,000	24,000	28,000
AGRICULTURE					
Wells	52,000	40,000	48,000	48,000	48,000
Streams & Springs	34,000	40,000	48,000	48,000	48,000
DOMESTIC					
Wells	970	3,400	4,100	5,400	6,300
Streams & Springs	320	90	110	140	170
COMMERCIAL, MINING AND INDUSTRIAL					
Wells	3,400	3,200	3,800	14,000	20,000
Streams & Springs		1,900	2,300	2,500	3,000
ELECTRIC POWER					
Wells					
Streams & Springs					
TOTAL WITHDRAWAL					
Wells	56,000	47,000	56,000	67,000	74,000
Streams & Springs	34,000	42,000	50,000	51,000	51,000

4.3 PROPOSED ALTERNATIVES TO WATER SUPPLY SHORTAGES

4.3.1 Alternatives for Clark County Water Supply

The fastest growing counties in the state are Douglas, Clark, and Nye (in that order). Of the two southern counties, Clark County is the only county which anticipates a significant water supply deficit. If Clark County opts for water supply in other hydrographic basins, potential impacts (i.e. contamination or depletion) from development of an alternative water supply to the proposed high-level waste repository area must be considered.

At present, the Las Vegas metropolitan area has a net population gain of 3,000 - 4,000 people a month (Wallen, personal communication, 1989); the county population is expected to reach a million people by 2005. This influx puts a great deal of strain on their already overtaxed water resources. The water purveyor of the metropolitan area (Las Vegas Valley Water District (LVVWD)) anticipates utilization of the full Colorado River allocation (300,000 acre-feet per year) by about 1993. As noted in Section

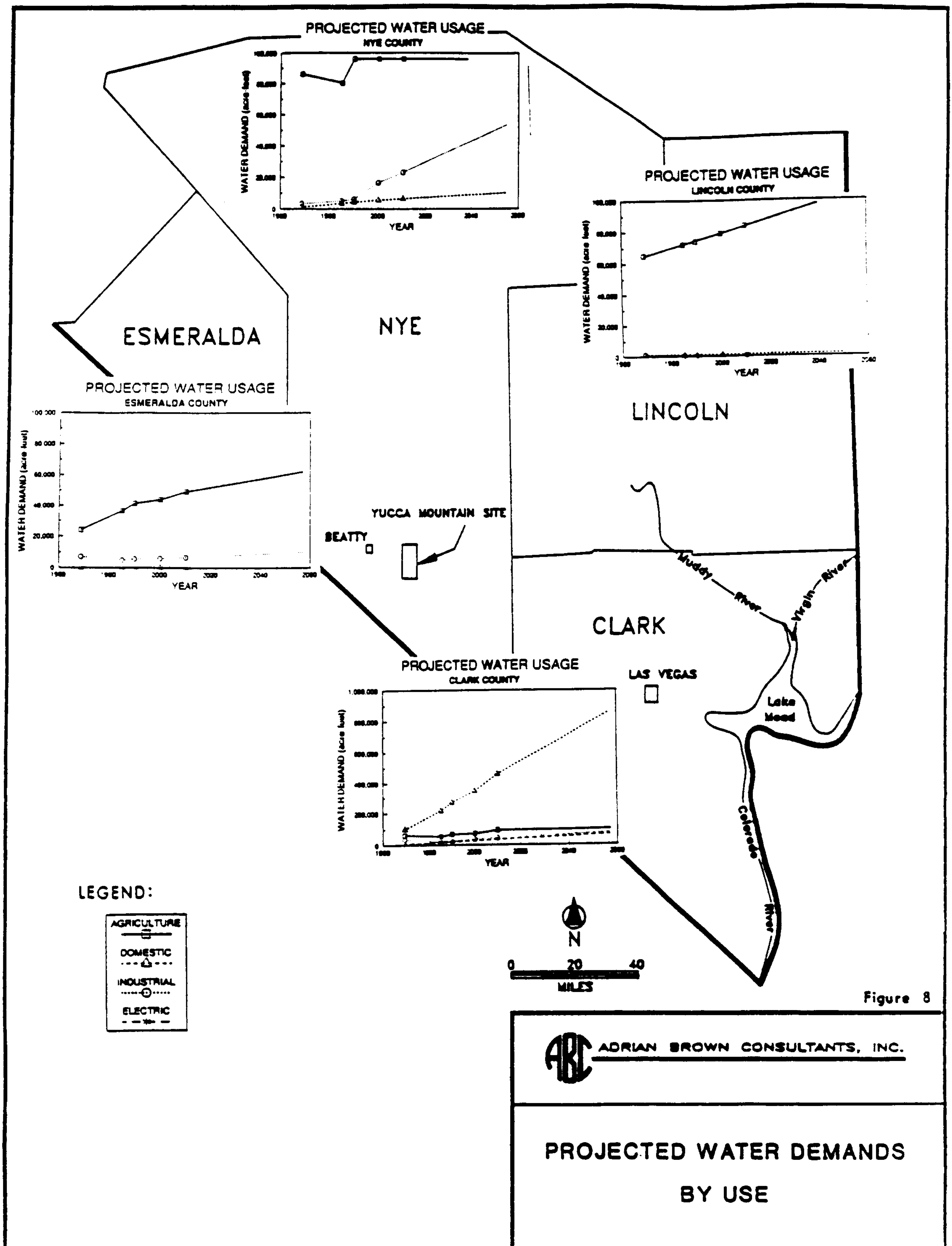


Figure 8

PROJECTED WATER DEMANDS BY USE

3.2, there are few other surface water resources available in Clark County. Hence, the future target is going to be retrieval of groundwater from various sources. Considering just the water supply from the local alluvial aquifers, the long-term water supply outlook from Las Vegas Valley alluvium realistically is about 50,000 acre-feet per year (30,000 recharge + 20,000 return flow to the shallow aquifer). As shown in Figure 7, more water will be necessary to supply the predicted demands.

Groundwater in the Las Vegas area has suffered from an overdraft since about 1960; problems including subsidence around Las Vegas have forced LVVWD to consider mitigating alternatives to mining groundwater in the highly populated areas (State of Nevada, 1982). LVVWD is also concerned with supplying enough water to meet the area's anticipated growth. To alleviate the overwithdrawal of groundwater in the Las Vegas Valley Basin, permit applications have recently been submitted to the State Engineer for approximately 500,000 acre-feet of groundwater to be drawn from valleys north of Las Vegas (Wallen, personal communication, 1989). Other alternatives which have been considered include importation of groundwater from other adjacent valleys, interstate water importation, exploration for and development of a deep carbonate aquifer below the valley-fill in Las Vegas Valley, and water banking of natural recharge or Colorado River water by storage in the principal aquifers.

Of these alternatives, the only alternative which could have a direct impact concerning the proposed HLWR would be that of mining groundwater from valleys adjacent to the HLWR site. Of the valleys studied, four valleys had the potential for supplying the needs of Las Vegas for about 35 years (State of Nevada, 1982). Amargosa Desert Valley, Pahrump Valley, Railroad Valley, and Pahranagat Valley are shown on Figure 9. According to State of Nevada (1982), the water was considered of acceptable quality except for the high fluoride concentration in the Amargosa Desert (which would require treatment). The quantities available from pumping an alternative primary valley fill aquifer (to include all the water in the upper 100 feet of saturated valley-fill) would supply Clark County over a 26 to 50 year span with slightly more than 100,000 acre-feet of water per year. Table 10 summarizes water availability in these valleys.

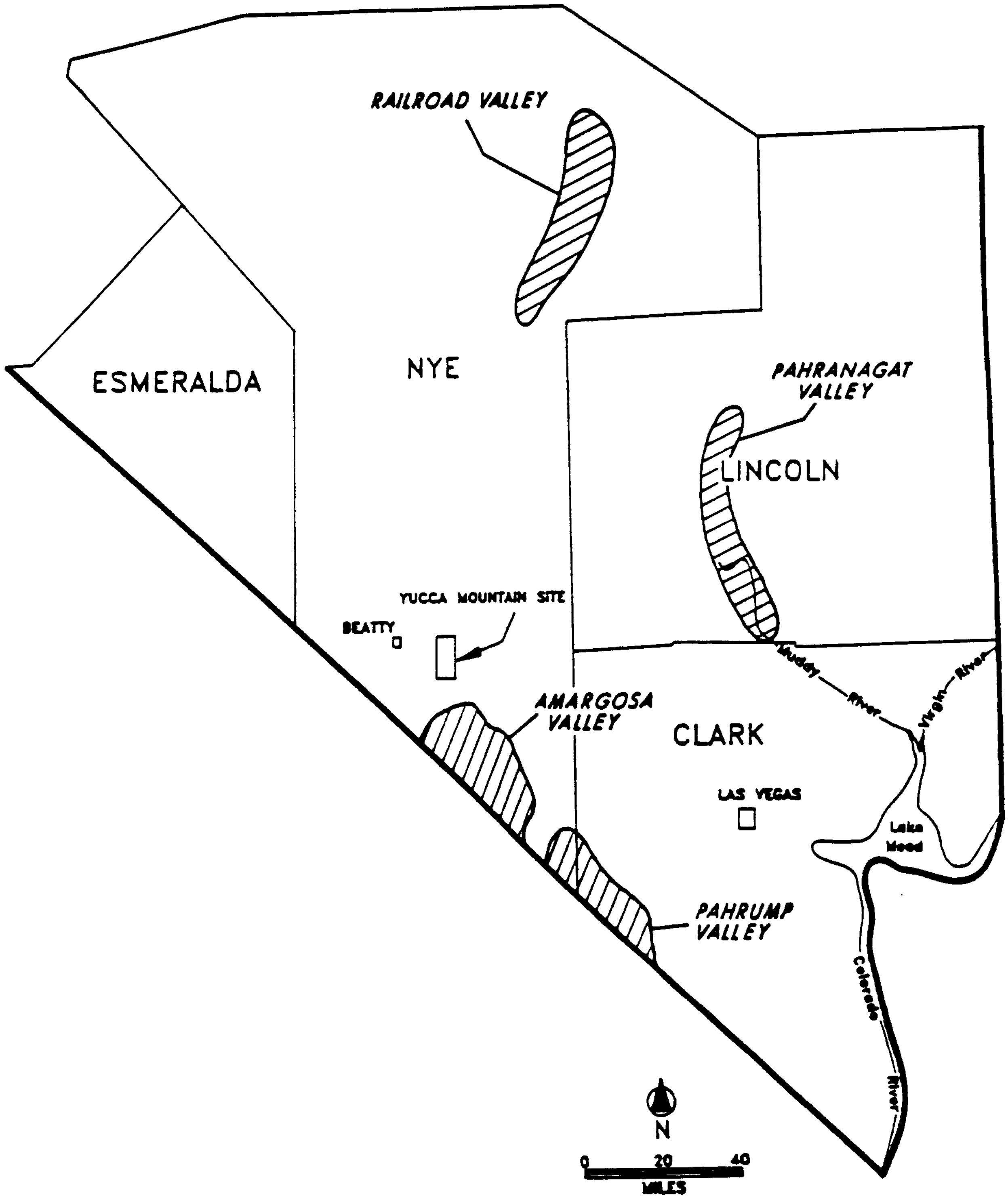


Figure 9

ADRIAN BROWN CONSULTANTS, INC.

CLARK COUNTY
ALTERNATIVE SUPPLY
SOURCES

Table 10. Available Water in Selected Valleys

Area of Import	Years	AF/Year	Water in Storage Upper 100 feet (Acre-feet)
Pahrump Valley	33	127,500	4,200,000
Amargosa Desert	27	110,000	2,970,000
Railroad Valley	50	156,000	7,800,000
Pahranagat Valley	26	110,000	2,870,000

Table 11 summarizes estimated project costs for development of the alternative water supply sources (State of Nevada, 1982). These costs are corrected to 1990 dollars (Appendix A) using a five percent inflation rate since 1980 and an interest rate over the expected useful project life of nine percent. Typical 1982 water costs for public supply users in southern Nevada was about $50/acre-ft (State of Nevada, 1982). The State's assessment in 1971 was that the needs of Las Vegas Valley could justify expenditures of up to $230/acre-ft (1970 prices). If we were to assume a five percent inflation rate on the 1970 price, a cost of $610/acre-ft would be justifiable today. The importation costs given in Table 11 are about twice as much as today's justifiable investment. Nevada's present water supply and economic system does not merit intrastate importation of water.

Table 11. Importation Costs for Selected Valleys*

Area of Import	Project Life (yrs)	Ann. Capital Cost (millions)	Ann. Oper. Cost (millions)	Unit Cost of Water $/ac-ft
Pahrump Valley	33	$ 90.0	$26.7	$ 915
Amargosa Desert	27	$116.4	$26.4	$1,298
Railroad Valley	50	$171.1	$23.2	$1,246
Pahranagat Valley	26	$ 98.1	$12.2	$1,003

* All costs are based on 1990 prices.

Aside from the high costs, further constraints on use of the water from these valleys exist due to the Protected Wetlands and the Endangered Species Act which lists fish sanctuaries in Pahranagat Valley, Railroad Valley and in Ash Meadows (Amargosa Desert).

Exploitation could dry up many of the habitat springs and surface waters.

4.3.2 Alternative Water Policy

The present Nevada policy is based on the safe yield concept, as discussed in Section 3.1. The water supply limitations discussed above (i.e. designating basins, limiting groundwater mining, etc.) are also based on this concept. If Nevada were to adopt an alternative policy, the water supply estimates for Las Vegas Valley (and other designated valleys) and the limitations predicted on the valley's water supply would change.

An alternative policy might be that of "optimal yield". An optimal yield policy is based on the premise that groundwater has value only by virtue of its use. Optimal yield must then be determined by selection of the best groundwater management program based on social and/or economic objectives (e.g., Domenico, 1972). In the case of arid lands such as southern Nevada, this could lead to more active mining of groundwater in storage - in some cases, even to complete depletion of water reserves in some basins.

Another alternative water policy might involve methods of better conservation. A water conservation program would promote a wiser use of Nevada's limited natural resource by reducing predicted potable water demands, investing in better wastewater management practices, and saving energy and, hence money, in requiring less pumping and heating costs. In the extreme, this policy would limit both water supply needs and economic growth. Extreme allocation of usage (e.g., no land irrigation permitted) and increased commodity costs (i.e., due to increased water costs) could slow the projected population and economic growth. Under a conservation policy, the previous water supply predictions and limitations would change drastically, potentially allowing the current water supply to last well into the next century.

5.0 SUMMARY AND CONCLUSIONS

Although careful water-use planning is imperative as a matter of policy for the arid climate of southern Nevada, review of the water resources available support the claim that, under current conditions, water shortages are not expected except in the highly populated Las Vegas Valley area. Abundant one-time water supply is available from groundwater in storage (i.e., usually in alluvium) and also perhaps in the deep carbonate aquifers, however, present economic conditions and current water policy do not merit development of these water resources.

Water supply alternatives for Clark County which could be directly related to the proposed high-level waste repository (HLWR) in Nye County are discussed in Section 4.3 of this report. Under certain extreme assumptions, development of water supply sources in the vicinity of Yucca Mountain could change the groundwater flow system, which could affect long-term waste isolation of the HLWR.

As discussed in Section 2.0, the natural-resource evaluations of Part 60 are concerned with two issues: (1) impacts which may affect compliance with NEPA (i.e., effects from the HLWR on the natural (or human) environment) and (2) impacts of human activities which may influence compliance with the performance standards of 10 CFR Part 60 (i.e., effects on the HLWR by natural resource exploitation). Both of these issues are of concern when considering groundwater exploitation and the resulting impacts from or on the proposed repository. Will the groundwater be safe for its intended use, based on HLWR impacts, and will exploitation of groundwater change the performance of a HLWR? A policy of extreme conservation would lead to no expected impacts (e.g., depletion of water resources, changes in groundwater flow system) and little growth in the State. The present safe-yield policy will limit growth and would lead to a small probability of adversely affecting the HLWR. Extreme exploitation of groundwater in the region would have the greatest potential for impact from the HLWR, although the HLWR design is such that groundwater contamination should be unlikely, based on the concepts of 10 CFR Part 60.

Possible impacts on performance of the HLWR could occur if the saturated zone within the controlled area contained a high concentration of radionuclides from the repository and if extensive pumping outside the controlled area caused a change in lateral hydraulic gradient which could expedite contaminant transport and provide a pathway (human consumption) that would endanger human health and safety. The probability of this occurring in the vicinity of Yucca Mountain is discussed in the third report of this series - A Methodology for Assessing Ground Water Resources as a Potential Source of Human Intrusion (1989). Based on current water policy, water supply, predicted water demands, and the proposed HLWR design, there is a very small likelihood of impact to performance of a HLWR at Yucca Mountain. Projected water supply needs and economic necessity are not anticipated to be so extreme as to instill the need to exploit all groundwater resources in southern Nevada to such a degree as to effect the general groundwater flow system in the vicinity of Yucca Mountain.

The projections given in this report face all the same uncertainties involved in any resource and economic planning. At present, Nevada economists have projected population growth to the year 2010 with probably reasonable accuracy. Predictions with respect to water planning past the 20-year span are regarded with a higher degree of uncertainty. However, population growth will eventually be controlled by water (and other natural-resource) supply constraints, as has been known since at least the time of Thomas Malthus (1798). Thus, population will not continue to increase at current rates for any extended period of time, as even at $900-$1,300 per acre-foot (Table 11), the exploitation of the four valleys is capable of producing only 100,000-150,000 acre-feet/year for only about 140 years. This is only a 35% increment on current water resources, which increment would be exhausted (and its potential hydrologic impact on the HLWR maximized) well within the containment period of 300-1,000 years (10 CFR Part 60.113(a)). In short, even if groundwater mining of the western valleys were considered economically feasible, its impact (if any, see ABC, 1989)) on the HLWR system is not expected to persist significantly into the repository lifetime.

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APPENDIX A
SAMPLE CALCULATIONS FOR 1990 COST ESTIMATES

The following is a set of sample calculations used to convert the State's 1980 project cost estimates (State of Nevada, 1982) for Clark County alternative water supply sources to current 1990 costs as was discussed in Section 4.3 of this report. A five percent inflation rate and an interest rate of nine percent is assumed.

Given that Pahrump Valley was estimated to have a useful project life of 33 years, an average water delivery of 127,500 acre-feet per year, an initial capital cost of $578,175,000 (1980 dollars), and an annual operating cost of $16,384,000 (1980 dollars), conversion to today's costs are as follows.

Convert initial capital cost and annual operating cost estimates to 1990 prices:

$$IC_{90} = IC_{80}\ (1+i)^{n}$$

and $$AOC_{90} = AOC_{80}\ (1+i)^{n}$$

where:
- IC_{90} = initial capital cost in 1990 dollars
- IC_{80} = initial capital cost in 1980 dollars
- i = annual rate of inflation (0.05)
- n = years difference between 1990 and 1980 (10)
- AOC_{90} = annual operating cost in 1990 dollars
- AOC_{80} = initial capital cost in 1980 dollars

$$IC_{90} = \$578,175,000\ (1+0.05)^{10} = \$942 \text{ million}$$

and $$AOC_{90} = \$16,384,000\ (1+0.05)^{10} = \$26.7 \text{ million}$$

The initial capital cost is amortized over the estimated project life (e.g., 33 years) by the following calculation:

$$ACC = IC_{90}\ (t(1+t)^{PL})/((1+t)^{PL} - 1)$$

where: ACC = annual capital cost
PL = project life (33 years)
t = annual interest rate (0.09)

$$ACC = \$942 \text{ million } ((0.09)(1+0.09)^{33})/((1+0.09)^{33} - 1)$$
$$= \$90.0 \text{ million}$$

Finally, the unit cost for water is calculated using the total estimated annual project cost (annual capital cost + annual operating cost) divided by the estimated water transported per year.

$$\text{Unit Cost} = (ACC + AOC_{90})/\text{yearly water transported}$$

$$\text{Unit Cost} = \frac{(\$90.0 \text{ million} + \$26.7 \text{ million})}{127{,}500 \text{ acre-feet per year}}$$

Unit Cost of Water = \$915/acre-ft

APPENDIX C

GROUND WATER CLASSIFICATION: "SIGNIFICANT" AND "SPECIAL" SOURCES AND THE INDIVIDUAL AND GROUND WATER PROTECTION REQUIREMENTS OF 40 CFR PART 191 AT YUCCA MOUNTAIN

FINAL REPORT
CNWRA Task Activity 3702-002-305-602

By

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May 30, 1990

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1.0 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) has requested that the Center for Nuclear Waste Regulatory Analyses (Center) review existing data concerning the Yucca Mountain site to develop a classification of the aquifer system(s) based on the definitions of 40 CFR Part 191, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes". Specifically, the Center has been directed to evaluate whether "Significant Sources of Groundwater" (40 CFR 191.15) and/or "Special Sources of Groundwater" (40 CFR 191.16) exist at or near the Yucca Mountain site.

In preparing this report, the Center has relied on the text of 40 CFR Part 191 as it was promulgated as a Final Rule on September 19, 1985 (50 FR 38066). The Final Rule has been remanded to the U. S. Environmental Protection Agency (EPA) by the 1st Circuit Court of Appeals to remedy certain procedural flaws with the individual and groundwater protection requirements. It is possible that when the Rule is repromulgated, there will be a new indexing scheme for sections of the Rule. However, for the purposes of this report, the reader is directed to the September, 1985 version for citations.

The Center recognizes that this groundwater classification report may require significant changes, depending on the nature and magnitude of revisions to the Rule which are now being considered by the EPA. In particular, the conclusions of this report may need to be changed if EPA alters significantly the definitions of significant and special sources of groundwater.

2.0 BACKGROUND

Pursuant to its authorities and responsibilities under the Atomic Energy Act of 1954, as amended, Reorganization Plan No. 3 of 1970, and the Nuclear Waste Policy Act of 1982, the EPA promulgated generally applicable environmental standards for the management and disposal of spent nuclear fuel and high-level and transuranic radioactive wastes in 1985 (40 CFR Part 191; 50 FR 38066, September 19, 1985). In the Final Rule, EPA added two sections - Individual Protection Requirements (40 CFR 191.15) and Ground Water Protection Requirements (40 CFR 191.16) - that had not been included in the Draft Rule. The purpose of the two new sections was "to provide protection for those individuals in the vicinity of a disposal system" (50 FR at 38072) and "to avoid any significant degradation of the important drinking water resources provided by these Class I ground waters" (50 FR at 38074).

The NRC regulation, 10 CFR Part 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories", requires that the geologic repository be sited and designed to comply with the generally applicable environmental standards (10 CFR 60.112). Thus, the geologic setting for a licensable repository must meet the individual protection and ground water protection requirements of 40 CFR Part 191.

2.1 Individual Protection Requirements

Section 191.15 states:

Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the repository shall not cause the annual dose equivalent to any member of the public in the accessible environment to exceed 25 millirems to the whole body or 75 millirems to any critical organ. All potential pathways (associated with undisturbed performance) from the disposal system to people shall be considered, including the assumption that individuals consume 2 liters per day of drinking water from any significant source of ground water outside the controlled area. (Emphasis added)

The critical portion of the requirement for this analysis has been emphasized, as its evaluation requires consideration of two definitions presented in 40 CFR 191.12:

(g) "Controlled area" means: (1) a surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system; and (2) the subsurface underlying such a location.

(n) "Significant source of ground water", as used in this Part, means (1) an aquifer that: (i) is saturated with water having less than 10,000 milligrams per liter of total dissolved solids; (ii) is within 2,500 feet of the land surface; (iii) has a transmissivity greater than 200 gallons per day per foot, provided that any formation or part of a formation included within the source of ground water has a hydraulic conductivity greater than 2 gallons per day per square foot; and (iv) is capable of continuously yielding at least 10,000 gallons per day to a pumped or flowing well for a period of at least a year; or (2) an aquifer that provides the primary source of water for a community water system as of the effective date of this Subpart.

2.2 Ground Water Protection Requirements

Section 191.16 states:

(a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not cause the radionuclide concentrations averaged over any year in water drawn from any portion of a special source of ground water to exceed:

(1) 5 picocuries per liter of radium-226 and radium-228;

(2) 15 picocuries per liter of alpha-emitting radionuclides (including radium-226 and radium-228 but excluding radon; or

(3) The combined concentrations of radionuclides that emit either beta or gamma radiation that would produce an annual dose equivalent to the total body or any internal organ greater than 4 millirems per year if an individual consumed 2 liters per day of drinking water from such a source of ground water.

(b) If any of the average annual radionuclide concentrations existing in a special source of ground water before construction of the disposal system already exceed the limits in 191.16(a), the disposal system shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not increase the existing average annual radionuclide concentration in water withdrawn from that special source of ground water by more than the limits established in 191.16(a). (Emphasis added)

The critical portion of the requirement for this analysis has been emphasized, as its evaluation requires consideration of another definition presented in 40 CFR 191.12:

(o) "Special source of ground water", as used in this Part, means those Class I ground waters identified in accordance with the Agency's Ground-Water Protection Strategy published in August 1984 that: (1) are within the controlled area encompassing a disposal system or are less than five kilometers beyond the controlled area; (2) are supplying drinking water for thousands of persons as of the date that the Department chooses a location within that area for detailed characterization as a potential site for a disposal system (e.g,in accordance with Section 112(b)(1)(B) of the NWPA); and (3) are irreplaceable in that no reasonable alternative source of drinking water is available to that population.

3.0 ANALYSIS

The individual and ground water protection requirements are very narrowly drawn with respect to the types of water that qualify for coverage. This is best seen through a logical analysis of the two key definitions. The analysis that follows uses the notation and definitions due to Copi (1986, especially chapters 8 and 9; see also Quine, 1982, especially Part I):

" . " : Conjunction

" V " : Disjunction

" ≡ " : Logical Equivalence

In addition, parentheses have their common algebraic meaning.

A definition that applies certain conditions can be viewed as a conditional statement under logical equivalence. For example, the definition

"Controlled area" means: (1) a surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the outer boundary of the original location of the radioactive Wastes in a disposal system; and (2) the subsurface underlying such a location. (40 CFR 191.12(g))

can be rewritten as:

"There is an area called the "Controlled area" if and only if there is a surface location (and the subsurface underlying such a location), to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the outer boundary of the original location of the radioactive Wastes in a disposal system."

When written in this form, which is the "standard form" for a statement of logical equivalence, the nature of the relationship between antecedent(s) and consequent can be seen clearly, even though the antecedent follows the consequent in the English sentence structure. Because logical equivalence is commutative, the order of antecedent and consequent may be adjusted to suit the convenience of the problem (or speaker).

Finally, conjunction, disjunction and logical equivalence are truth-functional statements, and the symbols " . ", " V ", and " = " are truth-functional connectives.

3.1 Logical Structure of "Significant Source of Ground Water"

Let **SgSGW** = "**Significant source of ground water**, as used in this Part"

TDS = "an aquifer that: (i) is saturated with water having less than 10,000 milligrams per liter of **total dissolved solids**"

Depth = "an aquifer that: (ii) is **within 2,500 feet of the land surface**"

T/K = "an aquifer that: (iii) has a **transmissivity** greater than 200 gallons per day per foot, provided that any formation or part of a formation included within the source of ground water has a **hydraulic conductivity** greater than 2 gallons per day per square foot"

Yield = "an aquifer that: (iv) is capable of continuously **yielding at least 10,000 gallons per day** to a pumped or flowing well for a period of at least a year"

CWS = "an aquifer that provides the primary source of water for a **community water system** as of the effective date of this Subpart"

Then the definition can be rewritten in standard form as:

(**TDS** . **Depth** . **T/K** . **Yield**) V (**CWS**) = (**SgSGW**)

Using the standard truth functions applied to material implication, if (**SgSGW**) is true (i.e., there exists a significant source of ground water), then either the multiple conjunction of part (1) of the definition is true or the premise "the aquifer is the primary source of ground water for a community water supply outside the controlled area" is true.

To evaluate the case with respect to the Yucca Mountain site, consider data for the saturated portion of the Topopah Springs member of the Paintbrush Tuff at Well J-13, which lies outside the controlled area (Figure 1), using data from Thordarson (1983).

First, the Topopah Springs unit does not provide the primary source of water to a community water supply as of September, 1985, nor is it expected to provide water to a community water supply by whatever date the Final Rule is repromulgated. Thus, part (2) of the definition is not true.

Second, for the multiple conjunction of part (1) of the definition to be true, all four components of the conjunction must be true. These are examined below:

- The water has a TDS significantly less than 10,000 mg/l. Component **TDS** is true.

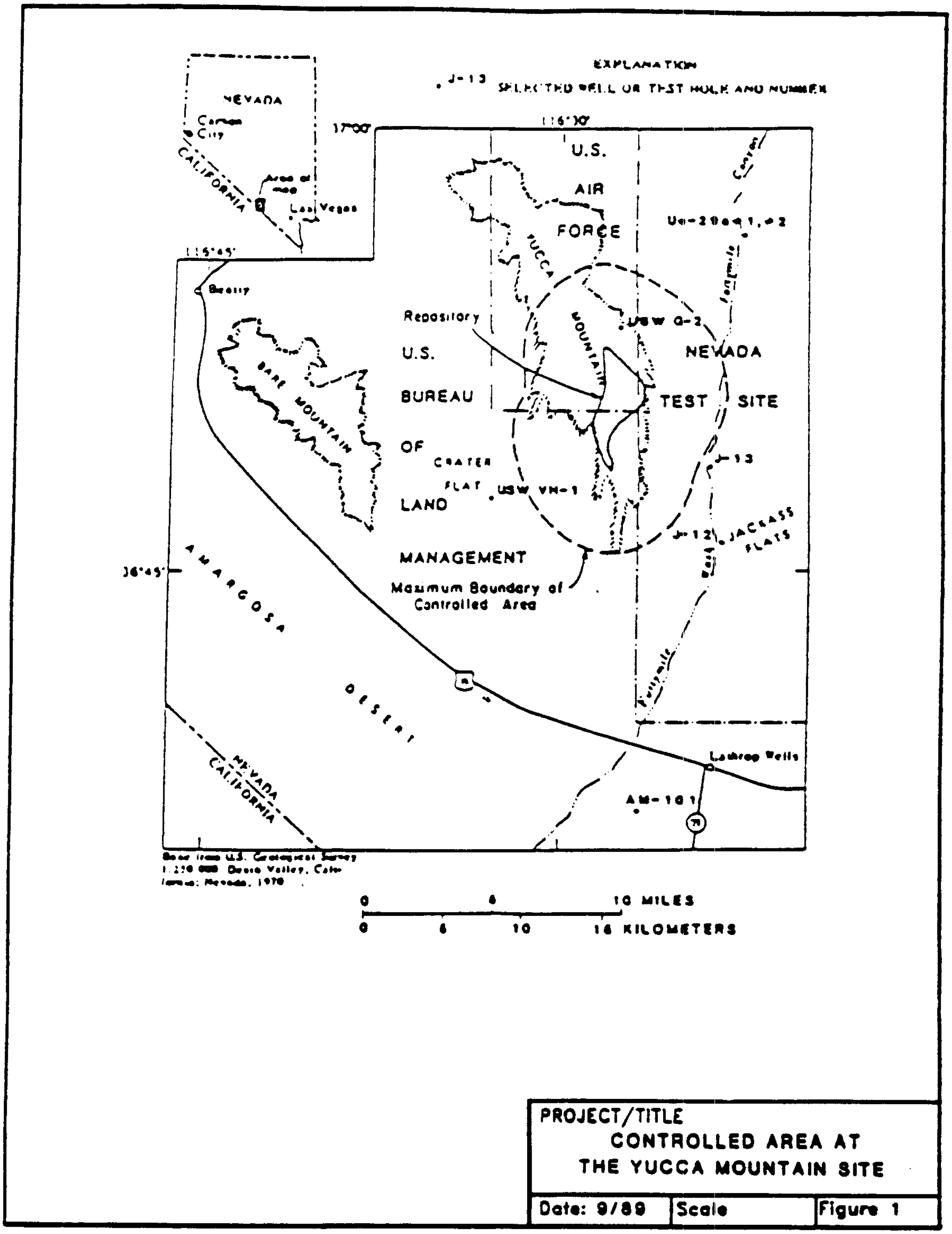
- The aquifer was penetrated from depths of 207.3 to 449.6 meters below ground surface, with a static water level of 282.2 meters (925.9 feet) below ground surface. Component **Depth** is true.

- A pumping test indicated a transmissivity of 120 meters squared per day (9,664 gpd/ft) and a hydraulic conductivity of 1.0 meter per day (24.54 gpd/sq.ft). Component **T/K** is true.

- The pumping history of the well and the aquifer parameters show that Well J-13 is capable of producing more than 10,000 gallons per day for a period of at least a year. Component **Yield** is true.

Because each component of the antecedent is true, the conjunction (**TDS . Depth . T/K . Yield**) is true, and therefore (**SgSGW**) is true. Thus, there is at least one significant source of ground water outside the controlled area at the Yucca Mountain site. The Topopah Springs unit generally forms the upper part of the saturated zone at and outside the accessible environment boundary along likely groundwater flow paths. It is generally the first saturated zone below the repository level, encountered outside the controlled area and therefore it is the key aquifer with respect to individual protection. (Within the controlled area the Topopah Spring is unsaturated and the water table is first encountered in the Prow Pass Member at wells USW WT#2, USW G-4, and USW H-4. The water table appears first in the Bullfrog Member at USW H-5) Outside the controlled area, it is expected that a family water supply well would be completed in the first unit that yields sufficient water of sufficiently high chemical quality to meet the family or individual needs. Thus, it is necessary for this analysis only to show that at least one "Significant Source of Ground Water" exists.

Figure 1 Controlled Area Near Yucca Mountain Site, Nevada



3.2 <u>Logical Structure of "Special Source of Ground Water"</u>

Let **SpSGW** = **"Special source of ground water**, as used in this Part"

CA = "those Class I ground waters identified in accordance with the Agency's Ground-water Protection Strategy published in August 1984 that: (1) are within the **controlled area** encompassing a disposal system or are less than five kilometers beyond the controlled area"

DW1000 = "those Class I ground waters identified in accordance with the Agency's Ground-water Protection Strategy published in August 1984 that: (2) are supplying **drinking water for thousands** of persons as of the date that the Department chooses a location within that area for detailed characterization as a potential site for a disposal system (e.g., in accordance with Section 112(b)(1)(B) of the NWPA)"

IRREP = "those Class I ground waters identified in accordance with the Agency's Ground-water Protection Strategy published in August 1984 that: (3) are **irreplaceable** in that no reasonable alternative source of drinking water is available to that population"

Then the definition can be rewritten in standard form as:

(CA . DW1000 . IRREP) = (SpSGW)

Note that the analysis used here does not, in the first instance, require that there be a Class I ground water resource (although the definition does). Clearly, if there are no Class I ground waters, then there can be no "Special Source of Ground Water". However, while Class I is a necessary condition, it is not sufficient, as it is a subclass of Class I ground waters that meet the EPA definition (see also NRDC et al. v. EPA, CA 1, 1987, Slip Opinion at 17). Thus, one may assume that the water is Class I and then look to the three conjunctive requirements for that resource. If the definition can be addressed through that analysis, it is not necessary to test the water resources for compliance with the requirements of the Ground-water Protection Strategy. Similarly, the fact that EPA - the responsible agency for ground-water classification - has not classified the water is irrelevant.

Using the standard truth functions applied to logical equivalence, if the consequent **(SpSGW)** is <u>true</u> (i.e., there exists a special source of ground water), then the multiple conjunction of the definition is true. For the conjunction (**CA .DW1000 . IRREP**) to be true, all three antecedent premises must be true. That is, to show that there is <u>not</u> a "special source of ground water", it suffices to show that any one of the three antecedents is false.

Given the existence of a "significant source of ground water" as a surrogate for the assumption of Class I water within five kilometers of the controlled area (see Section 3.1 above) and the obviously arid nature of the area as indicative of ground water as irreplaceable, the only antecedent that is a candidate for analysis is **DW1000**, the requirement that the aquifer is supplying drinking water for thousands of people. The aquifers within five kilometers of the controlled area do not now supply drinking water to thousands of people. Thus, **DW1000** is false, as is (**CA** . **DW1000** . **IRREP**). Thus, there can be no "Special Source of Ground Water" at the Yucca Mountain site, even if all other aspects of the designation of a Class I ground water under the 1984 Ground-water Protection Strategy were met. Therefore, with respect to this analysis, it is not necessary to determine whether there are Class I ground waters at or near the Yucca Mountain site.

4.0 CONCLUSIONS

Based on the definitions in 40 CFR Part 191 and the available technical data, the Topopah Springs unit of the Paintbrush Tuff qualifies as a "Significant Source of Ground Water", and DOE will be obligated to address the Individual Protection Requirements of 40 CFR 191.15 in its license application. However, no "Special Source of Ground Water" exists at the Yucca Mountain site (nor could one be defined in the future, because of the time-limiting restriction on the water-supply requirement). Therefore, the Ground Water Protection Requirement of 40 CFR 191.16 does not apply to the Yucca Mountain site.

5.0 REFERENCES

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