WBS: 1.2.1, 1.2.2, 1.2.4
SCPB: N/A
QA: L

Civilian Radioactive Waste Management System
Management & Operating Contractor

MINED GEOLOGIC DISPOSAL SYSTEM ADVANCED CONCEPTUAL DESIGN REPORT

VOLUME II OF IV
REPOSITORY

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March 1996

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1. INTRODUCTION

During the early phases of the Yucca Mountain design program, a three-phase approach for the development of the first Mined Geologic Disposal System (MGDS) was established:

- Conceptual Design Phase
  - Site Characterization Plan Conceptual Design (SCP-CD)
  - Advanced Conceptual Design (ACD)
- License Application Design Phase
- Final Procurement and Construction Design Phase.

The Conceptual Design for the Site Characterization Plan for a potential MGDS at Yucca Mountain, Nevada, was completed with the issuance of the *Site Characterization Plan Conceptual Design Report* (SCP-CDR) (SNL 1987). The report covered the following:

- Repository surface and subsurface facilities design
- Waste package design
- Material handling equipment
- Waste package fabrication equipment
- Waste treatment system
- Transportation, decontamination, and storage facilities
- All necessary support facilities and equipment.

The SCP-CD used the known site data and identified additional data needs to be obtained during the site characterization activities. Basically, this design demonstrated the feasibility of a potential repository at the Yucca Mountain site and was used as a basis for the repository input to a Total System Life Cycle Cost estimate.

The next step of the conceptual design phase, which is ACD, is intended to develop appropriate solutions to all identified design-related licensing issues, and explores repository and waste package design alternatives identified in the SCP-CDR and during subsequent studies. Several recommendations made by various external agencies and by the Nuclear Waste Technical Review Board are being considered for further investigation. New data from the site characterization and laboratory testing programs are being used. The ACD helped develop and, in some cases, refined the design criteria and concepts to be finalized in later design phases. Input for the Total System Life Cycle Cost estimate will be updated and revised using the design developed by ACD.

This design phase will be completed by the issuance of an MGDS ACD Summary Report, scheduled for March 1996.

The *Advanced Conceptual Design Work Plan* (CRWMS M&O 1992a) calls for a series of reviews to be performed on the progress of ACD at reasonable intervals prior to the development of the final summary report. To facilitate this action, the Initial Summary Report for Repository/Waste Package Advanced Conceptual Design was developed in September 1994, and acts as the first progress report representing a comprehensive compilation of ACD category work. The report is a compendium of input from Waste Package Development, Repository Surface Design, Repository Subsurface Design, and Systems Engineering. Input from each organization was not at an equal stage of maturity. The report was structured to include subject matter areas for all necessary areas of information, regardless of the amount of information available to date.

As mentioned above, the ACD effort which was originally planned to end in March 1997 is being closed out in March 1996 with the issuance of the MGDS ACD Report. Volume II of this report represents the Repository Segment design description, and contains a description of all repository design information that has been developed as of December 1995. The repository description is integrated with information presented in Volumes III and IV of the report through internal reviews and constant interaction of design staffs and other departments that may have an influence on designs and schedules.

2. SCOPE AND METHODOLOGY

2.1 REPORT SCOPE

The scope of Volume II of this Mined Geologic Disposal System (MGDS) Advanced Conceptual Design (ACD) Report is to provide a summary of all ACD work produced to date for the repository, and to ensure that all material included represents a fully integrated product not only between surface and subsurface design departments, but also with other program departments. These other departments include waste package, performance assessment, systems engineering, transportation, cost and schedule, and site investigation.

As implied by its title, the MGDS ACD Report is intended to put forth a compilation of integrated concepts in a form and format that can be used to review technical progress and adequacy as well as programmatic status. The report is formatted to include sections of technical and programmatic information that corresponds to issues identified for investigation in the *Advanced Conceptual Design Work Plan* (CRWMS M&O 1992a). Information for each of the identified areas may not be available at this time in the MGDS ACD Report; however, by structuring the report in this way, the reader will be able to assess both the progress of work and the level of effort required in all areas while planning for future design phases.

Volume II presents the ACD for the Repository Segment, consisting of surface and subsurface facilities at the repository, and the transportation systems within Nevada. The design and construction aspects of the Underground Facility Subsystem of the Engineered Barrier Segment are described in this volume.

The Repository Segment includes:

- An underground facility
- Site civil improvements
- Waste handling facilities
- Surface support facilities to house support functions such as:
  - Administration
  - Maintenance
  - Personnel support
  - Visitor center
  - Security
  - Safety
  - Health physics
  - Offices for the:
    - Nuclear Regulatory Commission (NRC)
    - Other oversight organizations

- Subsystems to supply, distribute, and control various utilities and services such as:
  - Electric power
  - Water
  - Communications.

Volume II provides a conceptual description of the repository, including an introduction, concept of operations, presentation of design inputs (e.g., requirements and assumptions), descriptions of surface and subsurface repository facilities and the Nevada transportation system, a discussion of design considerations for all operating modes and phases (e.g., emplacement, caretaker, retrieval, and closure), a preliminary hazards analysis, a discussion of driving design uncertainties and issues, and supporting references and appendices. All documents produced for ACD work will not be included in their entirety; but summaries of this work will be provided with reference to more comprehensive documents if necessary.

While Volume II deals with repository design details, information regarding other project elements can be found in Volumes I, III, and IV.

Volume I presents an executive summary of all report material, and an overview of program history, design evolution, description of requirements interpretation and allocation, discussion of major issues and interfaces, and explanation of other program structures.

Volume III presents the conceptual design of the Waste Package Subsystem within the Engineered Barrier Segment, including criteria, design bases, requirements, assumptions, material selections, performance, and interfaces with other segments and subsystems.

Volume IV provides life cycle cost data and associated life cycle schedules for the MGDS Segment including design, construction, startup, operations, and closure. More detailed outlines specific to each volume are included in the volumes themselves.

During ACD an emphasis is placed on the description of nuclear-related facilities, systems, subsystems, and operations. More general descriptions of balance of plant facilities are provided, but to a less detailed extent due to the understanding that these items can be designed using common industry practice and do not impact the nuclear safety or integrity of the project. The level of design work varied from area to area reflecting the funding limitations and ACD design priorities. As a result, the level of detail presented in the report also varies from section to section.

2.2 ACD DESIGN METHODOLOGY

The general methodology for the ACD begins with reference to the *Site Characterization Plan Conceptual Design Report* (SNL 1987). Information contained therein was developed to provide initial concepts from which further work would proceed. ACD re-examines requirements, criteria, and constraints, and combines the application of that input with the most recent available site data in developing new designs. Design alternatives are established through these new designs to incorporate the latest program developments and information. From these alternative designs, a selection is made of one or more designs to carry forward to the next design phase. In some cases, a single design selection may not be prudent due to need for design flexibility (e.g., thermal loading, backfill). This report contains some unqualified data that must be resolved and/or verified in future design phases. Before using data contained in this report for final design, procurement, fabrication, or construction, controls are required to be placed on that data in accordance with current procedures.

Throughout this design phase, close integration with other program elements was established. Particular emphasis was placed on integration with the waste package element for physical and performance design details on those items that affect the capability to handle the package in a confined environment, and also to establish shielding requirements for worker safety and performance requirements for the subsurface environment. The type of waste package and receipt schedule have major impacts on surface repository design. Information needs from the Performance Assessment group require a constant communication stream in which design information is provided to that organization and performance parameters were used to influence the design. Integration with Systems Engineering provides a dialogue on issues that impact several different groups, or have a programmatic impact such as thermal loading, transportation, and regulatory constraints.

3. DESIGN REQUIREMENTS AND STANDARDS

The primary source of requirements guiding design of the Mined Geologic Disposal System (MGDS) is 10 CFR 60, *Disposal of High-Level Radioactive Wastes in Geologic Repositories*. The requirements of 10 CFR 60, as well as those from many other sources, are captured in the *Civilian Radioactive Waste Management System Requirements Document* (CRD) (DOE 1995a) and from there flow down into the various systems requirements documents. For the MGDS Element, this system document is the *Mined Geologic Disposal System Requirements Document* (DOE 1995b), and from that document requirements are allocated to specific design requirements documents. Requirements for the design of the Repository Segment and Underground Facility portion of the Engineered Barrier Segment are presented in this volume. The input documents for Volume II are the *Repository Design Requirements Document* (RDRD) (YMP 1994a) and the *Controlled Design Assumptions Document* (CDA Document) (CRWMS M&O 1995a).

3.1 QUALITY ASSURANCE

Material presented in this volume has been developed in accordance with procedures that comply with the *Quality Assurance Requirements and Description* (DOE 1995c) and CRWMS M&O procedures designated as quality administrative procedures. The content of the report is conceptual in nature, and reflects work that may exist elsewhere in more detailed reports and analyses. Figures contained in technical documents are not required to be developed under QAP-3-10, *Engineering Drawings.*

3.1.1 Evaluation of Activities

Design activities described in this report have been evaluated in accordance with QAP-2-0, *Control of Activities*. These evaluations are described in this section.

The evaluation of the task of preparing this *Mined Geologic System Advanced Conceptual Design Report* (MGDS ACD Report) is documented in *Develop Repository Technical Documents and Reports* (CRWMS M&O 1995b). The results of that evaluation indicated that the activity was subject to the quality assurance (QA) program. In addition to those QA procedures applicable to all QA work, QAP-3-5, *Development of Technical Documents,* is cited as appropriate for this activity.

This MGDS ACD Report has been prepared in accordance with QAP-3-5. In accordance with that procedure, a Technical Document Preparation Plan (TDPP) has been prepared for this activity. The TDPP for the MGDS ACD Report, entitled *Technical Document Preparation Plan for the Mined Geologic Disposal System Advanced Conceptual Design (Revised) Report* (CRWMS M&O 1995c), contains the information required of TDPPs by QAP-3-5.

In addition to the activity of preparing the report, several other activities are represented in this work. These activities have been evaluated in accordance with QAP-2-0, and are listed below.

- Cost Estimating (CRWMS M&O 1995d)
- Scoping technical documents for Q-Items (CRWMS M&O 1995e)

- Design Basis Accident and Design Analyses (CRWMS M&O 1995f)
- Design Basis Accident for Non-Q Items (CRWMS M&O 1995g)
- Technical documents for Non-Q Items (CRWMS M&O 1995h)

The quality assurance procedures found to be applicable for each activity are noted in the referenced Activity Evaluations.

3.1.2 Classification of Systems, Structures, and Components

Prior to licensing, all systems, structures, and components (SSCs) of the repository must be evaluated to assess their importance to the nuclear safety of the operation. Depending on the outcome of that evaluation, the SSCs may be placed in one or more of the following classes:

- QA-1 – Items important to public radiological safety as described in 10 CFR 60; 10 CFR 71, *Packaging and Transportation of Radioactive Material*; and 10 CFR 72, *Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste.*

- QA-2 – Items and natural barriers important to waste isolation as described in 10 CFR 60.

- QA-3 – Items required for the control and management of site-generated radioactive waste other than spent fuel and high-level waste.

- QA-4 – Items required for the protection of items important to safety (IITS) and items important to waste isolation (IITWI) from the hazards of fire.

- QA-5 – Items not intended to perform a safety function but whose failure could impair the capability of other items to perform their intended safety or waste isolation functions.

- QA-6 – Items required for physical protection as defined by 10 CFR 73, *Physical Protection of Plants and Materials.*

- QA-7 – Items required to control occupational radiological exposure.

Exploratory Studies Facility (ESF) SSCs that may become a part of the repository have been classified in a number of classification analyses (CRWMS M&O 1995i, CRWMS M&O 1995j, CRWMS M&O 1995k, CRWMS M&O 1995l, and CRWMS M&O 1995m). These analyses were performed in accordance with QAP-2-3, *Classification of Permanent Items.* The SSCs were analyzed; results of these analyses are listed in Table 3-1.

Table 3-1. Classification of Repository-related ESF Configuration Items

Configuration Item	Classification
Ground Support Systems	QA-1, QA-5
Main Access Openings	QA-2
Test Support Areas	N/A
Operations Support Areas	N/A
Tunnel Boring Machine Starter Tunnel	QA-2

Preliminary classification analyses of repository SSCs have also been performed, but these analyses have not yet been released. The *Q-List* (YMP 1994b) contains QA classification information for repository SSCs. The *Q-List* discusses only IITS and IITWI, which are essentially synonymous with "QA-1" and "QA-2." All repository items placed on the *Q-List* were done so by "Direct Inclusion" as opposed to the more rigorous evaluation process of QAP-2-3. Such evaluation requires specific design information and an understanding of the credible Design Basis Accidents (DBAs) and their initiating Design Basis Events (DBEs). DBA and DBE issues are discussed in Section 10.

Those items considered Important To Radiological Safety are listed below. The reader is referred to the *Q-List* for a more detailed listing of the make-up of these items.

- Waste Package
- Surface Service and Utility Systems
- Surface Facilities
- Balance of Plant
- Waste Ramp/Topopah Spring North Ramp
- Men-and-Materials Shaft*
- Tuff Ramp
- Emplacement Area Exhaust Shaft
- Exploratory Studies Modifications for Waste Emplacement Area Air Intake
- Underground Excavations
- Underground Service and Utility Systems
- Seals
- ESF Starter Tunnel Drill-and-Blast Section.

* The current repository configuration does not incorporate a shaft having "Men-and-Material" functions.

Those items considered IITWI are listed below. Refer to the *Q-List* for a more detailed listing of the make-up of these items.

- Waste Package
- Institutional Barriers
- Waste Ramp/Topopah Spring North Ramp

- Men-and-Materials Shaft*
- Tuff Ramp
- Emplacement Area Exhaust Shaft
- Exploratory Studies Modifications for Waste Emplacement Area Air Intake
- Underground Excavations
- Seals
- ESF Starter Tunnel Drill-and-Blast Section.

* The current repository configuration does not incorporate a shaft having "Men-and-Material" functions.

3.1.3 Use of Computer Software

Several computer software packages have been used in the repository conceptual design work performed through early FY 1996. Computer programs have been used to model:

- The three-dimensional geologic structure of the site

- The geotechnical response of underground openings to stresses caused by thermal loading as well as the presence of the openings themselves

- The ventilation flow networks for the subsurface repository

- The thermal effects of the presence of heat producing waste packages in the repository emplacement drifts.

LYNX

A geologic model, Lynx Version 3.06 geologic modeling software (LYNX), running on a Silicon Graphics Indigo R4000 XS24Z workstation with an IRIX 5.2 operating system, is used in the development of the ESF and Geologic Repository Operations Area (GROA) layouts. LYNX Version 3.06 was qualified for quality affecting work and has been assigned the computer software configuration item number B00000000-01717-1200-30018. The LYNX geologic modeling software is appropriate for this application and was run within its range of validation. The use of the LYNX package, including its inputs, operation, and results, is described in *Definition of Potential Repository Block* (CRWMS M&O 1995n).

FLAC and UDEC

Two commercially available computer programs, Fast Lagrangian Analysis of Continua (FLAC) and Universal Distinct Element Code (UDEC), have been used for the numerical analysis of opening stability. Both codes are command-driven and run on a 90 MHZ Pentium microcomputer with 16 megabytes random access memory. Although these two programs are approved for use in design in accordance with CRWMS M&O computer software quality assurance procedures, and carry the appropriate computer software configuration item numbers as given below, their installation on the machines used for these analyses has not been documented. Additional documentation would be required before these computer results would be considered qualified.

FLAC is a two-dimensional, explicit finite difference code that simulates the behavior of structures built of soil, rock, and other materials and subjected to static, dynamic, and thermally-induced loads (Itasca 1993a). Modeled materials respond to applied forces or boundary restraints according to prescribed linear or non-linear stress/strain laws and undergo plastic flow when a limiting yield condition is reached. FLAC is based on a Lagrangian calculation scheme, especially suited for modeling large displacements, and has several built-in constitutive models that permit the simulation of highly non-linear, irreversible responses typical of many geologic materials. The FLAC program was initially developed by Dr. Peter Cundall and Itasca Consulting Group, Inc. in 1986, and the version of the program used for the analysis of opening stability is Version 3.22 (computer software configuration item number 20.93.3001-AAu3.22), which has been verified and validated according to applicable CRWMS M&O procedures.

UDEC is a two-dimensional numerical program based on the distinct element method of discontinue modeling (Itasca 1993b). The program was initially introduced by Dr. Peter Cundall and Itasca Consulting Group, Inc., in 1985. It simulates the response of discontinuous media (such as a jointed rock mass) subjected to thermal, static, or dynamic loading. The discontinuous medium is represented as an assemblage of discrete blocks. The discontinuities between blocks are treated as boundary conditions that permit block rotations and large displacements along the discontinuities. Individual blocks behave as either rigid or deformable material.

Deformable blocks are subdivided into a mesh of finite difference elements that respond according to a prescribed linear or non-linear force-displacement relation in both normal and shear directions. UDEC has several built-in material behavior models, for both intact blocks and discontinuities, which simulate discontinuous geologic materials. UDEC is also based on a Lagrangian calculation scheme which is suitable for modeling large deformations in a blocky system. The UDEC code used in the analysis of opening stability is Version 2.0 (computer software configuration item number B00000000-01717-1200-30004), which has been verified and validated according to applicable CRWMS M&O procedures.

VNETPC

A ventilation network simulation program, VNETPC Version 3.1, was used to provide examples for the air flow distribution and network balance. The program has already been verified and validated under QA procedures (CRWMS M&O 1993a). The application of the software to the study is appropriate and is used only within the validated range as described in the verification and validation documentation of VNETPC software (CRWMS M&O 1993a).

The VNETPC program ran on a Gateway 2000 computer equipped with an Intel P54C Pentium central processing unit operating at 90 MHZ. The computer has 8 megabytes of random access memory. The software was used within its verified range, and is appropriate for this application.

ANSYS

The commercially available computer code, ANSYS Revision 5.1, developed by Swanson Analysis Systems, Inc., was used to generate the thermal modeling examples to illustrate the concepts being examined.

The ANSYS finite element analysis program is a large-scale, general purpose software package used worldwide. It can be used to perform a variety of analyses, including thermal, structural, magnetic field, electric field, fluid, and coupled-field.

The thermal analysis phase of the software was used in this scoping analysis to calculate temperature distributions in the host rock under the influences of radioactive decay of the nuclear waste emplaced in an underground repository. It was used because of its capabilities of performing transient analysis, accommodating temperature-dependent material properties, explicitly modeling thermal radiation, and because of its acceptance by the nuclear industry and the Nuclear Regulatory Commission (NRC) (CRWMS M&O 1994). Two- and three-dimensional visualizations for verifying preprocessing data and reviewing postprocessing solution results were produced using ANSYS interactive graphics.

The thermal modeling examples presented in this report were generated from the ANSYS program installed on a Silicon Graphics IRIS Indigo^2 R4600SC graphics workstation running internally at 133 MHZ. The software was used within its verified range and is appropriate for this application.

3.2 DESIGN INPUT

Design inputs contained in this volume have been used to generate the repository MGDS ACD Report. For the repository, the design inputs consist of a combination of requirements from the RDRD (YMP 1994a) and assumptions from the CDA Document (CRWMS M&O 1995a). This report contains some unqualified data yet to be verified.

3.2.1 Design Requirements

The source of requirements guiding the RDRD (YMP 1994a) is the *Mined Geological Disposal System Requirements Document* (DOE 1995b), which is one of four system requirements documents obtaining requirements directly from the CRD (DOE 1995a). The CRD is the primary program source of requirements used in the design requirements documents and in system requirements. The CRD obtains its requirements (identified in its Section 2) from CFRs, DOE Orders, the *Nuclear Waste Policy Act of 1982*, and other sources.

3.2.2 Source Documents

The codes, regulations, standards, and guides applicable to the design of the repository are defined in Section 2 of the RDRD (YMP 1994a). The principal regulatory requirements are the technical requirements for repository operation provided in 10 CFR 60 and 10 CFR 960 and the environmental standards provided in the currently remanded 40 CFR 191. The primary sources of regulations that drive repository design requirements are those listed in Table 3-2.

Table 3-2. Repository Related Federal Regulations

Identifier	Title or Description
10 CFR 20	Standards for Protection Against Radiation
10 CFR 60	Disposal of High-Level Radioactive Wastes in Geologic Repositories
10 CFR 71	Packaging and Transportation of Radioactive Material
10 CFR 960	General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories
10 CFR 961	Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste
29 CFR 1926	Safety and Health Regulations for Construction
30 CFR 57	Safety and Health Standards Underground Metal and Nonmetal Mines
40 CFR 191	Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes (remanded for a Yucca Mountain Repository)

3.2.3 Design Requirements Summary

The RDRD (YMP 1994a) describes the functions to be performed by, and establishes the requirements for, the Repository Segment. The Repository Segment is one of the segments of the MGDS for the permanent disposal of spent nuclear fuel (SNF), including SNF loaded in multi-purpose canisters (MPCs), commercial high-level radioactive waste, and defense high-level radioactive waste (DHLW). The primary function of the Repository and Engineered Barrier Segments is to isolate waste, first by containing waste within the waste package and then, together with the geologic setting, isolating waste from the accessible environment. The major components of the Repository Segment consist of the surface and subsurface facilities.

The requirements identified in this summary (see Table 3-3) are those requirements appropriate for the level of design detail necessary to support the ACD. For this stage of design, key performance requirements, listed below, have been identified to provide additional selection criteria for design requirements in this summary. Requirements and assumptions associated with the key performance requirements have been included in this summary.

Table 3-3. Repository Design Requirements

Description	Identifier	Requirement
Waste Receipt Rate	RDRD 3.2.1.2.B	The repository shall be capable of receiving waste according to the schedule shown in Table 3-4 of this document. Note: Refer to requirement assumption RDRD 3.2.1.2.B and Key Assumptions 001 and 002 for further clarification on project approach.
Radiation Limits	RDRD 3.2.1.2.C RDRD 3.2.1.3 RDRD 3.2.1.4.C RDRD 3.2.2.1.C	The GROA shall be designed so that until permanent closure has been completed, radiation exposures, radiation levels, and releases of radioactive materials to unrestricted areas will at all times be maintained within the limits specified in 10 CFR 20 and applicable environmental standards for radioactivity established by the EPA[1], as listed in Section 3.2.2. [10 CFR 60.111(a)]
Retrieval	RDRD 3.2.1.4.A	The repository shall be designed and constructed to permit the retrieval of any SNF and DHLW emplaced in the repository, during an appropriate period of operation of the facility, as specified by the Secretary of Energy. Note: Refer to Key Assumptions 016, 017, and 055 for further clarification on project approach.
Retrieval	RDRD 3.2.1.4.B	The GROA shall be designed to preserve the option of waste retrieval throughout the period during which wastes are being emplaced and thereafter until the completion of a performance confirmation program and NRC review of the information obtained from such a program. To satisfy this objective, the geologic repository shall be designed so that any or all of the emplaced waste could be retrieved on a reasonable schedule starting at any time up to 50 years after waste emplacement operations are initiated, unless a different time period is approved or specified by the NRC. 10 CFR 60.111(b)(3) gives guidance for developing the schedule. [10 CFR 60.111(b)(1)] Note: Refer to Key Assumptions 016 (extends retrievability period "up to 100 years") and 017 for further clarification on project approach.

[1] U.S. Environmental Protection Agency

Table 3-3. Repository Design Requirements (Continued)

Description	Identifier	Requirement
Releases of Radionuclides to the Accessible Environment	RDRD 3.2.1.6C	The disposal system 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 all significant processes and events that may affect the disposal system shall have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table A-1 of Appendix A of 40 CFR 191; and have a likelihood of less than one chance in 1,000 of exceeding ten times the qualities calculated according to Table A-1 of Appendix A of 40 CFR 191. [TBR] [140 CFR 191.13(a)[TBR]] Note: Refer to requirement assumption RDRD 3.2.1.6C for further clarification on project approach.
Off-Normal Events	RDRD 3.2.1.7.A	The GROA design shall include explosion and fire detection alarm systems and appropriate suppression systems with sufficient capacity and capability to reduce the adverse effects of fires and explosions on SSCs important to safety. [10 CFR 60.131(b)(3)(iii)]
Off-Normal Events	RDRD 3.2.1.7B	The SSCs important to safety shall be designed to maintain control of radioactive waste and radioactive effluents, and permit prompt termination of operations and evacuation of personnel during an emergency. [10 CFR 60.131(b)(4)(I)]
Off-Normal Events	RDRD 3.2.1.7C	The SSCs important to safety shall be designed to perform their safety functions during and after credible fires or explosions in the GROA repository. [10 CFR 60.131(b)(3)(I)]
Radiological Protection	RDRD 3.2.2.1.A	The GROA shall, to the extent practicable, be designed and constructed to use procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are as low as reasonably achievable (ALARA). ALARA principles shall be based on the applicable sections of NRC Regulatory Guides 8.8 and 8.10. [10 CFR 20.1101(b)] Note: Refer to Key Assumption 013 for further clarification on project approach.

Table 3-3. Repository Design Requirements (Continued)

Description	Identifier	Requirement
Radiological Protection	RDRD 3.2.2.1.B	The GROA design and operations shall include provisions for controlling doses such that, when approved operational procedures are followed, the exposure dose limits specified in 10 CFR 20.1201 for occupational doses, and 10 CFR 20.1301 for individual members of the public, are not exceeded. [10 CFR 20] Note: Refer to Key Assumption 013 for further clarification on project approach.
Radiological Protection	RDRD 3.2.2.1.D	The GROA shall provide means to limit the levels of radioactive materials in effluents, during normal operations, anticipated occurrences, and under accident conditions. [10 CFR 60.131(b)(4)(I)]
Radiological Protection	RDRD 3.2.2.1.D.1	Releases shall be limited as follows: Under normal operations and anticipated occurrences, the annual dose equivalent to any real individual who is located beyond the controlled area must not exceed 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other organ as a result of exposure to: planned discharges of radioactive materials, radon and its decay products excepted, to the general environment; direct radiation from repository operations; and any other radiation from uranium fuel cycle operations within the region. [TBR] [40 CFR 191.03(a)(1)[TBR]] Note: Refer to Key Assumption 013 for further clarification on project approach.
Radiological Protection	RDRD 3.2.2.1.E	The disposal system shall be designed to meet the individual protection requirements specified by 40 CFR 191.15 [TBR]. [40 CFR 191.15 [TBR]] Note: Refer to Key Assumption 013 for further clarification on project approach.

Table 3-3. Repository Design Requirements (Continued)

Description	Identifier	Requirement
Public Protection	RDRD 3.2.2.2.A	Repository facilities shall be designed to operate so that the total EDE[2] to individual members of the public from the licensed operation does not exceed 0.1 rem (1 mSv) in a year, exclusive of the dose contribution from the facility's disposal of radioactive material into sanitary sewerage in accordance with 10 CFR 20.2003. However, the facility may apply for prior NRC authorization to operate up to an annual dose limit for an individual member of the public of 0.5 rem (5 mSv) in accordance with 10 CFR 20.1301(c). [10 CFR 20.1301(a),(c)]
Public Protection	RDRD 3.2.2.2.B	If members of the public have access to controlled areas, the limits for members of the public shall continue to be applicable to those individuals. [10 CFR 20.1301(b)]
Public Protection	RDRD 3.2.2.2.C	Repository facilities shall be designed to operate so that the dose in any unrestricted area from external sources does not exceed 0.002 rem (0.02 mSv) in any one hour. [10 CFR 20.1301(a)(2)]
Airborne Radioactive Material Control	RDRD 3.2.2.3.A	Concentrations of radioactive material in air shall to the extent practicable be controlled through the use of process or other engineering controls (e.g., containment or ventilation). [10 CFR 20.1701]
Airborne Radioactive Material Control	RDRD 3.2.2.3.B	When it is not practicable to apply process or other engineering controls in restricted areas to control the concentrations of radioactive material in air to values below those that define an airborne radioactivity area, the repository shall, consistent with maintaining the total EDE ALARA, have the capability to increase monitoring and limit intakes by one or more of the following: control of access, limitation of exposure times, use of respiratory protection equipment, or other controls. [10 CFR 20.1702]
Airborne Radioactive Material Control	RDRD 3.2.2.3.C	The GROA shall be capable of implementing and maintaining air sampling sufficient to identify potential hazards, to permit proper protective equipment selection, and to estimate exposures. [10 CFR 20.1703(a)(3)(I)]

[2] effective dose equivalent

Table 3-3. Repository Design Requirements (Continued)

Description	Identifier	Requirement
Criticality Protection	RDRD 3.2.2.5.A	All systems for processing, transporting, handling, storing, retrieving, emplacing, and isolating radioactive waste shall be designed to ensure that a nuclear criticality accident is not possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. Each system shall be designed for criticality safety under normal and accident conditions. The calculated effective multiplication factor must be sufficiently below unity to show at least a 5% margin, after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the method of calculation. [10 CFR 60.131(b)(7)]
Low-Level Waste Disposal	RDRD 3.2.2.6.A	If the design of the Repository Segment provides for the disposal of licensed low-level waste material into sanitary sewerage, the requirements of 10 CFR 20.2003 shall be met. [10 CFR 20.2003] Note: Refer to Key Assumption 024 for further clarification on project approach.
Low-Level Waste Disposal	RDRD 3.2.2.5.B	If the design of the Repository Segment provides for the treatment or disposal of licensed low-level waste material by incineration, only the amounts and forms specified in 10 CFR 20.2005, or specifically approved by the NRC pursuant to 10 CFR 20.2002, shall be allowed. [10 CFR 20.2004] Note: Refer to Key Assumption 024 for further clarification on project approach.
Repository Segment-Geologic Setting Interfaces	RDRD 3.2.3.2.3.A	The underground facility shall assist the geologic setting in meeting the performance objectives for the period following permanent closure. [10 CFR 60.133(h)]
Repository Segment-Geologic Setting Interfaces	RDRD 3.2.3.2.3.B	The ...[3] underground facility shall be designed to assure that releases of radioactive materials to the accessible environment following permanent closure conform to applicable environmental standards for radioactivity established by the EPA with respect to both anticipated processes and events and unanticipated processes and events. [10 CFR 60.112]

[3] The requirements for the geologic setting and the accesses, boreholes, and their seals are addressed in 3.7.1 and 3.7.5. Requirements for waste packages are in the *Engineered Barrier Design Requirements Document* (EBDRD).

Table 3-3. Repository Design Requirements (Continued)

Description	Identifier	Requirement
Repository Segment-Geologic Setting Interfaces	RDRD 3.2.3.2.3.C	The underground facility shall be designed, assuming anticipated processes and events, so that the release rate of any radionuclide from the underground following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the NRC; provided that this requirement does not apply to any radionuclide that is released at a rate less than 0.1% of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1,000 years of radioactive delay. [10 CFR 60.113(a)(1)(ii)(B)]
Security of Licensed Material	RDRD 3.2.4.3.1.4	The Repository Segment shall provide the capability to control and maintain constant surveillance over licensed material that is in a controlled or unrestricted area and that is not in storage. [10 CFR 20.1802]
High Radiation Area Access Control	RDRD 3.2.4.3.2.A	Access to high and very high radiation areas shall be controlled in accordance with the requirements specified by 10 CFR 20.1601 and 20.1602. [10 CFR 20.1601][10 CFR 20.1602]
Radioactive Materials Monitoring	RDRD 3.2.4.4	The Repository Segment shall be equipped to monitor the external surfaces of packages and casks known to contain radioactive material for radioactive contamination and radiation levels in compliance with 10 CFR 20.1906. [10 CFR 20.1906]
Structure, System, and Component Reliability	RDRD 3.2.5.1.3	SSCs that are important to safety shall be designed and located so that they continue to perform their safety functions effectively during and after credible fire and explosion conditions in the GROA. [10 CFR 60.131(b)(3)]
Utilities Reliability	RDRD 3.2.5.1.4.A	Each utility service system that is important to safety shall be designed so that essential safety functions can be performed under both normal and accident conditions. [10 CFR 60.131(b)(5)(I)]
Utilities Reliability	RDRD 3.2.5.1.4.B	The design of utility services and distribution systems that are important to safety shall include redundant systems to the extent necessary to maintain, with adequate capacity, the ability to perform safety functions. [10 CFR 60.131(b)(5)(ii)]

Table 3-3. Repository Design Requirements (Continued)

Description	Identifier	Requirement
Maintenance in Radioactive Environments	RDRD 3.2.5.2.6	Equipment which normally operates in a radioactive environment or in the vicinity of radioactive components shall be designed to be moved to a non-radioactive environment for maintenance or repair, whenever possible. When that is not possible, the design shall allow for installation of temporary shielding, permit minimizing radiation exposure times, and provide sufficient space for ease of operation, maintenance, and repair. [10 CFR 60.131(a)(2)]
Fire, Explosion, and Other Disaster Protection	RDRD 3.2.6.2.1.A	Repository Segment SSCs important to safety shall be designed to perform their safety functions during and after credible fire or explosion conditions at the repository. [10 CFR 60.131(b)(3)(I)]
Fire, Explosion, and Other Disaster Protection	RDRD 3.2.6.2.1.B	The Repository Segment shall be designed to include means to protect SSCs important to safety against the adverse effects of either the operation or failure of the fire suppression system. [10 CFR 60.131(b)(3)(iv)]
Fire, Explosion, and Other Disaster Protection	RDRD 3.2.6.2.1.C	Repository Segment SSCs important to safety shall be designed to withstand dynamic effects, such as missile impacts, that could result from equipment failure, and similar events and conditions that could lead to loss of their safety functions. [10 CFR 60.131(b)(2)]
Fire Resistance	RDRD 3.2.6.2.2.D	To the extent practicable, the Repository Segment facilities shall be designed to incorporate the use of noncombustible and heat resistant materials. [10 CFR 60.131(b)(3)(ii)]
General Design Criteria	RDRD 3.3.1.E	All design bases shall be consistent with the results of site characterization. [10 CFR 60.130]
General Design Criteria	RDRD 3.3.1.H	An assessment shall be provided to document the predicted effectiveness of engineered and natural barriers, including barriers that may not be themselves a part of the GROA, against the release of radioactive material from the waste package to the environment. The analysis will also include a comparative evaluation of alternatives to the major design features that are important to waste isolation, with particular attention to the alternatives that would provide longer radionuclide containment and isolation. [10 CFR 60.21(c)(1)(ii)(D)]

Table 3-3. Repository Design Requirements (Continued)

Description	Identifier	Requirement
General Design Criteria	RDRD 3.3.1.I	The performance of the major design SSCs, both surface and subsurface, shall be analyzed to identify those that are important to safety. For the purposes of this analysis, it will be assumed that operations at the GROA will be carried out at the maximum capacity and rate of receipt of radioactive waste stated in the application. [10 CFR 60.21(c)(1)(ii)(E)]
General Design Criteria	RDRD 3.3.1.J	A description and analysis of the design and performance requirements for SSCs of the geologic repository which are important to safety shall be provided. This analysis will consider: 1. The margins of safety under normal conditions and under conditions that may result from anticipated operational occurrences, including those of natural origin, and 2. The adequacy of SSCs provided for the prevention of accidents and mitigation of the consequences of accidents, including those caused by natural phenomena. [10 CFR 60.21(c)(3)]
Geologic Setting	RDRD 3.7.1.A	The geologic setting shall be selected ...[4] to assure that releases of radioactive materials to the accessible environment following permanent closure conform to applicable environmental standards for radioactivity established by the EPA with respect to both anticipated processes and events and unanticipated processes and events. [10 CFR 60.112]
Groundwater Travel Time	RDRD 3.7.1.B	The geologic repository shall be located so that the pre-waste-emplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years, or such other travel time as may be approved or specified by the NRC. [10 CFR 60.113 (a)(2)]

[4] The requirements for the Engineered Barrier System and accesses, boreholes, and their seals are addressed in 3.7.5 and in the EBDRD.

Table 3-3. Repository Design Requirements (Continued)

Description	Identifier	Requirement
Groundwater	RDRD 3.7.1.C	If any of the average annual radionuclide concentrations existing in a special source of groundwater, if one exists, before construction of the disposal system already exceed the limits in 40 CFR 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 the special source of groundwater by more than the limits established in 40 CFR 191.16(a). [TBR] [40 CFR 191.16 (b) [TBR]] Note: Refer to requirement assumption RDRD 3.7.1.C further clarification on project approach.
Adverse Effects	RDRD 3.7.1.D	Assuming the site has been found suitable and to meet the requirements specified in 10 CFR 60.122(a), the Repository Segment design organization shall account for the effects of any of the potentially adverse conditions listed in 10 CFR 60.122 (c) if they are found to be characteristic of the planned controlled area. 10 CFR 60.122(a) specifies that the effects of the potentially adverse conditions can be addressed by analysis, by compensation by favorable conditions (10 CFR 60.122(b)), or remedied [by engineering design]. [10 CFR 60.122]
Site Generated Waste Treatment	RDRD 3.7.3.9.A	Radioactive waste treatment facilities shall be designed to process any radioactive waste generated at the GROA into a form suitable to permit safe disposal at the GROA or to permit safe transportation and conversion to a form suitable for disposal at an alternative site in accordance with any regulations that are applicable. [10 CFR 60.132(d)]
Waste Handling	RDRD 3.7.4.1.A.1	Surface facilities in the GROA shall be designed to allow safe handling and lag storage (if needed) of wastes at the GROA, whether these wastes are temporarily on the surface before emplacement or as a result of retrieval from the underground facility. [10 CFR 60.132(a)]
Surface Facility Ventilation	RDRD 3.7.4.1.C	Surface facility ventilation systems supporting waste transfer, inspection, decontamination, processing, or packaging shall be designed to provide protection against radiation exposures and off-site releases as provided in 10 CFR 60.111(a). [10 CFR 60.132(b)]

Table 3-3. Repository Design Requirements (Continued)

Description	Identifier	Requirement
Underground Openings	RDRD 3.7.5.E.1	Openings in the underground facility shall be designed so that operations can be carried out safely and the retrievability option maintained. [10 CFR 60.133(e)(1)]
Underground Openings	RDRD 3.7.5.E.2	Openings in the underground facility shall be designed to reduce the potential for deleterious rock movement or fracturing of overlying or surrounding rock. [10 CFR 60.133(e)(2)]
Facility Orientation	RDRD 3.7.5.E.3	The orientation, geometry, layout, and depth of the underground facility, and the design of any engineered barriers that are part of the underground facility shall contribute to the containment and isolation of radionuclides. [10 CFR 60.133(a)(1)]
Underground Facility Performance Requirements	RDRD 3.7.5.E.7	The underground facility shall be designed so that the performance objectives will be met taking into account the predicted thermal and thermomechanical response of the host rock, and surrounding strata, and groundwater system. [10 CFR 60.133(I)]
Rock Excavation	RDRD 3.7.5.G.2	The design of the underground facility shall incorporate excavation methods that will limit the potential for creating a preferential pathway for groundwater to contact the waste packages or radionuclide migration to the accessible environment. [10 CFR 60.133(f)]
Flexibility	RDRD 3.7.5.H	The underground facility shall be designed to allow adjustments to accommodate specific site conditions identified through in situ monitoring, testing, or excavations. [10 CFR 60.133(b)]
Water and Gas	RDRD 3.7.5.I	The underground facility shall be designed to control water and gas intrusion. [10 CFR 60.133 (d)]
Seals	RDRD 3.7.5.J.1	Seals for accesses and boreholes shall be designed so that following permanent closure they do not become pathways that compromise the geologic repository's ability to meet the performance objectives for the period following permanent closure. [10 CFR 60.134(a)]

Table 3-3. Repository Design Requirements (Continued)

Description	Identifier	Requirement
Seals	RDRD 3.7.5.J.2	Materials and placement methods for seals shall be selected to reduce, to the extent practicable, (a) the potential for creating a preferential pathway for groundwater to contact the waste packages; or (b) for radionuclide migration through existing pathways. [10 CFR 60.134(b)(1) and (2)]
Seals	RDRD 3.7.5.J.3	The ...[5] seals for accesses and boreholes shall be designed to assure that releases of radioactive materials to the accessible environment following permanent closure conform to applicable environmental standards for radioactivity established by the EPA with respect to both anticipated processes and events and unanticipated processes and events. [10 CFR 60.112]
Radiological Protection	RDRD 3.7.7.A	The GROA shall be designed to maintain radiation doses, levels, and concentrations of radioactive material in air in restricted areas within the limits specified in 10 CFR 20. Design shall include: 1. Means to limit concentrations of radioactive material in air. 2. Means to limit the time required to perform work in the vicinity of radioactive materials, including, as appropriate, designing equipment for ease of repair and replacement and providing adequate space for ease of operation. 3. Suitable Shielding.
Radiological Protection (continued)	RDRD 3.7.7.A	4. Means to monitor and control the dispersal of radioactive contamination. 5. Means to control access to high radiation areas or airborne radioactivity areas. 6. A radiation alarm system to warn of significant increases in radiation levels, concentrations of radioactive material in air, and of increased radioactivity released in effluent. The alarm system shall be designed with provisions for calibration and for testing its operability. [10 CFR 60.131(a)]

[5] The requirements for the geologic setting and the Engineered Barrier System accesses and boreholes are addressed in 3.7.1A and 3.7.5 and in the EBDRD.

Table 3-3. Repository Design Requirements (Continued)

Description	Identifier	Requirement
Radiological Protection	RDRD 3.7.7.F	Surface facilities shall be designed to control the release of radioactive materials in effluents during normal operations so as to meet the perform objectives of 10 CFR 60.111(a). [10 CFR 60.132(c)(1)]
Radiological Protection	RDRD 3.7.7.G	The effluent monitoring systems shall be designed to measure the amount and concentration of radionuclides in any effluent with sufficient precision to determine whether releases conform to the design requirement for effluent control. The monitoring systems shall be designed to include alarms that can be periodically tested. [10 CFR 60.132(c)(2)]

Key Performance Requirements

- Substantially complete containment for 1,000 years with no more than 1 percent of waste packages failing within 1,000 years.
- Release rate of any radionuclide shall not exceed 1 part in 100,000 per year of the inventory of radionuclides calculated to be present at 1,000 years
- Nuclear criticality event not possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety.
- GROA radiation levels and releases to unrestricted areas are within 10 CFR 20 and Environmental Protection Agency standards until completion of closure.

Table 3-4. Waste Delivery Schedule (In Metric Tons of Initial Uranium or Equivalent) [TBR]

Year	Spent Nuclear Fuel		DHLW		Cumulative SNF and DHLW
	From MRS*	Cumulative	Annual	Cumulative	
2010	300	300	0	0	300
2011	600	900	0	0	900
2012	1,200	2,100	0	0	2,100
2013	2,000	4,100	0	0	4,100
2014	3,000	7,100	0	0	7,100
2015	3,000	10,100	400	400	10,500
2016	3,000	13,100	400	800	13,900
2017	3,000	16,100	400	1,200	17,300
2018	3,000	19,100	400	1,600	20,700
2019	3,000	22,100	400	2,000	24,100
2020	3,000	25,100	400	2,400	27,500
2021	3,000	28,100	400	2,800	30,900
2022	3,000	31,100	400	3,200	34,300
2023	3,000	34,100	400	3,600	37,700
2024	3,000	37,100	400	4,000	41,100
2025	3,000	40,100	400	4,400	44,500
2026	3,000	43,100	400	4,800	47,900
2027	3,000	46,100	400	5,200	51,300
2028	3,000	49,100	400	5,600	55,700
2029	3,000	52,100	400	6,000	58,100
2030	3,000	55,100	400	6,400	61,500
2031	3,000	58,100	400	6,800	64,900
2032	3,000	61,100	200	7,000	68,100
2033	1,900	63,000	0	7,000	70,000
2034	0	63,000	0	7,000	70,000

*Note: In years when SNF is shipped directly from the purchasers to the MGDS, the sum of the waste shipped directly and waste shipped from the monitored retrievable storage facility will be as stated in this column.

4. DESIGN BASIS ASSUMPTIONS AND DEVELOPMENT

The *Controlled Design Assumptions Document* (CDA Document) (CRWMS M&O 1995a) is a key element in the advanced conceptual design (ACD) approach that uses management decisions and/or assumptions, as necessary, based on the best available information or engineering judgment, to advance the design. The CDA Document (CRWMS M&O 1995a) contains these assumptions, as well as the rationale for the assumptions and references to plans and schedules to substantiate the assumptions, if necessary. The CDA Document (CRWMS M&O 1995a) also provides a concept of operations for the repository surface and subsurface operations. A key feature of the ACD approach is to allow assumptions regarding requirements, design concepts, and technical data to be made prior to the existence of qualified data. Such assumptions are considered to be of indeterminate quality and, therefore, may require substantiation activities to validate, qualify, and/or determine their suitability as design input. Refer to the CDA Document (CRWMS M&O 1995a) for a discussion of control of assumptions and resolution of key issues.

Assumptions are categorized as key assumptions, requirements assumptions, design concept assumptions, and technical data assumptions. Key assumptions include assumptions identified by Project Engineering and Systems Engineering staff. Requirement assumptions include requirements in the *Repository Design Requirements Document* (RDRD) (YMP 1994a) identified as TBD (to be determined), TBV (to be verified), and TBR (to be resolved). Design concept assumptions include identification of design judgments and/or decisions that have been made to move forward with the design. Design concepts included in the CDA Document (CRWMS M&O 1995a) are typically those that do not have sufficient technical data to support a final decision on the design. Technical data assumptions include data selected from ranges of data specified in the *Reference Information Base* (YMP 1995a) and elsewhere, as necessary, to support the MGDS ACD Report.

4.1 KEY ASSUMPTIONS

Repository key assumptions were identified by the Yucca Mountain Site Characterization Office Repository Project Engineering and Systems Engineering staff. The basic rationale for identifying an assumption as a key assumption is if the assumption involves a highly controversial issue that lacks a clear consensus among the DOE and participants or if the assumption cuts across more than one program element. Key assumptions that impact repository design are shown in Table 4-1.

Table 4-1. Key Assumptions

Description	Key Assumption Identifier	Assumption
Cask Arrival Scenario	001	The cask arrival scenario at the MGDS is as indicated in Table 4-2. Rail shipments total approximately 5,000 (MPC[1] = 4,400; HLW[2] = 600). There is a maximum of three railcars per spent nuclear fuel (SNF) shipment or five railcars per HLW shipment, with one transportation cask per railcar. Truck shipments total approximately 1,000; all uncanistered SNF. The following table is consistent with MGDSRD[3] Table 3-3. Rationale: The original source of data is from Jim Davis, Mark Fleming, John King, and Mark Rose (CRWMS M&O 1995af) and Jim Davis, Mark Fleming, and John King (CRWMS M&O 1995az). The assumption is in accordance with the Nuclear Waste Policy Act, OCRWM Mission Plan (DOE 1991), MPC concept, Proposed Program Approach (DOE 1994b), and MGDSRD and supporting requirements documents.
Waste Form Arrival Scenario	002	The waste form arrival scenario at the MGDS is as indicated in Table 4-3. The following table is consistent with MGDSRD Table 3-3. Rationale: The original source of data is from Jim Davis, Mark Fleming, John King, and Mark Rose (CRWMS M&O 1995af). The assumption is in accordance with the Nuclear Waste Policy Act, OCRWM Mission Plan (DOE 1991), MPC concept, Proposed Program Approach (DOE 1994b), and MGDSRD and supporting requirements documents.

[1] multi-purpose canister

[2] high-level waste

[3] *Mined Geologic Disposal System Requirements Document* (DOE 1995b)

Table 4-1. Key Assumptions (continued)

Description	Key Assumption Identifier	Assumption
Waste Package Emplacement Scenario Note: See Section 8 for a description of waste package	003	The waste package emplacement scenario at the MGDS for the reference thermal load is as indicated in Table 4-4. The table is compatible with the tables in Key Assumptions 001 and 002 for higher thermal loads. Total commercial SNF - 63,000 MTU[4] in about 9,000 MPCs and about 200 uncanistered fuel waste packages. The following table is consistent with MGDSRD Table 3-3. Rationale: The original source of data is from Jim Davis, Mark Fleming, John King, and Mark Rose (CRWMS M&O 1995af). The assumption is in accordance with the Nuclear Waste Policy Act, OCRWM Mission Plan (DOE 1991), MPC concept, Proposed Program Approach (DOE 1994b), and MGDSRD and supporting requirements documents.
Average SNF Characteristics	004	The average SNF characteristics upon receipt at the repository and based on the Oldest Fuel First acceptance strategy, no MRS[5], deferred dry storage, derated canisters, and four truck sites: 26.4 years old with 39.65 Gwd/MTU burnup and 3.68 wt.% enrichment [pressurized water reactor (PWR)]. 26.1 years old with 31.19 Gwd/MTU burnup and 2.97 wt.% enrichment [boiling water reactor (BWR)]. Table 4-5 provides the total repository emplacement decay heat by waste package type as a function of time. Rationale: These data have been provided by Interoffice Correspondence (CRWMS M&O, 1995az). The assumption is in accordance with the Nuclear Waste Policy Act, OCRWM Mission Plan (DOE 1991), MPC concept, Proposed Program Approach (DOE 1994b), and MGDSRD and supporting requirements documents.
Subsurface Waste Package Transport	010	Integrated rail transport will be used for subsurface transport of waste packages. Rationale: The subsurface transport must be capable of handling the current 21 and 12 PWR MPC waste package design.

[4] metric tons of uranium

[5] monitored retrievable storage

Table 4-1. Key Assumptions (continued)

Description	Key Assumption Identifier	Assumption
Horizontal In-Drift Emplacement	011	Waste packages will be emplaced in-drift in a horizontal mode. Rationale: Based on the current 21 and 12 PWR MPC program decision, the borehole emplacement option is impractical. Also, there are benefits in long-term criticality and thermal control associated with this approach.
No Human Entry in Emplacement Drifts Containing Waste Packages	013	No human entry is planned in emplacement drifts while waste packages are present. The waste emplacement/retrieval equipment may use robotics and/or remote control features to perform operations and monitoring within the emplacement drifts. Under off-normal conditions, human entry will be considered if protection to the workers can be provided. Rationale: RDRD (YMP 1994a): Geologic Repository Operations Area (GROA) shall to the extent practicable achieve occupational doses that are As Low As Reasonably Achievable (ALARA). Under off-normal conditions, radiation exposures to workers should be within allowable limits.
Retrievability Period	016	The repository will be designed for a retrievability period of up to 100 years after initiation of emplacement. Rationale: The Engineered Barrier Segment will be designed for a retrievability period of 100 years to be consistent with the repository period of retrievability. This key assumption was developed at a Key Assumption Workshop held in Las Vegas, Nevada, on May 4, 1994 (Letter W. B. Simecka to L. D. Foust, DOE 1994a).
Reasons for Retrieval	017	Retrieval of emplaced waste may be performed for the following reasons: • Failure in site, waste package, or some other system causing an unreasonable risk to public health and safety • The determination that recovery of valuable resources from the SNF is necessary. Rationale: This assumption is consistent with the NWPAA[6] guidance, and Retrievability System Study, September 1994 (CRWMS M&O 1994g).

[6] *Nuclear Waste Policy Amendments Act of 1987*

Table 4-1. Key Assumptions (continued)

Description	Key Assumption Identifier	Assumption
Thermal Load Range	019	Surface, subsurface, and waste package designs will be based on a reference thermal load of 80-100 MTU per acre. The reference thermal load for the MGDS ACD Report is 83 MTU per acre. Rationale: The reference thermal loading was developed at the CDA meeting held in Las Vegas, Nevada, on November 16, 1995 (CRWMS M&O 1995ba). No final decision regarding the design load has been made and flexibility for accommodating higher or lower thermal loads is part of the thermal strategy.
Repository Horizon	022	For the reference thermal loading of 80-100 MTU per acre, the repository horizon will be located mainly in the TSw2[7] geologic unit within the primary area. Rationale: ESFDR[8] states "the ESF Main Test Level shall be constructed at the planned repository horizon, which is currently the TSw2 rock unit." Recent evaluations indicate the TSw1/TSw2 contact is not well defined and some work within the presently defined TSw1 unit is suitable for the emplacement level. Revised assumption provides more flexibility. Primary area is consistent with site characterization activities. Primary area is as defined in *Preliminary Evaluation of the Subsurface Area Available for a Potential Nuclear Waste Repository at Yucca Mountain* (SNL 1984a). The primary area is not rigidly defined. Therefore, rigidly restricting the repository to an arbitrarily defined region is not warranted. Modest crossing of the boundary should be allowed. Assumption is consistent with the thermal strategy reference loading.

[7] Topopah Spring Welded Thermal/Mechanical Unit
[8] *Exploratory Studies Facility Design Requirements (YMP 1995i)*

Table 4-1. Key Assumptions (continued)

Description	Key Assumption Identifier	Assumption
Subsurface Fault Standoff	023	To the extent practical, repository openings will be located to avoid Type 1 faults. For unavoidable Type 1 faults that intersect emplacement drifts, allow a 15-m stand off from the edge of the fault zone to the nearest waste package. Avoidance is assumed to be adequate by using a 60-m offset from the main trace of a fault at the repository level. Exception: 120-m stand off should be used on the west side of the Ghost Dance Fault because the Topopah Spring Main Drift will be excavated before the Ghost Dance Fault characteristics are fully investigated. Rationale: NUREG -1494 (NRC 1994), Staff Technical Position on Consideration of Fault Displacement Hazards in Geologic Repository Design, September 1994. Key Assumption 023, Rev. 01, is a combined version of Key Assumption 023, Rev. 00; Key Assumption 034, Rev. 00; and Key Assumption 035, Rev. 00.

Table 4-1. Key Assumptions (continued)

Description	Key Assumption Identifier	Assumption
Site-Generated Wastes	024	Secondary site-generated waste (low-level, hazardous, mixed, and municipal) will be transported to government-approved off-site facilities for disposal. Temporary accumulations would be accommodated on-site to facilitate treatment of low-level waste, and packaging of all waste types prior to transport to designated facilities. Off-site disposal options are to be assessed. Rationale: Radioactive Waste (RW) policy excludes mixed waste from disposal at MGDS (June 22, 1995, Dreyfus memorandum bounding NEPA[9] analysis to non-RCRA[10] SNF and vitrified HLW) (DOE 1995d). Current planning calls for disposal of all secondary waste forms at off-site facilities. Low-level waste unsuitable for recycling will be collected, treated, and packaged on-site for transport to an off-site government-approved disposal facility. Mixed low-level wastes will be minimized or eliminated through waste minimization programs; if small quantities are generated, they will be collected and packaged on-site for transport to an off-site RCRA-approved treatment, storage, and disposal facility. Hazardous waste will be collected and packaged on-site for transport to an off-site RCRA-approved treatment, storage, and disposal facility. Municipal and construction wastes (non-radioactive, non-hazardous) will be collected in dumpsters for transport to state-permitted landfills.

[9] *National Environmental Policy Act of 1969*

[10] *Resource Conservation and Recovery Act*, 42 USC 6901-6987

Table 4-1. Key Assumptions (continued)

Description	Key Assumption Identifier	Assumption
Mechanical Tunnel Excavation	027	The primary method of tunnel excavation will be mechanical. Rationale: 10 CFR 60.133e(2): Openings shall be designed to reduce deleterious rock movement. 10 CFR 60.133(f): Use excavation methods that limit potential for creating preferential pathways for groundwater. NUREG 1347, Comment 132 (NRC 1989a): Compare the alternatives of drilling and blasting and mechanical excavation methods. Nuclear Waste Technical Review Board's (NWTRB) First Report to Congress (NWTRB 1990): Maximize use of the most modern mechanical excavation techniques in studies of tunnel excavation methods. Results of the ESF Alternative Study (SNL 1991) recommended mechanical excavation.
Tunnel Drill-and-Blast Option	028	Where it is impractical to use mechanical methods, drill-and-blast may be used to a limited degree primarily in non-emplacement areas of the repository. Rationale: 10 CFR 60.133e(2): Openings shall be designed to reduce deleterious rock movement. 10 CFR 60.133(f): Use excavation methods that limit potential for creating preferential pathways for groundwater. NUREG 1347, Comment 132 (NRC 1989a): Compare the alternatives of drilling and blasting and mechanical excavation methods. NWTRB First Report to Congress (NWTRB 1990): Maximize use of the most modern mechanical excavation techniques in studies of tunnel excavation methods. Results of the ESF Alternative Study (SNL 1991) recommended mechanical excavation.
Underground Rail Transport of Personnel and Supplies	030	Rail will be used for transporting underground supplies and personnel to the extent practical. Rationale: Rail system is compatible with handling of the current 21 and 12 PWR MPC waste package. Rail system is well-suited to in-drift emplacement mode. Ideal for supplying tunnel boring machine (TBM) operation and transportation of personnel. Repository subsurface gradient will allow use of rail system. Highly suitable for remote handled or automated operations.

Table 4-1. Key Assumptions (continued)

Description	Key Assumption Identifier	Assumption
Waste Package Shielding	031	A. Waste package containment barriers will provide sufficient shielding for protection of waste package materials from radiation-enhanced corrosion. B. Individual waste packages will not provide any additional shielding for personnel protection. C. Additional shielding for personnel protection will be provided on the subsurface transporter and in surface and subsurface facilities. Rationale: The cost, size, and weight of an individually shielded waste packages may be excessive; therefore, MGDS will meet ALARA requirement with more cost-effective shielding options. Personnel radiation protection from individual waste packages will be provided through the use of: (1) Remote handling equipment in the assembly and emplacement areas (2) A shielded waste package transporter during emplacement operations (3) Shielding and seals at the entrances to the emplacement drifts.
Backfill in Emplacement Drifts	046	Current design assumes no backfill in emplacement drifts. Options for backfill will be considered based on ongoing and future backfill studies. Rationale: No performance credit is currently allocated to backfill (since no backfill is assumed). Waste package will be designed to withstand expected rockfall during the substantially complete containment period. Potentially difficult and expensive to emplace a backfill. Backfill consisting of excavated or new materials will be evaluated to determine possible negative attributes including the potential to add thermal insulation, the potential to cause crevice corrosion, and potential to act as a water wick.

Table 4-1. Key Assumptions (continued)

Description	Key Assumption Identifier	Assumption
Backfill in Emplacement Drifts (continued)	046	Backfill consisting of excavated or new materials will be evaluated to determine the effectiveness of backfill to provide a capillary barrier, to control relative humidity at the waste package surface, to spread the flow of water and provide a drip barrier, to provide a diffusion barrier, to provide a retardation barrier for the transport of radionuclides, to provide structural protection to the waste package, and to provide a chemical barrier (before and/or after water enters/exits the waste package). Backfill requirements will be established once values and characteristics of the backfill are well understood.
Surface Facilities Location	047	The proposed repository waste handling and administrative surface facilities will be located adjacent to the North Portal. Rationale: SCP-CDR[11] proposed the location of the central surface facilities at the entrance to the waste ramp portal. Northern Midway Valley is more likely to contain an area demonstrably free of late Quaternary surface faults. The ESF alternatives study recommended relocation of the waste and tuff ramps portals based on Option 30 findings. The current technical baseline identifies a North and South Portal locations in accordance with the ESF enhanced configuration. The ESF is presently located at the entrance to the north portal. The South Portal will have a steeper ramp grade (2.57%) compared to the North Portal ramp (2.15%). Planned site improvements for the ESF can be used for the proposed repository surface facilities.

[11] *Site Characterization Plan Conceptual Design Report* (SNL 1987)

Table 4-1. Key Assumptions (continued)

Description	Key Assumption Identifier	Assumption
Addition of Filler Material at the Repository	052	Table 4-6 provides a scenario for receipt of first procurement MPCs that may have to be opened each year at the repository for the insertion of reactivity control additives. The table may be used to provide an upper bound for abnormal MPCs requiring remedial operations at the repository. Rationale: Based on programmatic guidance documented in (CRWMS M&O 1995bb), verification assumptions made in that memo and complete execution of the direction, this assumption should provide an upper bound on the number of MPCs needing remedial operations at the repository. The table is based on several considerations: (1) the assumption that five years of MPCs from the first procurement could be deployed and loaded with fuel that may not meet final disposal requirements on MPCs; (2) several criticality control-related activities must occur before disposal requirements on MPCs could be finalized (e.g., completion of the Disposal Criticality Control Topical Report, approval of a Burnup Credit Topical report that would include principal isotopes (including some fission products) and completion of basket material corrosion testing; (3) the analysis in the memo indicated below. Based on these assumptions and this analysis, 113 of the first procurement MPCs will require additional criticality control measures. This number was determined by comparing each of the 544 individual MPC k_{∞} values with an estimated value that reflected the demarcation point between those MPCs that should be opened and those that did not have to be opened. This estimated value, which assumes principal isotope burnup credit and no credit for engineered neutron absorbers, varied depending on whether the MPC being evaluated was large or small, and whether it contained BWR or PWR assemblies. This analysis is described in detail in the memo from M.A. Balady, "Update to Rationale for Selection of First Procurement MPCs to be Opened" (CRWMS M&O 1995bc). The reopening of MPCs will be an off-normal operation. Adding filler additives or other reactivity control additives will also be considered an off-normal operation.

Table 4-1. Key Assumptions (continued)

Description	Key Assumption Identifier	Assumption
Off-Normal Waste Handling Building (WHB) Capability	053	The MGDS shall have the capability to handle any abnormal MPCs and other canistered waste forms that require remedial processing. Such processing may include opening the canister, transferring the waste form, adding filler material, and resealing. Rationale: Since this MGDS requirement excludes other methods of opening an MPC except for cutting it open, it is assumed that this requirement pertains to MPCs intended not to be opened. Also, the referenced 10 CFR 60 and *CRWMS Requirements Document* (DOE 1995a) sections are off-normal headings. Therefore, this requirement applies to an off-normal occurrence. The justification for moving the spent fuel assembly in and out or even resealing an MPC before being sealed into a waste package is not clear. The importance of undamaged waste is also unclear. Surface design will provide for the area necessary to open an MPC, based on the assumption that this analysis either exists or will be provided. Opening an MPC is considered an off-normal occurrence. A separate cell is proposed to prevent special operations from interfering with normal waste handling operations. It is assumed that, until better defined, the probable equipment and systems (such as cutter, welder, and bare fuel handler) in the special operations cell for uncanistered fuel assembly casks and performance confirmation will accommodate the mitigation needs of an off-normal MPC. This special operations cell will need to be adaptable to multiple functional roles for one-time or low-volume events. Probable events and best remedial methodology will need to be investigated before operations and equipment can be defined for this area. Programmatic guidance defines an approach where filler material may be unnecessary (CRWMS M&O 1995bb).

Table 4-1. Key Assumptions (continued)

Description	Key Assumption Identifier	Assumption
Normal WHB Capability (No Filler Material)	054	The design for the WHB MPC standard handling operations is based on no capability to add filler material to MPCs at the repository. The addition of filler material to first procurement MPCs will be performed as an off-normal operation in accordance with Key Assumption 053. Rationale: Programmatic guidance defines an approach where filler material may be unnecessary (CRMWS M&O 1995bb). Since the initial MPC deployment would occur in the years prior to the opening of the repository, those MPCs would be held in some temporary storage yet to be defined. Therefore, it is reasonable to administratively control the shipment of these early MPCs, spreading them evenly over the long duration of repository waste handling operations. They could then be handled as off-normal units that would not interfere with the normal flow of modern MPCs through the WHB operations. A separate cell for accommodating unusual or off-normal operations is presently planned (see Key Assumption 053). Such limited operations could include performance confirmation examinations, bare fuel assembly handling, and opening damaged MPCs. When the modification criteria for these early MPCs are established, this off-normal operation cell design could be modified to correct the MPC as required (filler material, repack, etc.).
Retrieval Demonstration	055	Proof-of-principle demonstrations of waste package retrieval will be conducted following license application. The proof-of-principle demonstration is consistent with the DOE position as stated in Appendix D, "Department of Energy Position of Retrievability for a Geologic Repository," of the Generic Requirements Document for a Mined Geologic Disposal System (OGR/B-2) (DOE 1987c).
Interim Fuel Storage	056	The repository will interface with an interim storage facility located outside the State of Nevada. Rationale: Interim storage is a Congressional program requirement.
Burnup Measurements	057	Burnup measurements of bare uncanistered SNF assemblies, if required at the repository, will be performed non-destructively. Rationale: Burnup measurements of SNF in MPCs will be performed, if required, at purchaser sites. Surface repository will not have the facilities to perform destructive testing. This assumption is based on the future successful development of radiation-based non-destructive measurement equipment.

Table 4-1. Key Assumptions (continued)

Description	Key Assumption Identifier	Assumption
Transportation Mode/Route within Nevada	058	SNF and HLW arriving in Nevada on main line commercial rail lines will be transported to the repository via rail. Rail routes being considered are described in the *Nevada Potential Repository Preliminary Transportation Strategy, Study 2* (CRWMS M&O 1995ax). For costing purposes, four of the routes being considered will be evaluated using a straight average. The four routes to be averaged are (1) Caliente-base route, (2) Carlin-Monitor Valley via Ralston, (3) Valley Modified-via Indian Hills, and (4) Jean-Wilson Pass Option via Stewart Valley. Rationale: These were the least expensive options from the four rail corridors being considered according to the findings of the *Nevada Potential Repository Preliminary Transportation Strategy, Study 2* (CRWMS M&O 1995ax). Using the average of four routes is consistent with the position that the route will be selected once the NEPA process is concluded. It is noted that no decision has been made relative to the transportation mode. The heavy haul transportation mode remains an option. The final decision can be made only in accordance with the NEPA process.

Table 4-1. Key Assumptions (continued)

Description	Key Assumption Identifier	Assumption
MGDS Architecture	059	The configuration item groups (CIGs) of the repository (surface and subsurface) are organized as shown: Surface Repository - Site Preparation Systems - Site Transportation Systems - Site Utilities Systems - Waste Handling Facilities - Operational Support Facilities - General Support Facilities - Surface Closure - Off-site Utilities - Off-site Transportation Subsurface Repository - UG[12] Excavated Openings - UG Support Facilities - UG Utilities Systems - UG Ventilation Systems - UG Shielding Equipment/Systems - UG Waste Package Handling Equipment - UG Operations Support Systems - UG Closure - UG Performance Confirmation Systems - UG Construction Equipment and Temporary Facilities Rationale: The CIGs are based on ACD development and configuration management.

[12] Underground

Table 4-2. Transportation Cask Arrival Scenario

Key 001	Transportation Cask Arrival Scenario								
Cask Contents	MPC					Uncanistered Fuel Assemblies		HLW Canister	Total Casks per Year
Cask Designation	B-LG	P-LG	B-SM	P-SM	B-IN-P	B-LWT	P-LWT	HLW	
Year*	Number of Transportation Casks**								
1	24	12	11	5	0	1	9	0	62
2	20	21	43	26	2	0	25	0	137
3	28	61	80	22	1	1	64	0	257
4	63	116	88	31	2	0	52	0	352
5	120	163	87	34	4	0	72	0	480
6	88	179	111	43	3	1	54	159	638
7	100	190	76	36	3	0	69	161	635
8	106	189	87	34	2	0	54	160	632
9	98	212	62	28	4	0	43	160	607
10	101	196	54	37	1	0	48	159	596
11	98	206	46	46	2	0	29	160	587
12	102	193	72	29	2	0	40	160	598
13	105	211	39	40	2	0	55	160	612
14	113	187	59	37	3	0	29	161	589
15	116	204	62	18	1	0	36	160	597
16	86	210	61	38	0	0	33	160	588
17	111	201	40	29	8	0	57	159	605
18	119	202	63	28	0	0	10	160	582
19	100	206	47	40	0	0	60	160	613
20	98	205	74	33	0	0	37	160	607
21	123	191	56	41	0	0	41	37	489
22	139	185	49	33	0	0	23	87	516
23	115	182	84	34	0	0	57	83	555
24	69	119	54	23	0	0	29	0	294
Total Casks	2,242	4,041	1,505	765	40	3	1,026	2,606	12,228

* Year of MGDS Operation

** Cask quantities are the number of unit casks arriving; they do not necessarily imply that each cask is fully loaded.

Table 4-2. Transportation Cask Arrival Scenario (continued)

Key 001 Legend		
MPC	B-LG	Transportation cask that holds a large BWR MPC containing a maximum of 40 assemblies
	P-LG	Transportation cask that holds a large PWR MPC containing a maximum of 21 assemblies
	B-SM	Transportation cask that holds a small BWR MPC containing a maximum of 24 assemblies
	P-SM	Transportation cask that holds a small PWR MPC containing a maximum of 12 assemblies
	B-IN-P	Transportation cask that holds a small PWR MPC containing a maximum of 12 Big Rock Point assemblies
Uncanistered Fuel Assemblies	B-LWT	GA-9 transportation cask that holds a maximum of 9 BWR assemblies
	P-LWT	GA-4 transportation cask that holds a maximum of 4 PWR assemblies
HLW Canister	HLW	Transportation cask that holds a maximum of 5 defense or commercial HLW canisters
Base Case Waste Stream, 2010 MGDS, oldest fuel first (OFF) with Deferred Dry Storage, Derated Canisters, 4 Truck Sites		

Table 4-3. Waste Form Arrival Scenario

Key 002	Waste Form Arrival Scenario								
Waste Form (WF)	MPC					Uncanistered Fuel Assemblies		HLW Canister	Total Waste Form Units per Year
WF Designation	B-LG	P-LG	B-SM	P-SM	B-IN-P	B-LWT	P-LWT	HLW	
Max WF Units per Transp. Cask	1	1	1	1	1	9	4	5	
Year*	Number of Waste Form Units								
1	24	12	11	5	0	1	36	0	89
2	20	21	43	26	2	0	100	0	212
3	28	61	80	22	1	4	253	0	449
4	63	116	88	31	2	0	208	0	508
5	120	163	87	34	4	0	288	0	696
6	88	179	111	43	3	2	213	795	1,434
7	100	190	76	36	3	0	276	805	1,486
8	106	189	87	34	2	0	216	800	1,434
9	98	212	62	28	4	0	172	800	1,376
10	101	196	54	37	1	0	192	795	1,376
11	98	206	46	46	2	0	116	800	1,314
12	102	193	72	29	2	0	153	800	1,351
13	105	211	39	40	2	0	191	800	1,388
14	113	187	59	37	3	0	112	805	1,316
15	116	204	62	18	1	0	118	800	1,319
16	86	210	61	38	0	0	111	800	1,306
17	111	201	40	29	8	0	188	795	1,372
18	119	202	63	28	0	0	40	800	1,252
19	100	206	47	40	0	0	185	800	1,378
20	98	205	74	33	0	0	110	800	1,320
21	123	191	56	41	0	0	130	185	726
22	139	185	49	33	0	0	62	435	903
23	115	182	84	34	0	0	188	408	1,011
24	69	119	54	23	0	0	61	0	326
Total Handling Units	2,242	4,041	1,505	765	40	7	3,719	13,023	25,342

* Year of MGDS Operations

Table 4-3. Waste Form Arrival Scenario (Continued)

Key 002 Legend		
MPC	B-LG	Large BWR MPC containing a maximum of 40 assemblies
	P-LG	Large PWR MPC containing a maximum of 21 assemblies
	B-SM	Small BWR MPC containing a maximum of 24 assemblies
	P-SM	Small PWR MPC containing a maximum of 12 assemblies
	B-IN-P	Small PWR MPC containing a maximum of 12 Big Rock Point assemblies
Uncanistered Fuel Assemblies	B-LWT	BWR assembly
	P-LWT	PWR assembly
HLW Canister	HLW	Defense or commercial HLW canister
Base Case Waste Stream, 2010 MGDS, OFF with Deferred Dry Storage, Derated Canisters, 4 Truck Sites		

Table 4-4. Waste Package Emplacement Scenario

Key 003	Waste Package Emplacement Scenario								
WP Content	MPC					Uncanistered Fuel Assemblies		HLW Canister	Total Waste Pkgs per Year
WP Content Designation	B-LG	P-LG	B-SM	P-SM	B-IN-P	B-LWT	P-LWT	HLW	
Max Waste Form Units per WP	1	1	1	1	1	40	21	4	
Year*	Number of Waste Packages**								
1	24	12	11	5	0	1	1	0	54
2	20	21	43	26	2	0	5	0	117
3	28	61	80	22	1	1	12	0	205
4	63	116	88	31	2	0	10	0	310
5	120	163	87	34	4	0	14	0	422
6	88	179	111	43	3	1	10	199	634
7	100	190	76	36	3	0	13	202	620
8	106	189	87	34	2	0	10	200	628
9	98	212	62	28	4	0	8	200	612
10	101	196	54	37	1	0	10	199	598
11	98	206	46	46	2	0	5	200	603
12	102	193	72	29	2	0	7	200	605
13	105	211	39	40	2	0	10	200	607
14	113	187	59	37	3	0	5	202	606
15	116	204	62	18	1	0	6	200	607
16	86	210	61	38	0	0	5	200	600
17	111	201	40	29	8	0	9	199	597
18	119	202	63	28	0	0	2	200	614
19	100	206	47	40	0	0	9	200	602
20	98	205	74	33	0	0	6	200	616
21	123	191	56	41	0	0	7	47	465
22	139	185	49	33	0	0	4	109	519
23	115	182	84	34	0	0	10	102	527
24	69	119	54	23	0	0	4	0	269
Total WPs	2,242	4,041	1,505	765	40	3	182	3,259	12,037

* Year of MGDS operation

** For UCF and HLW packages, numbers are rounded up; WP may not be fully loaded

Table 4-4. Waste Package Emplacement Scenario (Continued)

Key 003 Legend		
MPC	B-LG	Waste package that holds a large BWR MPC containing a maximum of 40 assemblies
	P-LG	Waste package that holds a large PWR MPC containing a maximum of 21 assemblies
	B-SM	Waste package that holds a small BWR MPC containing a maximum of 24 assemblies
	P-SM	Waste package that holds a small PWR MPC containing a maximum of 12 assemblies
	B-IN-P	Waste package that holds a small PWR MPC containing a maximum of 12 Big Rock Point assemblies
Uncanistered Fuel Assemblies	B-LWT	UCF waste package that holds a maximum of 40 BWR assemblies
	P-LWT	UCF waste package that holds a maximum of 21 PWR assemblies
HLW Canister	HLW	Waste package that holds a maximum of 4 defense or commercial HLW canisters
Base Case Waste Stream, 2010 MGDS, OFF with Deferred Dry Storage, Derated Canisters, 4 Truck Sites		

Table 4-5. Repository Total Heat Output

FY95CDAO - OFF, DERATE, DEFERRED DRY STORAGE, 4 TRUCK SITES										
MGDS TOTAL HEAT OUTPUT [MW]										
Year*	Total REP	Total BWR	Total PWR	B-LWT	P-LWT	B-LG	P-LG	B-SM	P-SM	B-IN-P
0	62.96	20.27	43.68	0.00	1.56	15.29	37.22	4.95	3.90	0.03
10	52.03	16.75	35.28	0.00	1.31	12.56	30.75	4.17	3.22	0.03
20	44.14	14.24	29.90	0.00	1.11	10.65	26.06	3.57	2.72	0.02
30	37.92	12.25	25.67	0.00	0.96	9.15	22.39	3.09	2.33	0.02
40	33.00	10.71	22.29	0.00	0.84	7.98	19.44	2.71	2.02	0.02
50	29.04	9.44	19.60	0.00	0.74	7.02	17.09	2.41	1.77	0.02
60	25.84	8.42	17.42	0.00	0.65	6.26	15.19	2.15	1.57	0.01
70	23.20	7.60	15.61	0.00	0.59	5.63	13.62	1.96	1.40	0.01
80	21.11	6.94	14.17	0.00	0.54	5.13	12.37	1.79	1.27	0.01
90	19.34	6.37	12.96	0.00	0.49	4.71	11.31	1.66	1.16	0.01
100	17.92	5.93	11.99	0.00	0.46	4.37	10.47	1.55	1.07	0.01
200	11.26	3.78	7.48	0.00	0.28	2.76	6.55	1.01	0.65	0.01
300	8.92	3.01	5.91	0.00	0.22	2.19	5.17	0.81	0.51	0.01
400	7.52	2.54	4.99	0.00	0.19	1.84	4.36	0.69	0.43	0.00
500	6.52	2.20	4.33	0.00	0.16	1.60	3.79	0.60	0.38	0.00
600	5.73	1.93	3.80	0.00	0.14	1.40	3.33	0.52	0.33	0.00
700	5.11	1.71	3.40	0.00	0.13	1.24	2.97	0.47	0.30	0.00
800	4.58	1.53	3.05	0.00	0.12	1.11	2.67	0.42	0.27	0.00
900	4.15	1.38	2.77	0.00	0.11	1.00	2.42	0.38	0.24	0.00
1000	3.79	1.26	2.54	0.00	0.10	0.91	2.22	0.34	0.22	0.00
2000	2.03	0.65	1.38	0.00	0.05	0.48	1.20	0.18	0.12	0.00
3000	1.58	0.50	1.08	0.00	0.04	0.36	0.95	0.14	0.10	0.00
4000	1.41	0.44	0.97	0.00	0.04	0.32	0.84	0.12	0.09	0.00
5000	1.32	0.41	0.90	0.00	0.04	0.30	0.79	0.11	0.08	0.00
6000	1.22	0.38	0.83	0.00	0.03	0.28	0.73	0.10	0.07	0.00
7000	1.14	0.36	0.78	0.00	0.03	0.26	0.68	0.10	0.07	0.00
8000	1.07	0.34	0.73	0.00	0.03	0.24	0.64	0.09	0.06	0.00
9000	1.01	0.32	0.69	0.00	0.03	0.23	0.60	0.09	0.06	0.00
10000	0.96	0.30	0.65	0.00	0.03	0.22	0.57	0.08	0.06	0.00

Notes: Total BWR column is the sum of B-LWT + B-LG + B-SM + B-IN-P
Total PWR column is the sum of P-LWT + P-LG + P-SM
Total REP column is the sum of Total BWR + Total PWR

* Time scale is based on the collapse technique (see Rationale). Time 0 is emplacement time; however, time dating is inaccurate for 0-100 year and more accurate for longer term calculations.

Table 4-6. First MPC Procurement Requiring Opening at Repository, No MRS, 2010 MGDS, Off (FY95DAO)

Years*	MPCs					Total
	B-LG	P-LG	B-SM	P-SM	B-in-P	
1	0	0	0	3	0	3
2	0	0	0	3	0	3
3	0	0	0	4	0	4
4	0	1	0	7	0	8
5	0	5	0	1	0	6
6	0	4	0	0	0	4
7	0	6	0	3	0	4
8	0	0	1	0	0	1
9	0	10	0	0	0	10
10	0	6	0	1	0	7
11	0	1	0	7	0	8
12	0	18	0	0	0	18
13	0	6	0	0	0	6
14	0	1	0	0	0	1
15	0	1	0	0	0	1
16	0	9	0	0	0	9
17	0	8	0	0	0	8
18	0	4	0	0	0	4
19	0	4	0	0	0	4
20	0	3	0	0	0	3
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0
Total	0	87	1	29	0	117

*Years of MGDS operation
BASIS (CRMWS M&O 1995af)

Program Approach scenario (No MRS).

First procurement MPCs in the five-year period 1998-2002 are loaded with OFF and placed in reactor dry storage.

Pickup from dry storage is deferred until no fuel older than 10 years remains in spent fuel pools.

Pickup from only four trucks (no-rail) purchasing utilities is assumed.

Waste package heat limit for emplacement is 14.2 kW.

Transportation casks are derated as shown.

Cask Derating

Operation	MPC Heat Limits (kW)			
	B-LG	P-LG	B-SM	P-SM
Storage	17.60	23.90*	10.56	13.68
Transportation	12.0	14.20	7.20	8.76
Emplacement	14.20	14.20	14.20	14.20

See Key Assumptions 001 to 003 for legend.

*17.85 kW used at various sites for post-shutdown dry storage.

4.2 REPOSITORY DESIGN REQUIREMENTS DOCUMENT ASSUMPTIONS

The assumptions for requirements in the RDRD (YMP 1994a) identified as TBD (to be determined), TBV (to be verified), and TBR (to be resolved) are provided in Table 4-7. Appropriate requirements assumptions are provided for surface and subsurface repository in the sections that follow.

Table 4-7. Requirements Assumptions

Description	RDRD Assumption Identifier	Assumption
Waste Receiving Schedule	RDRD 3.2.1.2.B	Design of waste handling operations are presently based on tables in Key Assumptions 001, 002, 003, and 052. Rationale: Key Assumptions 001, 002, 003, and 052 contain the latest and most accurate data available; they are being used by Surface Design to proceed with waste handling design. Further updates are expected.
Disposal System Postclosure Performance	RDRD 3.2.1.6.C	The disposal system shall be designed to provide a reasonable expectation, based on performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table A-1 of Appendix A of 40 CFR 191; and have a likelihood of less than one chance in 1,000 of exceeding 10 times the quantities calculated according to Table A-1 of Appendix A of 40 CFR 191. Rationale: The removal of the "TBR" does not change the basic concept of the MGDS design to be compatible with specific long-term (10,000 years) performance goals. Thus, the MGDS design must complement, or at least not adversely impact, those goals set in 40 CFR 191, Appendix A, and elsewhere, such as 10 CFR 960.4-2-1; 10 CFR 960.4-2-7; and 10 CFR 960.5-2-11.
Physical Barriers	RDRD 3.2.1.6.D	Facilities shall be provided to support active institutional controls at the repository site, including physical barriers to human intrusion. Facilities to maintain the institutional controls and physical barriers shall also be provided. Rationale: Logic says the apparent wording was not what was intended. Physical barriers to maintenance facilities make no sense. Detail beyond the need for such facilities and barriers is not deemed necessary for ACD.

Table 4-7. Requirements Assumptions (continued)

Description	RDRD Assumption Identifier	Assumption
Emplacement Concept	RDRD 3.2.3.2.2.A.7	The Repository Segment shall accommodate the emplacement concept selected during ACD. Rationale: The requirement as stated is valid without the TBD. There is no need for the RDRD to specify what that emplacement method will be. The method will be determined during ACD.
Repository Layout to Limit Waste Package-Water Contact	RDRD 3.2.3.2.2.A.11.a	The repository layout shall be designed so that a combination of characteristics will limit the amount of liquid water allowed to come into contact with the waste packages consistent with the requirement that, at most, 1% of the waste packages will be breached at a 1,000 years and that the mean time to breaching is well in excess of 1,000 years. Rationale: The requirement, as written, supports the concept of substantially complete containment developed as a Key Assumption at a Key Assumption Workshop held in Las Vegas, Nevada, on May 4, 1994 (Letter W.B. Simecka to L.D. Foust, DOE 1994a). (Key Assumptions 037 and 038 of this document.)
Non-Potable Water	RDRD 3.2.3.4.B	The Repository Segment will connect with the existing NTS[13] water supply system. Rationale: Use existing water supply system.
Telephone Communications	RDRD 3.2.3.4.D	The Repository Segment shall connect to the existing NTS telephone system. Rationale: DOE/NTS Standard Operating Procedure Chapter 5301, Telecommunications, defines the responsibilities and interfaces for all aspects of telecommunications at the Nevada Test Site. RDRD requirement 3.2.3.4.D is consistent with current policy. See the following: YMP-FOI-5301, Field Telecommunications NTS-SOP-5301, Telecommunications NTS-SOP-5302, Telecommunications – Radio Utilization Program

[13] Nevada Test Site

Table 4-7. Requirements Assumptions (continued)

Description	RDRD Assumption Identifier	Assumption
Special Sources of Groundwater	RDRD 3.7.1.C	There are no special sources of groundwater at Yucca Mountain as defined in 40 CFR 191.12(0); therefore, the requirements of 40 CFR 191.16 do not impact Yucca Mountain. Rationale: "Special source of groundwater" is defined in 40 CFR 191.12(o) as those Class I groundwaters identified in the EPA's Groundwater Protection Strategy that: (1) are within the repository controlled area or are less than 5 km beyond the controlled area; (2) are supplying drinking water for thousands of persons near Yucca Mountain; and (3) are irreplaceable in that no reasonable alternative of drinking water is available to that population. The conditions that must be met for designation as a Class I source are that the source is irreplaceable in that no reasonable alternative is available to substantial populations or that the source is ecologically vital in that it provides baseflow to a sensitive ecological system. If it is determined that there are no special sources of water at or near Yucca Mountain, the requirements of 40 CFR 191.16 will not impact the project. Based on preliminary investigations at the site, there do not appear to be any special sources of water at the site, below the site, within the boundaries of the controlled area, or within 5 km of the controlled area boundary (see Section 8.3.5.1.5 of the SCP[14] for a discussion of special sources of groundwater, and Page 8.3.5.15-6 for a discussion of preliminary findings). Therefore, based on these findings, it is assumed that the requirements of 40 CFR 191.16 will not impact Yucca Mountain.
General Underground Lighting	RDRD 3.7.3.5.A.1	General lighting for underground shall meet OSHA[15] and MSHA[16] codes. Rationale: Setting numerical limits for underground lighting should not be in the RDRD. Those limits are established in building codes governing underground construction, as well as MSHA and OSHA requirements, and MIL-STD-1472D.[17]

[14] *Site Characterization Plan* (DOE 1988a)

[15] Occupational Safety and Health Administration

[16] Mine Safety and Health Administration

[17] HFE Design Criteria for Military Systems, Equipment, and Facilities

Table 4-7. Requirements Assumptions (continued)

Description	RDRD Assumption Identifier	Assumption
Underground Service Facilities Lighting	RDRD 3.7.3.5.A.2	General lighting for underground service facilities not related to waste handling or security shall meet OSHA and MSHA codes. Rationale: Setting numerical limits for underground lighting should not be in the RDRD. Those limits are established in building codes governing underground construction, as well as MSHA and OSHA requirements and MIL-STD-1472D.
Site-Generated Hazardous Waste	RDRD 3.7.3.9.E	Hazardous waste will be collected and packaged on-site for transport to an off-site RCRA-approved treatment, storage, and disposal facility. Rationale: This assumption is needed to document the requirement to provide compliance with appropriate DOE requirements involving the handling of nonradioactive hazardous wastes. The quantities of this waste will be determined during the course of the ACD. See related Key Assumption 024.
Storage Capacity for Waste Receipts	RDRD 3.7.4.1.A.2	The corresponding RDRD requirement is deleted (based on RDRD - 3.7.4.1.A.3 assumption). Rationale: Requirement for surface facility holding or buffer areas will determine the capacity of waste handling facility or other facility storage requirements. No need for requirement. See Rationale for Assumption RDRD 3.7.4.1.A.3

Table 4-7. Requirements Assumptions (continued)

Description	RDRD Assumption Identifier	Assumption
Waste Handling Holding Areas	RDRD 3.7.4.1.A.3	Waste handling facilities shall have buffer or holding areas at certain steps spread out within these operations. These areas will have sufficient capacity so that in the event of an unplanned stoppage, operations may be completed to a reasonable safety shutdown condition. This includes the receipt of in-transit casks, emptying casks, filling and sealing disposal containers, and decontaminating and emptying cask dispatch. Rationale: The term "storage" has many connotations on this project. Capacity to receive unlimited off-site waste has significant design impact, which cannot be necessarily met at this time. Until other criteria is established to limit this capacity, this assumption defines the limit as that waste that is in-processing or in-transit to reduce the need to reverse an operation as a result of a stoppage anywhere in the MGDS. "Buffer" capacity is needed to provide "surge" in the process activities and to maintain steady process flow in the overall system. Because the NWPA does not permit extensive, long-term, interim storage at the repository, this assumption interprets any reference to storage in surface facilities as a short-term holding area for steady process flow and for safe, unplanned stoppages. Holding area capacities will be determined by design process flow simulations.
Underground Air Supply	RDRD 3.7.5.B.6	Supply air to and exhaust adequate quantities of air to and from underground working areas such that operator safety, health, and productivity requirements are maintained. Rationale: The requirement as stated is valid without the TBD. The air quantity is architecture and operations dependent and does not belong in the RDRD.
Shaft Size	RDRD 3.7.5.N.5	If shafts are used, the shaft size shall be determined by the size of the conveyances needed to move materials, personnel, and equipment underground; the volume of ventilation flow needed; and the space required for utility lines. Rationale: The requirement as stated is valid without the TBD. The requirement gives the criteria for determining the shaft size; it need not also give the shaft size or the areas required for the items used to determine the shaft size. These will be determined during design and are architecture and operations dependent.

4.3 DESIGN CONCEPT ASSUMPTIONS

Design concept assumptions for the surface and subsurface repository are identified in Table 4-8 as DCS and DCSS, respectively. The appropriate design concept assumptions are provided for surface and subsurface repository in the sections that follow.

Table 4-8. Design Concept Assumptions

Description	Design Concept Identifier	Assumption
MGDS Operational Center	DCS 001	A future MGDS operational center will be required to maintain communications with the transportation network, maintain inventories, and support security and safeguards requirements. This center will be located at the repository.
Occupational Exposure Limits	DCS 003	Surface facilities housing radioactive materials or in which work is performed on radioactive materials will be designed to control occupational exposures to ALARA and less than 500 millirem per year.
ALARA Studies	DCS 004	ALARA studies will be conducted as needed to establish the allowable dose rates upon which various radiological safety calculations will be based.
One WHB	DCS 005	WHBs 1 and 2 in the SCP-CDR will be consolidated into a single structure.
Waste Treatment Building (WTB)	DCS 007	A WTB will be incorporated into the GROA to treat solid and liquid low-level radioactive wastes in preparation for transport to a government-approved off-site facility for treatment, storage, and disposal.
Decontamination Equipment and Space	DCS 008	Necessary equipment and space required for decontamination will be provided in each building where contamination will be present.
Hazardous Waste Disposal	DCS 010	Hazardous waste will be accumulated and staged for up to 90 days at the source of generation. These wastes will be periodically transported to an RCRA-approved off-site treatment, storage, and disposal facility. Subsurface hazardous wastes will be collected at a surface staging area outside the radiologically controlled area (RCA).
Underground Waste Generation	DCS 011	Significant quantities of secondary mixed or low-level radioactive wastes will not be generated by underground emplacement operations.
No HLW in Waste Treatment Building	DCS 012	The WTB will not process secondary transuranic or HLW. If such waste materials are generated, they will be packaged at the point of generation and disposed in the underground emplacement area via the WHB.

Table 4-8. Design Concept Assumptions (continued)

Description	Design Concept Identifier	Assumption
Waste Generated by Performance Confirmation Activities	DCS 013	Waste quantities generated by the performance confirmation operations will be: • Negligible during the construction/emplacement phase of the MGDS. • Less during the caretaker phase than the waste quantities generated during the construction/emplacement phase normal and off-normal operations. As a result, wastes generated by the performance confirmation operations will not impact the design of the WTB.
Cask Maintenance Operation	DCS 014	Cask maintenance facilities may be integrated into facilities rather than in a separate, standalone structure.
Transportation Cask Fleet Inventory	DCS 015	The cask fleet inventory is based on a sealed canister system (MPC or dual purpose) and consists of a maximum of 12 truck casks and 72 rail casks.
Transportation Cask Fleet Maintenance Frequency	DCS 016	Maintenance requirements for the transportation fleet (as identified in DCS 015) will be comparable to those for existing casks. • Each truck cask is serviced a maximum of three times per year. During one visit, the cask system certificate of compliance inspection is performed. • Each rail cask is serviced once per year during the certificate of compliance inspection.
Repository Layout-Orientation	DCSS 001	Repository layout - preferred orientation: • Orientation of emplacement drifts will be at least 30 degrees from dominant joint orientations. Using the latest information on joint orientations, the emplacement drift orientation will generally fall between N70W and S75W. • Orientation of maintainable access drifts, mains, ramps, etc., will be as needed to complement emplacement drift orientation, generally forming intersections of 70 to 90 degrees where practicable. Repository layout - contingency orientation: • Contingency layouts not meeting the preferred orientations are required in case substantiation of TDSS-017 indicates the joint orientations assumed are incorrect.

Table 4-8. Design Concept Assumptions (continued)

Description	Design Concept Identifier	Assumption
Drift Excavation Methods	DCSS 005	Drift excavation methods: • Primary: TBM • Secondary: other mechanical methods, and drill-and-blast where mechanical methods are impractical.
Maximum Excavation Extraction Ratio	DCSS 006	Maximum excavation extraction ratio for emplacement drifts: 30%.
Maximum Ramp Grade	DCSS 009	Maximum grade in ramps: ≤3% to accommodate rail transport. Maximum grade in mains: minimize, but ≤2% in mains used for emplacement drift access. Maximum grade in emplacement drifts: minimize within 0.25 to 0.75% range for drainage.
Repository Material Handling Equipment	DCSS 010	Repository material handling equipment: • Supplies: Rail transport • Excavated rock: Conveyor belt, or conveyor belt variation preferred when practical.
Shaft Excavation Method	DCSS 014	Shaft excavation method: Mechanical where practical.
Ventilated Air Properties	DCSS 015	Properties of ventilation air: standard density: 1.2 kg/m^3 Thermal conductivity: 0.02564 W/mK Heat capacity: 1.2082 kJ/m^3K
Maximum Underground Air Velocity	DCSS 016	Maximum allowable air velocity in: Ramps: 7.6 m/s Ventilation shaft: 20.3 m/s Personnel shaft: 11.7 m/s Emplacement drifts during construction: 3.0 m/s Exhaust mains: 10.2 m/s Service mains: 7.6 m/s Waste Handling Main: 7.6 m/s Ductwork: 30.5 m/s
Minimum Underground Air Velocity	DCSS 017	Minimum required air velocity in: (For Active Excavation),(For Development Maintenance) Ramps: 0.51 m/s, 0.31 m/s Shafts: 0.51 m/s, 0.31 m/s Emplacement drifts: 0.51 m/s, 0.31 m/s Exhaust mains: 0.51 m/s,0.31 m/s Service mains: 0.51 m/s, 0.31 m/s Waste Handling Main: 0.51 m/s, 0.31 m/s Ductwork: 12.7 m/s, 10.2 m/s

Table 4-8. Design Concept Assumptions (continued)

Description	Design Concept Identifier	Assumption
Minimum Underground Air Volume	DCSS 018	Minimum required air volume per: Diesel kW: 0.0791 (m^3/s)/kW Underground worker: 0.0944 (m^3/s)/person
Maximum Underground Air Temperatures-Emplacement Drifts	DCSS 019	Maximum allowable air temperature in emplacement drifts during: Construction: 27°C effective Emplacement: 50°C dry bulb, only in portion requiring access Caretaker: no limit, determined by rock temperature Retrieval: 50°C dry-bulb, only in portion requiring access Backfilling: 50°C dry-bulb
Maximum Underground Air Temperatures-Access Mains	DCSS 020	Maximum allowable air temperature in access (ventilation intake) mains during: Construction: 27°C effective Operations: 27°C effective Caretaker: 27°C effective Retrieval: 27°C effective Backfilling: 50°C dry-bulb
Underground Air Quality	DCSS 021	Underground air quality in drifts occupied by personnel during: Construction: $O_2 \geq 19.5\%$, air cooling power ≥ 260 W/m^2, contaminants <TLV values Operations: $O_2 \geq 19.5\%$, air cooling power ≥ 260 W/m^2, contaminants <TLV values Underground air quality in drifts occupied by personnel during: Caretaker: $O_2 \geq 19.5\%$, air cooling power ≥ 260 W/m^2, contaminants <TLV values Retrieval: $O_2 \geq 19.5\%$, air cooling power ≥ 260 W/m^2, contaminants <TLV values Backfilling: $O_2 \geq 19.5\%$, air cooling power ≥ 260 W/m^2, contaminants <TLV values

Table 4-8. Design Concept Assumptions (continued)

Description	Design Concept Identifier	Assumption
"K" Factor for Ventilation Air Flow	DCSS 022	"K" factor for ventilation air flow in: Shafts: Ventilation shaft 0.0030 kg/m³ "A" Man-and-material shaft 0.0176 kg/m³ "B" Ramps: Waste ramp 0.0056 kg/m³ "C" Tuff ramp 0.0111 kg/m³ "D" Exhaust mains: 0.0111 kg/m³ "D" Service mains: 0.0130 kg/m³ "E" TBM launch mains: 0.0130 kg/m³ "E" Waste main: 0.0111 kg/m³ "D" Emplacement drifts Without waste packages: 0.0130 kg/m³ "E" With waste packages: 0.0158 kg/m³ "F"
Maximum Preclosure Rock Surface Temperature	DCSS 023	Maximum allowable preclosure rock surface temperature in: Shafts: 35°C- unventilated Ramps: 50°C- unventilated Mains: 50°C Emplacement drifts: 200°C Temporary increases in these temperatures are allowed during initial cooling of emplacement drifts for maintenance, performance confirmation, retrieval, and backfilling.
Maximum CHn[18] Temperature	DCSS 025	Maximum allowable surface temperature within CHn: 115°C
Rock Support Materials-Organic Materials Prohibited	DCSS 027	Organic materials (e.g., epoxy resin, timber) are limited for use as rock support and other postclosure permanent materials in all openings. Organic admixtures used in cementitious materials should be minimized to the extent practical. Concrete and steel are allowable preclosure construction materials in all openings.

[18] Calico Hills Nonwelded Thermal/Mechanical Unit

Table 4-8. Design Concept Assumptions (continued)

Description	Design Concept Identifier	Assumption
Emplacement Drift, Shafts, Ramps Maintenance Plans	DCSS 028	Emplacement drifts will be designed to be stable through the caretaker period, with the goal to minimize or eliminate planned maintenance to sustain the ability to retrieve, sample, or relocate waste packages. Shafts, ramps, and all other drifts will be designed to be stable, but may rely on periodic planned maintenance.
Maximum Underground Air Temperatures-Exhaust Mains	DCSS 029	Maximum allowable air temperature in exhaust mains during: Construction: 27°C effective Operations: 50°C dry-bulb Caretaker: 50°C dry-bulb Retrieval: < emplacement drift rock surface temperature Backfilling: 50°C dry-bulb
Limit Ground Surface Uplift	DCSS 030	Limit surface uplift to less than 0.5 cm/yr and relative motion of the top of TSw1 to less than 1 m with no intact rock failure and no continuous joint slip.
Limit Temperatures in PTn[19]	DCSS 031	Limit temperatures in PTn to less than 115°C
Temporary Surface Facilities for Underground Construction	DCSS 032	Underground construction will not use the North Portal for access once emplacement operations begin.

[19] Paintbrush Tuff Nonwelded Thermal/Mechanical Unit

4.4 TECHNICAL DATA ASSUMPTIONS

Technical data assumptions for the surface and subsurface repository are identified in Table 4-9 as TDS and TDSS. The appropriate technical data assumptions are provided for surface and subsurface repository in the following sections.

Table 4-9. Technical Data Assumptions

Description	Technical Data Assumption Identifier	Assumption
Fault Displacement, Locations, Attitudes	TDS 001	Surface facilities fault displacements, fault locations, and fault attitudes shall be as described in Section 1.23 of the RIB[20].
Topography/ Morphology	TDS 002	Topographical survey data and surface morphology shall be as described in Section 1.11 of the RIB.
Soil Properties	TDS 003	Soil properties are described in Sections 1.1311, 1.1312, and 1.1314 of the RIB. Soil hydrologic properties, soil mechanical properties, soil geochemical properties, and soil physical properties are given.
Meteorology	TDS 004	Site meteorology includes data on normal atmospheric and climatic conditions at the site based on historical data. These conditions are described in Section 1.3 of the RIB.
Design Basis Tornadoes	TDS 006	The Design Basis Tornado will be based on the "parameters of Design-Basis Tornadoes (DBTs) for NTS," which are given in the RIB, Section 1.3b, Table 2. Although tornadoes have never been observed on the NTS or within 150 miles of the NTS, the surface facilities design will be consistent with that used at the NTS.
Winds (Operating Basis and Standard)	TDS 007	The prevailing wind summary given in the RIB, Section 1.3a, Table 4, will be used as the Operating Basis Wind and Standard Wind for surface facilities design considerations.
Floods (Design Basis)	TDS 008	The Design Basis Flood shall be the 100-year and 500-year Probable Maximum Floods described in Section 1.54a of the RIB; Table 3 identifies the estimated ranges for peak flood characteristics.

[20] *Reference Information Base* (YMP 1995a)

Table 4-9. Technical Data Assumptions (continued)

Description	Technical Data Assumption Identifier	Assumption
In Situ Stress	TDSS 001	Rock in situ stress at proposed repository horizon: <u>Parameter</u> Vertical Stress Average Value — Range 7.0 MPa — 5.0 - 10.0 MPa Min Horiz/Vert Stress Average Value — Range 0.5 — 0.3 - 0.8 Max Horiz/Vert Stess Average Value — Range 0.6 — 0.3 - 1.0 Bearing - Min Horiz Stress Average Value — Range 57W — N50W - N65W Bearing - Max Horiz Stress Average Value — Range N32E — N25E - N40E
Ground Surface Temperature, Rock Thermal Gradient	TDSS 002	Rock temperature at ground surface: 18.7°C. Thermal gradient in rock: 0.0196.8°C/m for depth 0 to 150 m 0.018°C/m for depth 150 to 400 m 0.030°C/m for depth 400 to 541 m
TSw2 In Situ Saturation	TDSS 003	In situ degree of saturation (%)-TSw2: 65
TSw2 Rock Densities	TDSS 004	Rock index properties: In Situ Density TSw2: 2297 kg/m^3 Dry Density TSw2: 2219 kg/m^3
TSw2 Thermal Conductivity	TDSS 005	Thermal conductivity of in situ rock mass-TSw2: 2.1W/mK

Table 4-9. Technical Data Assumptions (continued)

Description	Technical Data Assumption Identifier	Assumption
TSw2 Heat Capacitance	TDSS 006	Heat capacitance of in situ rock - TSw2: 2.0324×10^6 J/m^{3}K at 25°C 2.1280×10^6 J/m^{3}K at 50°C 2.2638×10^6 J/m^{3}K at 94°C 10.7683×10^6 J/m^{3}K at 95°C 10.4690×10^6 J/m^{3}K at 105°C 10.1984×10^6 J/m^{3}K at 114°C 2.0065×10^6 J/m^{3}K at 115°C 2.1114×10^6 J/m^{3}K at 155°C 2.1912×10^6 J/m^{3}K at 195°C 2.2692×10^6 J/m^{3}K at 235°C 2.3410×10^6 J/m^{3}K at 275°C
TSw2 Thermal Expansion	TDSS 007	Thermal expansion coefficient of in situ rock during heating - TSw2: <u>For Majority of Rock Mass</u> 9.1×10^{-6}/C at 25 - 50°C 8.2×10^{-6}/C at 50 - 100°C 6.8×10^{-6}/C at 100 - 150°C 9.7×10^{-6}/C at 150 - 200°C <u>For Rock (welded and devitrified tuff only) at or Near a Free Surface (Very Near Field)</u> 5.4×10^{-6}/C at 25 - 50°C 8.0×10^{-6}/C at 50 - 100°C 9.8×10^{-6}/C at 100 - 150°C 17.0×10^{-6}/C at 150 - 200°C
TSw2 Elastic Modulus	TDSS 008	Elastic modulus of intact rock-TSw2: 32.7 GPa (at ambient temperature)
TSw2 Poisson's Ratio	TDSS 009	Poisson's ratio (at ambient temperature): Intact Rock-TSw2: 0.22 Rock Mass-TSw2: 0.22
TSw2 Uniaxial Compressive Strength	TDSS 010	Uniaxial compressive strength of intact rock - TSw2: 155 MPa (at ambient temperature).
TSw2 Mohr-Coulomb Strength Parameters	TDSS 011	Mohr-Coulomb strength parameters of intact rock - TSw2 (at ambient temperature): Cohesion 37.8 MPa Friction Angle 36.5°
TSw2 Porosity	TDSS 012	Porosity of intact rock-TSw2: 0.121

Table 4-9. Technical Data Assumptions (continued)

Description	Technical Data Assumption Identifier	Assumption
Rock Joint Orientation and Frequency	TDSS 017	Rock joint orientation: Major Joint Set Strike Dip N10 - 12W 75 - 90 NE/SW Minor Joint Sets Strike Dip N25E 10SE N - N45E 80 - 90 SE/NW Rock joint frequency: TSw2:2.51/m for 70-80 degree joints, 11.28/m for 80-90 degree joints (mean value)
Surface Air Temperature/ Humidity	TDSS 021	Surface air temperature: Maximum: 42.2°C Minimum: -25.6°C Annual Average: 12.7°C Surface Air Humidity: Maximum: 71% Minimum: 13% Annual Average: 54%
Wind Intensity	TDSS 022	Wind intensity: Annual Average: 3.22 m/s Peak: >26.8 m/s

4.5 DESIGN BASIS DRIVERS

Although an assumption is listed in the CDA Document (CRWMS M&O 1995a), it may or may not provide a specific value or concept, but, rather, may provide a range of values from which any selection is allowable. For example, thermal loading assumes an acceptable range of from 80 MTU per acre to 100 MTU per acre. In these instances, a design may be based on any value in this range, but should be sufficiently flexible to adjust to all values in the range. In all cases, a value selected for any given point design is rationalized for use within the specific conditions of that design and must be reasonable, but not necessarily optimal.

The MGDS ACD Report is based upon a number of assumptions applicable to this particular point design and which are considered as design drivers. This section lists design drivers that form the bases of the design currently being presented. These are main issues and assumed values (or concepts) having the greatest impact on the design. The list does not contain design features which implement the design bases, are more detailed, and are part of the engineering discretionary function. Design features do not drive the design, but are a part or result of the design process, and will be presented in the report text.

The following lists are presented in a tabular format and state the design bases in a concise manner. A more detailed description of the rationale for selection and/or how the drivers were implemented can be found in the following sections. Note that this list of drivers is specific to this MGDS ACD Report design. Should conditions cause any number of these drivers to change, the design would require modification to reflect those changes. It should also be noted that this list and associated design represents a feasible design scenario without regard to optimization of design features. As such, this list represents the bases chosen for this particular design.

The information presented in the attached list was based on input from the CDA Document (CRWMS M&O 1995a) and current information developed by the repository design staff. The CDA Document (CRWMS M&O 1995a) provided basic information from key assumptions, requirements assumptions [Engineered Barrier Design Requirements Document (EBDRD) (YMP 1994c) and RDRD (YMP 1994a)] and design concepts for surface, subsurface, and waste package. These items were reviewed to select only those assumptions that are design drivers, to confirm the applicability of the assumption to the design, and to indicate selected values wherever a range might have existed.

The list is intended to provide an easy reference to the main drivers affecting the design as presented in the MGDS ACD Report. Some of the design drivers may be the focus of programmatic controversy and/or policy shifts that may require subsequent design changes. The table is organized into the following sections, which have been reviewed to ensure an integrated list of design bases:

- MGDS ACD Report design bases common to all areas
- Surface-related design bases
- Subsurface-related design bases
- Waste package-related design bases that affect the repository design

It is important to note that this list is not a dynamic product. It functions solely to describe the design basis drivers for this particular design. However, this list can be updated for use in describing design bases of future or current designs that have progressed beyond the conceptual phase.

4.5.1 Design Bases Applicable to All Design

Table 4-10. Common Design Bases for the MGDS ACD Report

Design Component/Attribute	Design Basis Driver	Rationale
1. Waste Package Containment Barrier Shielding	• Waste package containment barriers will provide sufficient shielding to protect materials from radiation-enhanced corrosion. • Waste packages will not be shielded for personnel protection. • Shielding for personnel protection will be provided on the transporter and in surface and subsurface facilities. • Emplacement transport shield is a standard three-layer approach with neutron shielding between gamma shielding. • Shielding materials are 5% boron-polyethylene for neutron, and lead for gamma shielding, encased in 316L stainless steel for structural support.	• Cost, size and weight of individually shielded waste packages would be excessive. • MGDS will meet design requirements and strive to achieve ALARA design with more cost-effective shielding options. • Materials are in common use in the nuclear industry, and their use is proven technology.
2. Average SNF Characteristics	• 26.4 yrs old, 39.64 GWd/MTU burnup, 3.68 wt.% enrichment (PWR) • 26.1 yrs old, 31.21 GWd/MTU burnup, 2.97 wt.% enrichment (BWR)	• Oldest fuel first. • No MRS. • Deferred dry storage. • Derated canisters. • Four truck sites. • In accordance with the NWPA, OCRWM Mission Plan, Proposed Program Approach.
3. Lag storage	• Sized to accommodate minor interruptions only (i.e., not designed for cooling, retrieval, or interim storage) • 40 disposal containers	• Consistent with thermal management approach and retrieval design basis.
4. Waste Form	• Based on receipt of canistered fuel. • Receipt of uncanistered fuel is not precluded. • Defense high-level waste. • Navy fuel is not included in the MGDS ACD Report. • The CDR-type MPC is used for cost and design purposes.	• Based on current requirements. • Designs already performed are bounded by 21 PWR MPC parameters for size, weight, and heat output.

4.5.2 Surface Design Bases

Table 4-11. Surface Design Bases for the MGDS ACD Report

Design Component/Attribute	Design Basis Driver	Rationale
1.* Performance Confirmation	• Open 1 WP every 10 . • Bare fuel facility can support performance category mission. • No additional labs required.	• Long measurement periods are consistent with WP design life. • Similar operations can be performed in under-utilized cell. • Infrequent test samples are cost effectively analyzed off-site.
2. Waste Forms and Receipt Rates	• Mostly MPCs at 638 waste shipments per year (maximum): canistered = 424 uncanistered = 55 HLW = 159 • Cask receipt rate and mix of waste form types vary each year per CDA Key Assumption 001 schedule. • HLW will be received in canisters that are not larger than a CDR-type MPC.	• Consistent with program approach (e.g., CDA). • Cost effective to standardize equipment and operations, and Naval fuel needs to be visually obscured.
3. Filler Material	• Added to first procurement canisters (117). • Shipment rates will be limited to meet single-train capacity.	• Consistent with first procurement assumptions. • Minimizes investment for this temporary mission.
4.* Safeguards and Security	Little or no material tracking and a single fence around the RCA.	• Does not impact basic design concepts. • Will be revisited in future design phases.
5.* International Atomic Energy Agency (IAEA) Inspection	No inspection.	• Does not impact basic design concepts. • Will be revisited in future design phases.
6. Retrieval	Facilities will be designed and constructed when retrieval is needed.	Cost effective because retrieval is unlikely.
7a. Low-Level Secondary Waste Disposition	Solids and non-recyclable liquids will be compacted, grouted, packaged and shipped off-site for disposal.	Off-site disposal avoids on-site license.
7b. Low-Level Mixed Secondary Waste Disposition	• Not generated under normal operations. • If generated, will be packaged, and shipped off-site for treatment and disposal.	• Waste minimization. • Minute quantities make off-site treatment cost effective and off-site disposal avoids on-site license.
8.* Wet vs. Dry Shielding Technology	• WHB will use shield walls and hot cells (e.g., dry). • Cask Maintenance Facility (CMF) will use pools (e.g., wet).	• Promote a dry canister interior. • Accommodates more flexible contact operations.
9. CMF Design	MRS design adapted to repository.	Functions and requirements are similar.

Table 4-11. Surface Design Bases for the MGDS ACD Report (continued)

Design Component/Attribute	Design Basis Driver	Rationale
10.* Integrated Nuclear Operations	Separate facilities will be used for nuclear operations (i.e., WHB, CMF and WTB)	Isolated buildings are feasible and resulting design is conservative.
11. Support Facility Design	Same designs and facilities as described in the SCP-CDR.	Designs are representative for a waste storage plant.
12.* Support Area Location	East of the nuclear facilities.	Prevailing wind is least likely to carry emissions from the nuclear buildings to the non-rad support area.
13.* Seismic Design	• Structures will be assigned performance categories in accordance with DOE-STD-1021-93. • For each performance category design basis hazards are developed according to DOE-STD-1020-94.	Approach is prescribed in Topical Report: *Seismic Design Methodology for a Geologic Repository at Yucca Mountain* (YMP 1995d).

Note: * Denotes a component/attribute not currently controlled in the RDRD (YMP 1994a), RDRD (YMP 1994a), or CDA Document (CRWMS M&O 1995a).

4.5.3 Subsurface Design Bases

Table 4-12. Subsurface Design Bases for the MGDS ACD Report

Design Component/Attribute	Design Basis Driver	Rationale
1. Layout Option	• Central main • Long parallel emplacement drifts • In-drift emplacement • Upper and lower blocks	• Allows for potential backfill. • Facilitates retrieval. • Facilitates performance confirmation. • Access for off-normal situations and maintenance/inspection.
2. Emplacement Support Mechanism	Packages remain on railcar.	• Ease of emplacement. • Accommodates retrieval.
3. Waste Package Transportation Underground	By rail.	• Handles heavy loads. • Proven technology. • Capability of automation.
4. Emplacement Mode	Horizontal in-drift.	• Simple and cost-effective emplacement/retrieval as compared to borehole emplacement.
5.* Emplacement Drift Ventilation	Not ventilated after emplacement.	• Does not exceed thermal limits. • Ventilation will remain available if needed during the preclosure period.
6. Emplacement Drift Ground Support	Support according to rock categories (e.g., steel and lagging for Category IV).	• Efficient application of materials. • Cost.
7.* Invert Material	Concrete/crushed tuff combination.	• Proven technology. • Maintainability.
8. Use of North Ramp for Waste Transport	Yes	• Least slope. • Access to facilities. • Concept of operations.
9. Remote Operation	Yes	• Radiological safety. • Proven technology. • Hostile environments.
10. Backfill in Emplacement Drifts	No	• Backfill is not precluded. • Not currently required in emplacement drifts. • Potential for backfill is considered in selection of other design bases.
11. Thermal Loading	21 kg/m^2 (83 MTU/acre)	• Results in conservative layout size.
12. Emplacement Drift Monitoring	• As scheduled (TBD) • Non-continuous	• Emplacement side exhaust ventilation is continuously monitored. • Instrumentation limitation.
13. Retrieval Option	• Maintained for 100 years.	• Accommodated in layout and all affected designs. • Meets 10 CFR 60 and DOE requirements.

Table 4-12. Subsurface Design Bases for the MGDS ACD Report (continued)

Design Component/Attribute	Design Basis Driver	Rationale
14. Emplacement and Development Ventilation	• Separate networks for development and emplacement.	• Positive pressure from development side to emplacement side. • Systems are physically isolated, but vary in size with operations.
15. Emplacement Drift Entrance Doors	Required.	• Doors needed for access and ventilation control.
16. Emplacement Scenario	• 63000 MTU commercial SNF. • 7000 MTU HLW.	• Supports the NWPA, OCRWM Mission Plan, Proposed Program Approach, and program requirements. • Satisfies Key Assumption 003.
17. Human Entry in Drifts Containing Waste Packages	• No human entry allowed under normal conditions.	• Achieves occupational doses that are ALARA.
18. Reason for Retrieval	• Failure in site, waste package, or some other system causing safety risk. • Recovery of the resource.	• NWPA. • Retrievability study M&O 1994 (CRWMS M&O 1994g).
19. Performance Confirmation Area	• Can be accommodated in layout. • Size and lateral extent is flexible.	• Needed to support specific testing and monitoring functions. • Satisfies need for flexibility in thermal loading/thermal management.
20. Repository Horizon	• Located mainly in the TSw2 unit.	• Modest crossing of the boundary is allowed. • Consistent with site characterization activities. • Satisfies 10 CFR 960 requirement of 200 m distance below the surface.
21. Subsurface Fault Standoff	• Openings are located to avoid Type I faults traversing major portions of the emplacement area. • 60-m offset from main Type I fault traces in the emplacement area. • 120-m offset used on the west side of the Ghost Dance Fault.	• NUREG-1494 Technical Position is satisfied (NRC 1994).
22. Excavation Method	• Primary method is mechanical. • Drill and blast may be used where mechanical methods are impractical.	• Limits potential for preferential pathways. • Proven results in ESF construction.
23. Underground Transport of Personnel and Supplies	• Rail.	• Compatible with rail haulage schemes for emplacement. • Efficiency.
24. Maintainable Preclosure Service Life	• 150 years following first emplacement of waste (rounded up from 144).	• Derived from 100-year retrieval plus 10 years retrieval preparation plus 24 years to perform retrieval plus 10 years closure.

Table 4-12. Subsurface Design Bases for the MGDS ACD Report (continued)

Design Component/Attribute	Design Basis Driver	Rationale
25. Emplacement Drift Wall Temperatures	• <200°C emplacement drift wall temperature.	• EBDRD requirement.
26. TSw3 Temperature Limit	• <115°C.	• SCP-listed thermal goal at the basal vitrophyre.
27. Ground Surface Temperature Limit	• Limit maximum change to a 2°C rise.	• Conservative goal stated by K. Olster to the NWTRB (DOE 1988a).
28. Access Mains Wall Rock Temperature Limit	• Maximum 50°C during preclosure normal operations.	• SCP-listed thermal goal.
29. Code Requirements	• OSHA and MSHA.	• OSHA controlled and MSHA advised. • Mandated by 10 CFR 60.
30. Emplacement Drift Orientation	• 30 degrees from dominant joint orientations. • Generally between N70W and S75W. • Intersections at 70 to 90 degrees where practical.	• Maximize stability. • Based on current site characterization data.
31. Extraction Ratio	• Maximum 30% in emplacement area.	• Conservative estimate for drift stability. • Based on stress analysis.
32. Ramp Grade	• ≤3% for rail haulage. • ≤2% in mains used for emplacement drift access. • 0.25 to 0.75% for drainage in emplacement drifts. • Other design grades are unimportant as design drivers.	• Operational safety.
33. Preclosure Rock Surface Temperature	• Maximum allowable rock surface temperatures - Shafts: 35°C unventilated Ramps: 35°C unventilated Mains: 50°C unventilated Emplacement Drifts: 200°C.	• SCP-stated values. • Mains may exceed the value during cooling for retrieval or backfill.
34. Maximum CHn Temperature	• 115°C.	• SCP Thermal Goals Reevaluation Report (CRWMS M&O 1993c).
35. Organic Rock Support Materials	• Organic materials (e.g., epoxy resin, timber) are limited for rock support and permanent postclosure materials in all openings. • Organic admixtures in cementitious materials are minimized to the extent practical.	• Organic materials aid in the development of soluble and insoluble complexes, which can potentially be transported via hydrologic mechanism.

Table 4-12. Subsurface Design Bases for the MGDS ACD Report (continued)

Design Component/Attribute	Design Basis Driver	Rationale
36. Limit Ground Surface Uplift	• Surface uplift limited to less than 0.5 cm/year. • Relative motion of the top of TSw1 is limited to less than 1 m with no intact rock failure and no continuous slip.	• SCP Thermal Goals Reevaluation Report (CRWMS M&O 1993c).
37. Maximum Temperature in PTn	• 115°C.	• SCP Thermal Goals Reevaluation Report (CRWMS M&O 1993c). • Requires substantiation.
38. North Portal Access	• Underground construction will not use North Portal access once emplacement operations begin.	• Logistics, safety, separation of operation functions. • South Portal or shaft access is designated for development support.
39. Accesses	• Ramp and shaft penetrations will be monitored as required for ventilation and radiation levels. • Two ramps and two shafts are shown in this design. • Main ramps are 7.62 m diameter, shafts are 6.1 m inside diameter.	• Performance assessment monitoring will be required in specified locations throughout the repository. • The number of penetrations are minimized as per requirements, and sized to accommodate ventilation.
40.* Seismic Design	• Structures will be assigned performance categories in accordance with DOE-STD-1021-93. • For each performance category, design basis hazards are developed according to DOE-STD-1020-94.	Approach is prescribed in Topical Report: *Seismic Design Methodology for a Geologic Repository at Yucca Mountain* (YMP 1995d).

Note: * Denotes a component/attribute that is not currently controlled in the RDRD (YMP 1994a), RDRD (YMP 1994a) or CDA Document (CRWMS M&O 1995a)

4.5.4 Waste Package Design Bases Affecting Repository Design

Table 4-13. Engineer Barrier Segment Design Bases for the MGDS ACD Report

Design Component/Attribute	Design Basis Driver	Rationale
1. External Waste Package Dimensions	• Diameter: 1,802 mm for 21 PWR canistered fuel package (MPC); 1,629 mm for 21 PWR UCF (5) waste package tube type. • Length: 5,682 mm for 21 PWR canistered fuel package (MPC); 5,335 mm for 21 PWR UCF (5) waste package tube type. • Nonstandard fuel (South Texas) will be accommodated to the extent possible through special processing which is not addressed as a driver in this design.	• Determined by waste package design analyses and reported in the waste package section of the MGDS ACD Report. • The MGDS EBDRD requirements classify South Texas fuel as nonstandard, and specifies the possibility of the need for special handling processes and equipment.
2. Waste Package Weight	• 65,900 kg for the 21 PWR canistered fuel package (MPC). • An additional maximum 20,327 kg for the internal filler material in the above-mentioned package.	• Based on MPC of 21 PWR/40 BWR. • Weights determined through waste package design analyses.
3. Waste Package Drop Tolerance	• After being sealed, can tolerate a 2-m drop onto a flat unyielding surface.	• Engineering experience in the design of storage and transportation casks. • TBV.
4. Container Loads	• Container has mechanical integrity to sustain static loads of 25 kN during routine handling and transportation.	• Indicated through initial stress calculations on the multi-barrier waste package.
5. Container Weight	• Weight of empty container shall not exceed 32,000 kg.	• Determined through waste package design analysis. • The weight represents the container portion of the waste package weight identified above.
6. Burnup Credit	• Will receive credit for principal isotope burnup.	• Burnup credit committee discussions with NRC staff indicate possibility for credit.
7. Expected Waste Package Life	• Mean lifetime well in excess of 1,000 years. • Less than 1% containment failures in the first 1,000 years.	• Meets 10 CFR 60 requirements. • Conforms to DOE position on substantially complete containment. • Consistent with multi-barrier approach to waste package design.
8. Criticality Control Period	• Indefinite or until trends indicate that risk will continue to decrease out to 1,000,000 years.	• In accordance with 10 CFR 60 and National Academy of Science recommendations.

Table 4-13. Engineer Barrier Segment Design Bases for the MGDS ACD Report (continued)

Design Component/Attribute	Design Basis Driver	Rationale
9. Waste Package Materials	• Inner barrier - UNS N08825 • Outer barrier for SNF packages - UNS G10200. • Outer barrier for HLW packages - UNS C71500.	• UNS N08825 chosen as a reasonable compromise between high corrosion resistance and low cost. • UNS G10200 provides predictable corrosion rates and low cost. • UNS C71500 provides significant corrosion resistance.
10. SNF Weight	• Spent fuel waste form will be the high-level radioactive waste and any encapsulating or stabilizing matrix, such as cladding associated with spent fuel. • Up to 887 kg per PWR assembly and 332 kg per BWR assembly.	• Based on a bounding condition which is the maximum value. • BWR weight comes from DOE/RW-0184-R1 (DOE 1992).
11. Engineering Barrier Segment Reliability	• Probability of failure of an individual waste package during preclosure shall be less than 10^{-6} per year, based on credible hazards.	• Based on statistical analysis of credible hazard event type, size, frequency of occurrence, and location relative to the waste package.
12. Rock Induced Waste Package Loading	• Uniform external pressure of 0.50 MPa and a dynamic load of 50 kN.	• Stress calculations based on the expected load from a rock falling onto the waste package.
13. Limit of Fuel Cladding Temperature	• Less than 350oC.	• SCP thermal goal, reconfirmed in 1993 analysis (CRWMS M&O 1993c).
14. Limit of HLW Glass Temperature	• Less than 500oC.	• SCP thermal goal, reconfirmed in 1993 analysis (CRWMS M&O 1993c).
15. Engineering Barrier Segment Components	• Waste package (canistered, uncanistered, and HLW), invert, filler, shielding, and packing are addressed in the report. • Backfill, waste package support during preclosure, and the emplacement drift opening are not addressed from the engineered barrier performance aspect.	• Waste package is specified in EBDRD 3.7.1. • Invert is needed for emplacement operations. • CDA Key Assumption 046 specifies no backfill.
16. Waste package performance	• Mean lifetime well in excess of 1,000 years. • Control release from Engineered Barrier Segment after containment period. • Control criticality. • Resist mechanical loads. • Limit waste form temperature. • Limit radiation. • Less than 1% containment failure in the first 1,000 years.	• EBDRD 3.7.1.2.B; also see Item 7. • EBDRD 3.7.E, 3.7.1.2.C. • EBDRD 3.7.1.3.A; also see Items 6, and 8. • EBDRD 3.7.F, 3.7.1.1.F, 3.7.1.2.A; also see Items 3, 4, and 12. • CDA DCWP 001, DCWP 002; also see Items 13 and 14. • CDA Key Assumption 031.

Table 4-13. Engineer Barrier Segment Design Bases for the MGDS ACD Report (continued)

Design Component/Attribute	Design Basis Driver	Rationale
17. Invert performance	• No performance allocated to invert as an engineered barrier.	• No invert requirements in EBDRD
18.* Near-field environment	• Water flux Typical: 0 Extreme: 0.1 mm/yr • pH Typical: 7.4 Extreme: 2 to 12 • Water chemistry Typical: J-13 Extreme: Concentrated J-13, acidified or alkalized • Relative humidity range: 10% (max. dryout) to 98% (ambient) • Temperature, drift wall, typical: 25°C at emplacement 109°C at 1 year 152°C at 10 years 165°C at 40 years 159°C at 100 years 134°C at 1,000 years	• Dryness of ESF, (CRWMS M&O 1995bd and CRWMS M&O 1995be). • UCRL-LR-107476, (LLNL 1993) LLNL SIP-CM-01(LLNL 1995). • UCRL-LR-107476, (LLNL 1993) LLNL SIP-CM-01(LLNL 1995). • Calculations by Buscheck (LLNL 1994). • Calculations by Bahney (CRWMS M&O 1994h) for 20.5 kgU/m^2 (83 MTU/acre).

Note: * Denotes a component/attribute that is not currently controlled in the RDRD (YMP 1994a), RDRD (YMP 1994a) or CDA Document (CRWMS M&O 1995a)

5. CONCEPT OF OPERATIONS

5.1 INTRODUCTION

5.1.1 Purpose

This concept of operations provides a high-level operational description of the design described in this volume of the *Mined Geologic Disposal System Advanced Conceptual Design* (MGDS ACD) Report, and includes the Repository Segment consisting of surface and subsurface facilities at the repository and the rail transportation system within Nevada.

5.1.2 Scope

The Repository Segment includes the surface and subsurface facilities necessary to receive, package for emplacement, and emplace the spent nuclear fuel (SNF) and defense and commercial vitrified high-level waste (DHLW); and to support the maintenance and operation of the repository. The rail transportation system within Nevada includes main rail routes, junction points, connecting rail lines and line-haul carriers.

The Repository Segment is part of the MGDS, which includes two other segments: the Engineered Barrier Segment and the Site Segment. The Engineered Barrier Segment includes the emplaced waste package and subsurface features designed for waste isolation. The Site Segment includes surface and subsurface facilities and activities for collecting site characterization data. The concept of operations for the entire MGDS is provided in Volume I, Section 3.

The concept of operations included in this section provides a summary level description of the repository facilities and operations. More detailed descriptions of the repository are provided in Sections 7, 8, 9, and 11 of this volume.

5.1.3 Organization

The remainder of this section is organized as follows:

- Section 5.2 provides a summary of the operational environment including the repository mission; descriptions of the operational phases, repository site, repository facilities, and waste forms; and an overview of the operations and maintenance approach.

- Section 5.3 provides a high-level description of the major repository operations in each operational phase.

5.2 OPERATIONAL ENVIRONMENT

5.2.1 Mission

The mission of the repository is to provide for the receipt and disposal of 63,000 metric tons of initial heavy metal (MTIHM) of civilian owned SNF, and 7,000 MTIHM of DHLW, such that public health and safety and the environment are protected.

5.2.2 Operational Phases

Operational phases associated with the Repository Segment are described below. A schedule showing the phases for two retrieval scenarios is shown in Figure 5.2.2-1. These phases are consistent with the definitions provided in Section 5.3.1.4 of the CDA Document (CRWMS M&O 1995a); however, operations occurring prior to the start of repository segment operations were excluded (i.e., site characterization). Descriptions of the operations performed in each phase are provided in Section 5.3, except for off-normal.

A. *Construction* – This phase includes all surface construction and sufficient (about 10 percent) subsurface excavation to permit a steady rate of waste disposal. The construction phase is expected to last six years, beginning with the receipt of a license to construct the repository and ending when emplacement start-up operations begin.

B. *Development* – This phase includes the bulk of subsurface excavation that occurs after emplacement operations begin. This phase runs concurrent with the first 22 years of emplacement and ends when the subsurface excavation is complete.

C. *Emplacement* – This phase includes the receipt, packaging, and emplacement of SNF and DHLW. This phase is expected to last 24 years, beginning when construction is complete and ending when all the waste has been emplaced.

D. *Caretaker* – This phase is a waiting period of 76 years, during which the option to retrieve emplaced waste is preserved. This phase begins after emplacement is complete.

E. *Retrieval* – This phase includes all activities required to retrieve some or all of the emplaced waste. Waste retrieval could be required to remove public health or safety concerns, or to recover the waste as a valuable resource. This optional phase could occur anytime after the beginning of emplacement and before closure. Retrieval of all waste packages is allowed to take 30 years as described in 10 CFR 60.111(b)(3) (i.e., about 10 years to design and construct and 20 years to remove the waste).

F. *Off-normal* – The repository is designed, and the operations personnel are trained and equipped to handle unexpected accident, natural disaster, and other events, which can occur during any operational phase.

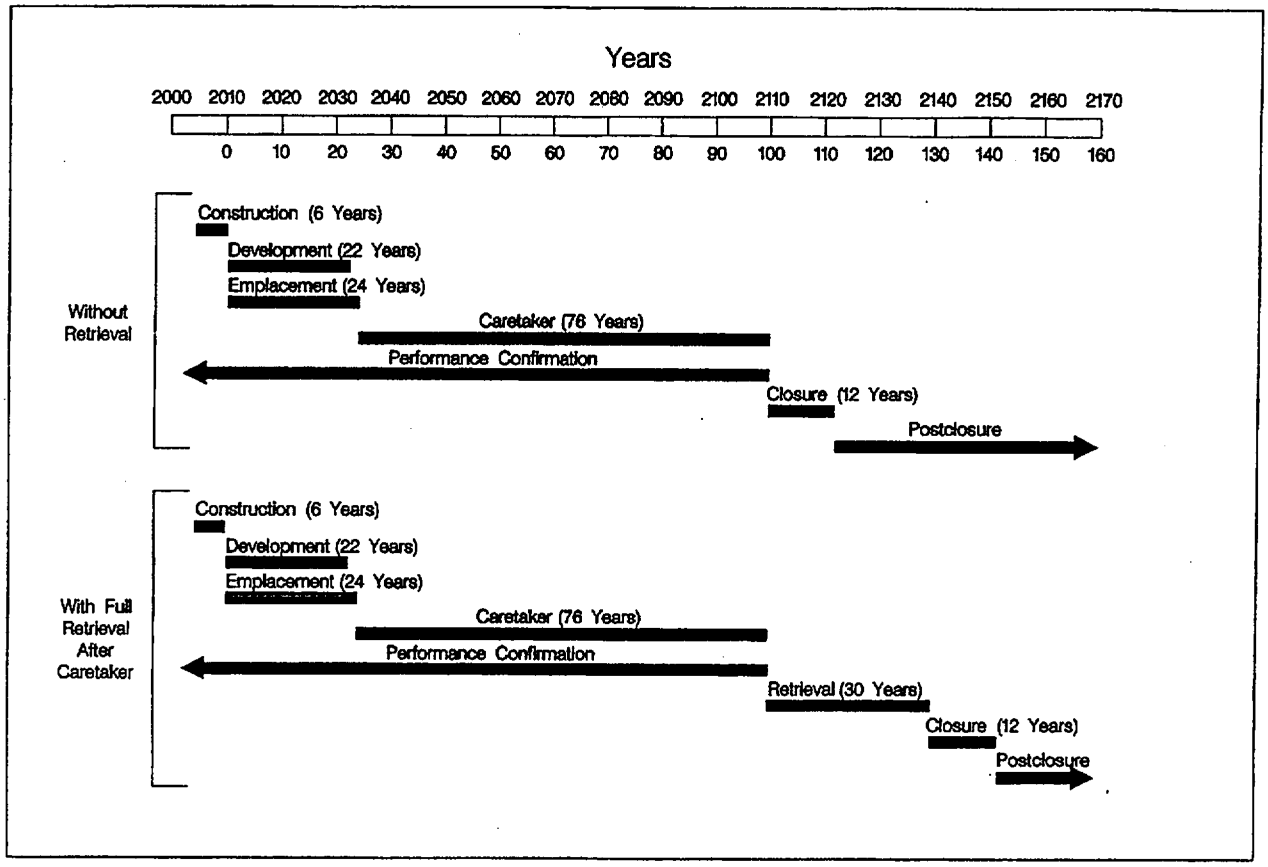

Figure 5.2.2-1. Schedule for Repository Segment Operational Phases

G. *Performance Confirmation* – The performance confirmation phase includes data collection; performance assessment using the collected data to analyze the performance of waste packages, seals, and barriers; and taking corrective action if required. These activities will begin prior to construction during site characterization. The laboratory testing ends at start of closure. In situ monitoring may end at closure or continue in postclosure.

H. *Closure* – This phase includes backfilling and sealing portions of the underground, decontaminating the nuclear surface facilities, dismantling the surface facilities, reclaiming the site, and establishing a system of physical and institutional barriers. This phase is expected to last 12 years, beginning when the U.S. Nuclear Regulatory Commission (NRC) amends the license to authorize permanent closure.

I. *Postclosure* – This phase includes the maintenance and enforcement of the institutional barrier system (markers and land-use records). If a system for postclosure monitoring is established, this phase also includes maintenance of the monitors. This phase begins after closure.

5.2.3 Site

The candidate repository site is Yucca Mountain which is located approximately 100 miles northwest of Las Vegas, Nevada. This desert location is on federal land remote from populated areas.

The site geology includes an underground layer of welded tuff, which is used as the waste emplacement area. The candidate host rock is the Topopah Spring Member, a unit of the Paintbrush Tuff. The Topopah Spring unit is approximately 330 meters (1,100 feet) thick. The unit dips about six degrees to the east. Potentially usable repository areas are outlined by major faults. These areas, which total about 3,700 hectares (9,150 acres), include a primary area and expansion areas. Expansion areas are used if required for a cooler repository design. Location of the repository horizon provides a minimum overburden of 200 meters (650 feet). The regional water table is about 230 to 380 meters (750 to 1,250 feet) below the horizon proposed for the emplacement of the waste packages.

At the start of repository construction, the site will include the surface and subsurface areas of the Exploratory Studies Facility (ESF) that were used for the site characterization activities. The subsurface facilities include the north ramp, main drift, and south ramp. The surface facilities include a change house, electrical and water supply systems, sanitary sewer systems, muck piles, and a number of minor temporary structures. Some or all of these facilities will be used to support repository construction.

Refer to Section 6 for a more detailed description of the repository site.

5.2.4 Facilities

The overall arrangement of the repository surface and subsurface operational areas is shown in Figure 5.2.4-1. Each of the four operational surface areas and the subsurface areas as well as the off-site rail transportation system in Nevada is described below. All structures, systems, and components (SSCs) comply with applicable regulations and standards for safety, health, environmental protection, and operations and maintenance, including 10 CFR 60.

5.2.4.1 North Portal Operations Area

This area covers about 32 hectares (80 acres) and includes 19 structures. It is located adjacent to the North Portal, where disposal containers are loaded and brought underground for emplacement. The operations area includes a radiologically controlled area (RCA), where all nuclear operations are performed, and a balance of plant (BOP) area, where general support facilities are located. Figure 5.2.4-2 is a site map of this area.

Each of the major facilities in the RCA is described below. The Transporter Maintenance Building (TMB), used to conduct maintenance of on-site waste transporters, is described in Section 7.2.6.

A. *Waste Handling Building* (WHB) – The WHB is a five-floor concrete and steel structure that includes several hot cells, operating galleries, and support areas. The facility has a zoned heating, ventilation, and air conditioning (HVAC) confinement system. This building houses systems and components for transferring the waste from transportation casks to disposal containers. The design and operations of the WHB are described in Section 7.2.2.

B. *Cask Maintenance Facility* (CMF) – The CMF is a three-floor concrete and steel structure that includes a pool, operating pits, and support areas. The facility has a zoned HVAC confinement system. This facility houses systems and components for performing maintenance on transportation casks and cask carriers. The design and operations of the CMF are described in Section 7.2.3.

C. *Waste Treatment Building* (WTB) – The WTB is a two-floor metal and concrete block building that includes open operating areas with localized concrete shield walls. The building includes systems and components for processing low-level liquid and solid waste, and accumulation of mixed waste. The design and operations of the WTB are described in Section 7.2.4.

D. *Carrier Staging Shed* (CSS) – The CSS is a single-floor prefabricated metal building with a gable roof. The building is a large open structure that can accommodate up to eight rail or truck cask carriers. The building houses systems and components for preparing cask carriers for cask removal or off-site shipment. The design and operations of the CSS are described in Section 7.2.5.

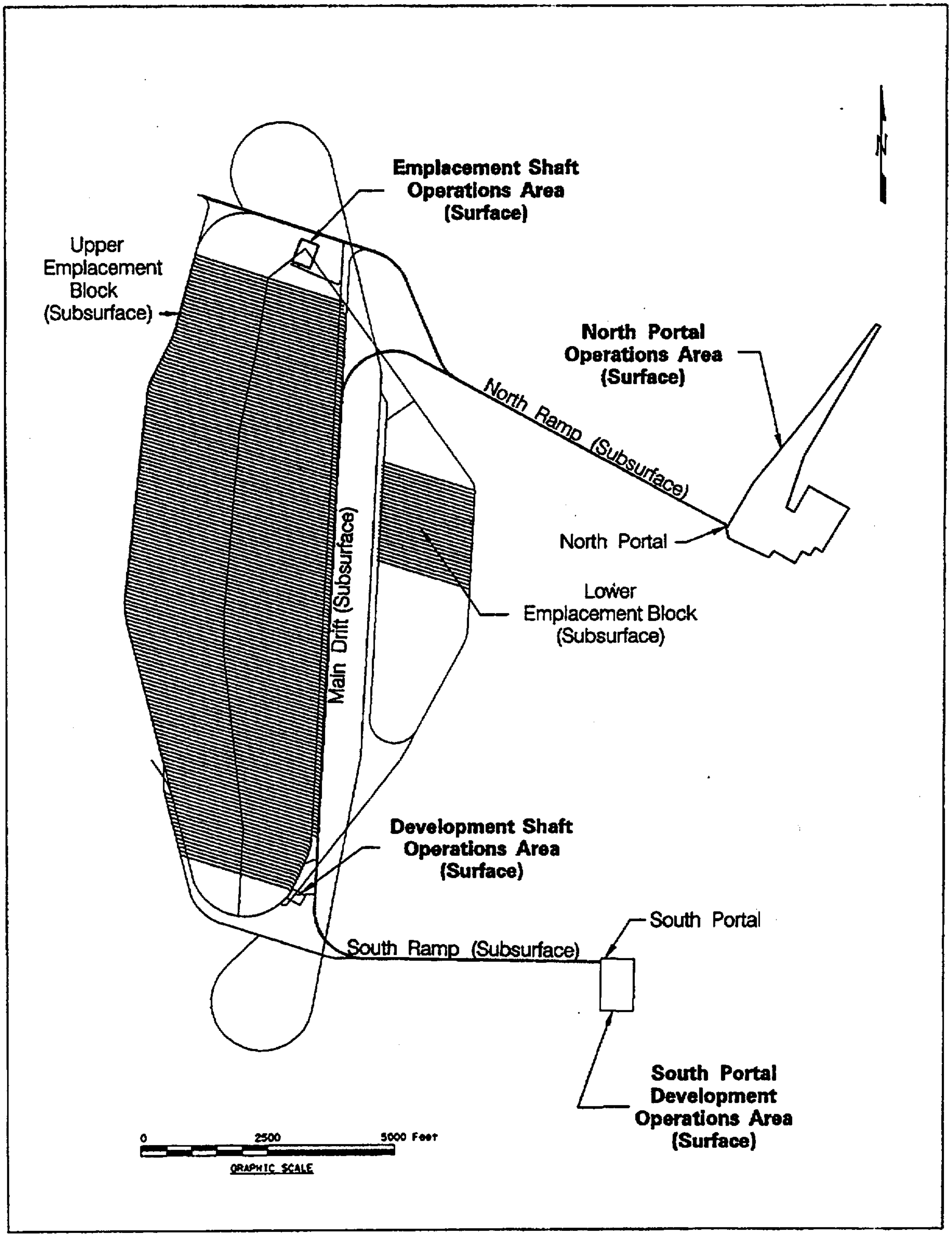

Figure 5.2.4-1. Overall Repository Site Map

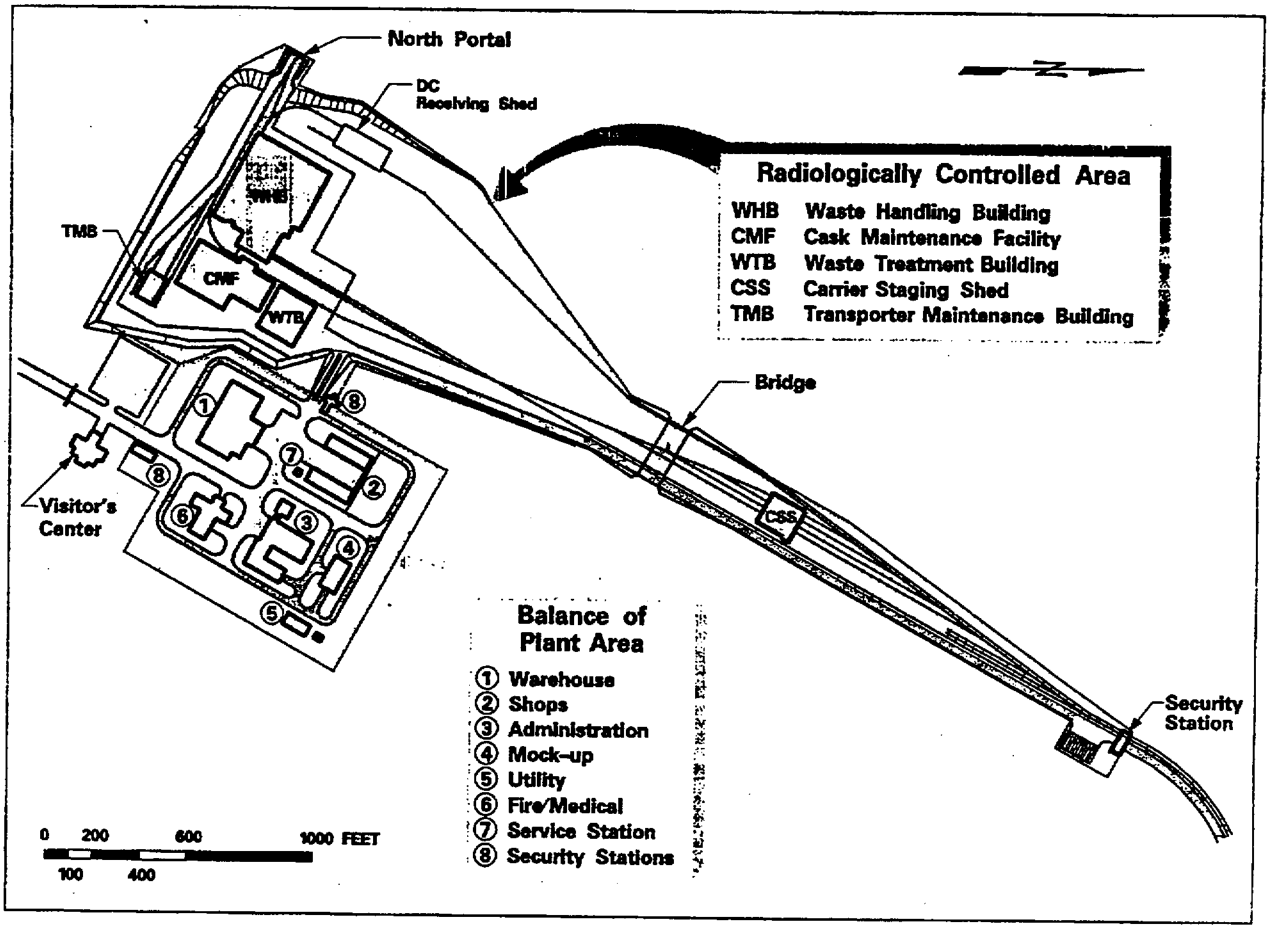

Figure 5.2.4-2. North Portal Operations – Area Site Map

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The BOP area includes structures that support operations in all areas (e.g., general administration, medical center, training center, shops, motor pool, central warehouse, and centralized utilities). These structures are briefly described in Section 7.2.7.

Various systems are provided to support operations at the North Portal and other repository areas (e.g., utility systems; communication systems; monitoring and control systems; and site management systems such as security, administration, transportation, maintenance, and engineering). These systems are briefly described in Section 7.2.8.

5.2.4.2 South Portal Development Operations Area

This area covers about 5 hectares (12 acres) and includes 8 structures. It is located adjacent to the South Portal to support the excavation of the underground and the operation of the development area ventilation supply fans. The area functions independently and includes the basic facilities needed for personnel support, maintenance, warehousing, material staging, security, and transportation. This area is staffed during the development phase and is unmanned after underground excavation is complete. These facilities are briefly described in Section 7.3.

5.2.4.3 Emplacement Shaft Surface Operations Area

This area includes two structures and is located at the opening to the north shaft. The main facility is provided to house the emplacement ventilation system, including exhaust fans and high efficiency particulate air (HEPA) filters, and to support the maintenance of this system. This area is normally unmanned. The facilities in this area are briefly described in Section 7.4.

5.2.4.4 Development Shaft Surface Operations Area

This area includes one structure and is located at the opening to the south shaft. The main facility houses the head frame and shaft conveyance needed for underground emergency personnel egress and inspection access. The area also includes the exhaust for the underground development ventilation system and electrical equipment. This area is normally unmanned. The facilities in this area are briefly described in Section 7.5.

5.2.4.5 Subsurface Facilities

The repository subsurface layout is shown in Figure 5.2.4-3. The subsurface facilities include waste emplacement drifts, two shafts, two ramps, service main drifts, and exhaust ventilation drifts. The total lengths and diameters of the ramps, shafts, and drifts are shown in Table 5.2.4-1.

The emplacement area is located at least 200 meters (650 feet) below the surface in a welded tuff unit that was described in Section 5.2.3. This area is divided into an upper block and a lower block that are separated by the Ghost Dance Fault. The upper block provides about 324 hectares (800 acres) for waste emplacement and is about 70 meters (230 feet) higher than the lower block. The lower block provides about 69 hectares (170 acres) for waste emplacement.

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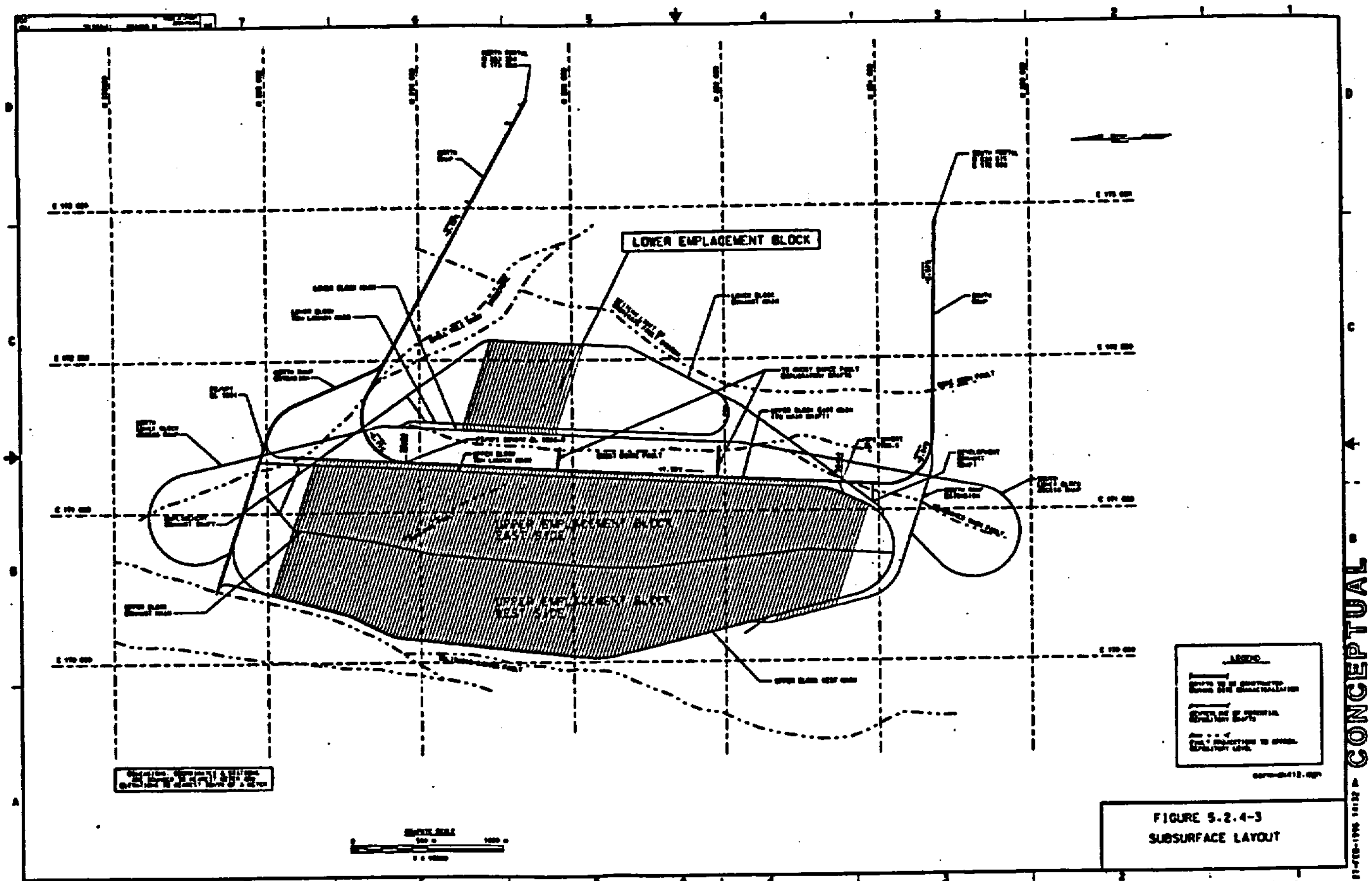

FIGURE 5.2.4-3
SUBSURFACE LAYOUT

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Table 5.2.4-1. Subsurface Excavation Data

Subsurface Feature	Diameter	Total Length or Depth	Construction Method
TBM Launch Mains and Recovery Mains	9.0 meters (30 feet)	11,400 meters (7.1 miles)	TBM
Ramps and Mains	7.62 meters (25 feet)	13,900 meters (8.6 miles)	TBM
Emplacement Drifts	5.0 meters (16 feet)	179,000 meters (111 miles)	TBM (2 machines)
Shafts	6.7 meters (22 feet)	320 meters (1050 feet) and 385 meters (1260 feet)	Mechanical Excavation and Drill and Blast
Upper Block Exhaust Main and Miscellaneous Access Drifts	955,900 cubic meters (1,250,000 cubic yards)		Mechanical Excavator (2 machines)

TBM = tunnel boring machine

The waste emplacement drifts are provided with rail tracks, enabling waste package emplacement in a horizontal position on railcars. The drifts are designed to require minimum maintenance after waste has been emplaced. During the development phase, the emplacement drift excavation continues from the south ramp while emplacement operations occur through the north ramp. Barriers and separate ventilation systems are provided to isolate the development area from the emplacement area.

The service main functions as the primary access for development operations personnel, equipment, and materials haulage; and as a primary ventilation airway in emplacement and development operations. The central exhaust main functions as a primary exhaust ventilation airway.

The north ramp is the primary access for emplacement operations between the North Portal surface operations area and the subsurface emplacement drifts. The ramp is used for the rail transportation of waste packages, materials, personnel, and equipment. It also functions as the main ventilation intake airway for the emplacement side of the repository.

The south ramp is the primary access for development operations between the South Portal surface operations area and the subsurface emplacement area. The ramp is used for the rail transportation of personnel and equipment. It also serves as the main ventilation intake airway for the development side of the repository.

The south shaft supports repository development operations, functioning as the primary ventilation exhaust airway for repository development operations. The north shaft supports emplacement operations, functioning as the principal ventilation exhaust airway on the emplacement side of the repository and an emergency egress route. The ventilation shafts are lined.

The TBM launch and recovery drifts are excavated to support construction. The upper block TBM recovery drift is later used for waste handling.

5.2.4.6 Off-site Rail Transportation Within Nevada

Rail transportation within Nevada includes the main rail routes, connecting rail lines linking the main rail lines to the repository, and junction points (i.e., interchange yards) where the lines meet. The junction point equipment includes trackage, switches, controls, signals, maintenance items, and support facilities. The connecting rail line includes trackage, crossings, bridges, culverts, and signaling as required.

Train service is provided by commercial line-haul carriers (e.g., Southern Pacific and Union Pacific). A train likely consists of two 3,000-horsepower diesel-electric locomotives pulling three SNF transportation cask carriers or five DHLW cask carriers. Options are being considered where trains operating on the main line routes pull commercial freight along with the cask carriers.

The four connecting rail route alternatives being studied are described in Section 11. These routes include: Carlin (north, about 530 km [330 miles] from the Nevada Test Site [NTS]), Jean (south, about 190 km (120 miles) from the NTS), Caliente (east, about 550 km [340 miles] from the NTS), and Dike (southeast, about 160 km [100 miles] from the NTS). The junction points for each candidate route are located in areas suitable as home terminals for the Yucca Mountain transportation crews.

5.2.5 Waste Forms and Receipt/Emplacement Rates

This section briefly describes the waste forms and rates for the SNF and DHLW as this material is received at, and emplaced in, the repository. SNF is in the form of pressurized water reactor (PWR) assemblies and boiling water reactor (BWR) assemblies. DHLW is in canisters that are 80 percent filled with a solid mass of vitrified waste (i.e., glass).

Waste At Receipt

SNF arrives at the repository as uncanistered waste in GA-4 or GA-9 legal weight truck casks or as canistered waste in large or small rail casks. SNF canisters are typically 2.54 centimeters (1 inch) thick. DHLW canisters, which are nominally 9.53 centimeters (3.8 inch) thick, arrive in rail casks. All casks ride on customized carriers installed with impact limiters and personnel barriers. Casks or canisters are provided with baskets and spacers to hold the waste in position. Approximate waste quantities and numbers of shipments are reported for each waste form in Table 5.2.5-1.

Waste At Emplacement

Canistered or uncanistered fuel assemblies or canistered DHLW are packaged in disposal containers for underground emplacement. The disposal containers are welded closed and include two barriers. The total thickness of the disposal container is about 12 centimeters (4.8 inches) for SNF containers and 7 centimeters (2.8 inches) for DHLW containers. The disposal containers are emplaced in a horizontal orientation on an emplacement railcar. Approximately 117 of the SNF canisters may also include filler material as a moderator displacement technique to ensure long-term criticality control. Approximate waste quantities and numbers of shipments are reported for each emplacement waste form in Table 5.2.5-2. Details of the disposal container design are provided in Volume III.

NOTE: After the disposal container is loaded with waste, welded closed, and qualified through non-destructive testing, the configuration meets the 10 CFR 60 definition of a waste package. The waste package as defined in 10 CFR 60 would also include any shielding, packing, or absorbent material immediately surrounding the individual disposal container, but the ACD concept does not include such materials.

Table 5.2.5-1. Transportation Cask Arrival Forms and Quantities

Cask	Transport Mode	Contents	Number of Shipments			Waste Quantity (MTIHM)
			Peak Annual	Avg. Annual	Total	
Large Canister	Rail	40 BWR Assemblies in a Canister	139	93	2,242	16,000
		21 PWR Assemblies in a Canister	212	168	4,041	35,000
Small Canister	Rail	24 BWR Assemblies in a Canister	111	63	1,505	6,500
		12 PWR Assemblies in a Canister	46	32	765	3,800
		12 BWR Assemblies in a Canister	8	2	40	99
GA-9	Legal Weight Truck	1 to 4 BWR Assemblies	1	0	3	1
GA-4		4 PWR Assemblies	72	43	1,026	1,600
DHLW	Rail	5 Canisters of Vitrified Waste	161	109	2,606	7,000
All Casks			*638	510	12,228	70,000

* The peak value of 638 for all casks is less than the sum of the peak values because the number of shipments do not peak in the same year for all cask types.

Table 5.2.5-2. Waste Emplacement Forms and Quantities

Disposal Container	Contents	Number of Emplacements			Waste Quantity (MTIHM)
		Peak Annual	Avg. Annual	Total	
Large Canister	40 BWR Assemblies in a Canister	139	93	2,242	16,000
	21 PWR Assemblies in a Canister	212	168	4,041	35,000
Small Canister	24 BWR Assemblies in a Canister	111	63	1,505	6,500
	12 PWR Assemblies in a Canister	46	32	765	3,800
	12 BWR Assemblies in a Canister	8	2	40	99
Bare Spent Fuel Assembly	1 to 4 BWR Assemblies in Rack	1	0	3	1
	Up to 21 PWR Assemblies in Rack	14	8	182	1,600
DHLW Canister	4 Canisters of Vitrified Waste	202	136	3,259	7,000
All Containers		*634	502	12,037	70,000

* The peak value of 634 for all containers is less than the sum of the peak values because the number of emplacements do not peak in the same year for all container types.

5.2.6 Operations and Maintenance Approach

Operation and maintenance of SSCs used to conduct nuclear operations is conducted in accordance with NRC requirements. Operation and maintenance of general support facilities is conducted in accordance with industry best management practices and the *Project Operations and Maintenance Plan* (YMP 1995h). Industry practices may include but are not limited to Institute of Nuclear Power Plant Operations and DOE regulations.

The operations and maintenance programs address the following issues:

- Maintenance
- Quality assurance
- Visitor control
- Safety and health
- Radiation protection
- Environmental protection
- Training.

Administrative operations include the following activities:

- Procedure development, recording and reporting
- Identification of operational limits
- Preservation of records
- Site markers
- Operation scheduling
- Personnel support.

Maintenance

Maintenance is performed on repository facilities, systems, equipment, instruments, and vehicles. Maintenance operations include the following activities:

- Scheduling and performing maintenance
- Maintaining records of failures and repairs
- Managing spares inventories
- Reporting on failure histories and trends
- Issuing advisories for preventive maintenance procedures.

These operations are managed from the Administration Building in the BOP area.

Maintenance for nuclear operations requires a specialized work force certified in the operation of remote handling and contaminated equipment. A formal maintenance and training program is implemented, and specialized maintenance procedures are developed. Where possible, maintenance is performed in place. Faulty components are removed and replaced. On-site and off-site shop facilities are used to repair and recertify components, where practical.

Organization

The repository includes functional organizations each tasked with specific surface, subsurface, analysis, and support responsibilities. Managers from each organization report to the MGDS Operations Manager. The MGDS Operations Manager reports to the resident DOE Manager. Each functional organization is staffed with the appropriate management, scientific, engineering, medical, technical/specialist, clerical, and craft personnel required to perform their functions.

Personnel Training

Training of repository personnel uses classrooms, audiovisual aids, and mock-up facilities for classroom, field, and on-the-job training. Personnel are certified and re-certified as required, and records are maintained at the Administration Building central computer. The associated training systems are located at various facilities throughout the site including the Administration Building, Training Auditorium, and Mock-up Building. Personnel assigned to waste handling, safety, and quality affecting responsibilities are formally trained and certified to perform their tasks, including specialized operations such as those involved in handling radioactive materials.

Quality Assurance

Site operations and maintenance on components used to conduct nuclear operations are carried out in accordance with a Quality Assurance Program meeting NRC requirements and as defined in the NRC license application.

Work Schedule

The repository operates 250 days per year, normally using the schedule summarized below. Shifts may be added occasionally to increase production rates to recover from unexpected downtime or peak waste receipt rates.

- 3 shifts, 7 days per week – Security and waste receipt operations
- 3 shifts, 5 days per week – Subsurface development operations
- 2 shifts, 5 days per week – WHO operations
- 1 shift, 5 days per week – All other repository operations

Personnel Transportation

Most personnel are expected to live in the cities of Las Vegas, Pahrump, and surrounding areas. Due to the long distance from cities to the repository, most personnel are expected to use buses. Buses are expected to be subcontracted, in which case the repository is not liable for their maintenance. Bus parking is accommodated at the repository.

Some personnel, such as the health physics staff on overnight call, are expected to stay in Mercury or alternative locations outside the repository. Accommodation for such personnel exists in Mercury. Vehicles are expected to be provided to these personnel.

5.3 REPOSITORY OPERATIONS

This section provides a high-level description of the major repository operations occurring in each operational phase described in Section 5.2.2, except off-normal.

5.3.1 Construction

Prior to beginning repository operations, all of the surface facilities, and enough of the subsurface areas, are constructed to permit a steady rate of waste disposal. Construction is scheduled to avoid peaks in construction staffing and resource utilization, to ensure resources are available when needed, and to accommodate the necessary approvals and inspections. The total construction period is six years.

Prior to construction the site is used for site characterization activities. These activities involve both surface and subsurface construction. It is expected that some construction infrastructure (e.g., utility system) will exist when repository construction begins.

Surface Construction

Surface construction begins with site preparation, which includes grading and grubbing and establishing the building pads. This operation likely requires moving the existing muck pile. Following site preparation, structures are built and finished. Routine structures may be prefabricated off site.

The rail route system is constructed on connecting rail route rights-of-way including earthwork, grade crossings, bridges, tunnels, culverts, and trackage.

Subsurface Construction

Subsurface excavation is initially conducted from the North Portal using facilities and equipment that remain from the site characterization activities. When the South Portal support facilities are available, operations are shifted to the South Portal.

Underground excavation is primarily performed with TBMs. The TBMs, road headers, and associated equipment perform the excavation and transferring of excavated rock or muck. Excavated rock is transferred to the surface and placed in a storage pile. The pile is stored with appropriate means to prevent deterioration, as the material may be used for site reclamation and backfill during repository closure.

Where use of a TBM is not feasible, other mechanical methods such as road header-type machines, or drill-and-blast excavation is used. For drill-and-blast excavation, rock must be picked up by loading equipment.

Following excavation, the openings are stabilized using appropriate combinations of rockbolts, welded wire fabric, shotcrete, and steel sets. Consideration is also being given to cast-in-place concrete and segmented precast linings commensurate with postclosure waste isolation requirements.

5.3.2 Development

During development, the emplacement drifts are excavated concurrently with waste package emplacement operations. Excavation techniques are described in Section 5.3.1.

To isolate the development workforce from airborne radionuclides that could be present in the emplacement area, two separate ventilation systems are used. The two systems are physically separated by bulkheads to minimize air leakage between the two areas. Differential pressure is maintained to ensure air leakage between systems is always from the development to the emplacement side. The requirement for separate development and emplacement ventilation areas is in accordance with 10 CFR 60.133(g)(3). Figure 5.3.2-1 shows a simplified illustration of the ventilation flow paths.

Development side ventilation fans are located on the intake and force air into the underground, resulting in the development system air pressure being above atmospheric pressure. The emplacement system ventilation fans pull air through the underground, resulting in the emplacement system being below atmospheric pressure. The flow path for the development system involves intake down the south ramp to the emplacement horizon. Most of the development side air moves to the main drifts and to the active TBM operations.

Development is conducted in phases. As a phase is ready for emplacement, the bulkheads are relocated and the excavation of the next phase begins. At completion of subsurface construction, the development area ventilation system is shutdown; however, this system is maintained until closure, as it may be required to support retrieval operations.

5.3.3 Emplacement

The following emplacement operations are described in this section:

A. *Waste Receipt* – Casks on transportation carriers enter the repository and are staged in a parking area.

B. *Carrier Staging* – Preparations are made to remove the cask from the carrier.

C. *Waste Handling* – Casks are removed from the transportation carrier, waste is transferred from the cask to a disposal container (DC), and the DC is closed and placed in the underground waste package transporter.

D. *Underground Emplacement* – The DC is transported to an underground emplacement position.

E. *Cask Maintenance* – Transportation casks are recertified, reconfigured, or repaired.

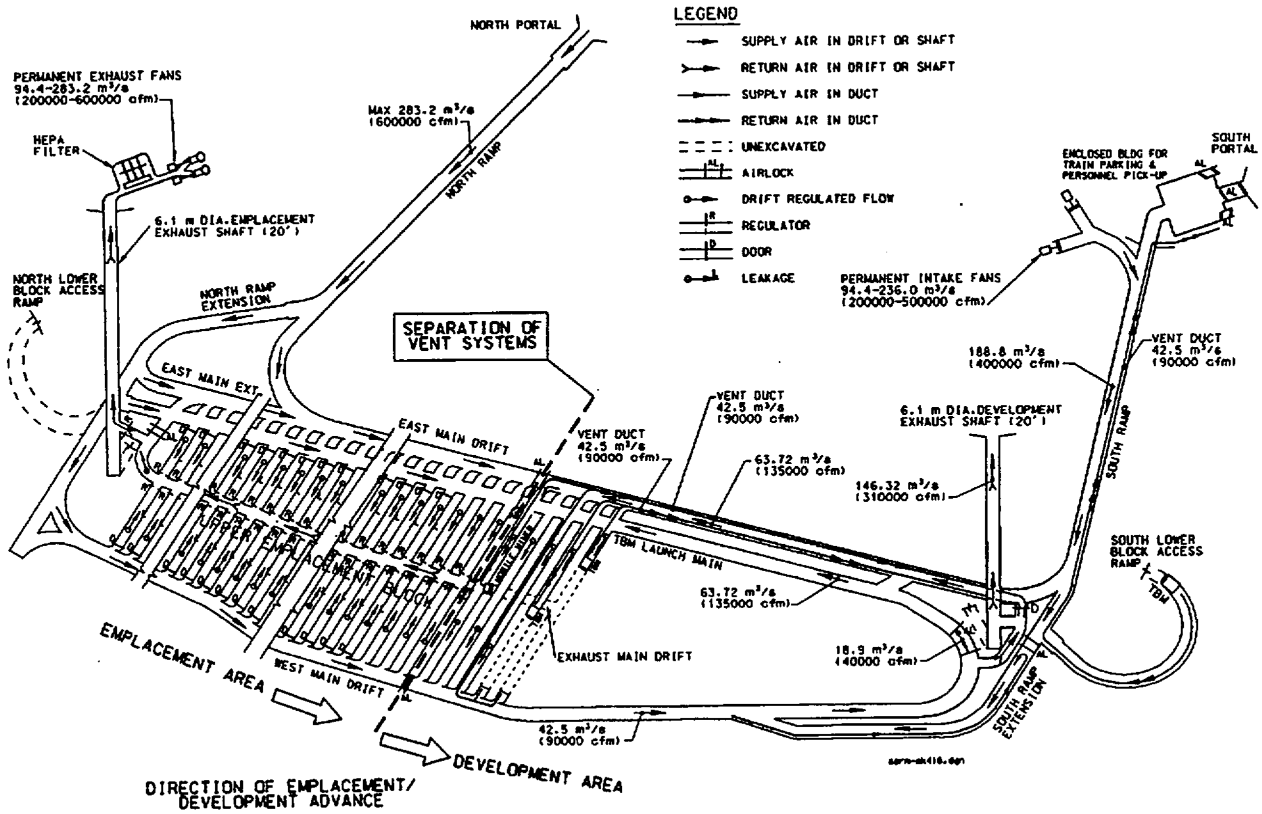

Figure 5.3.2-1. Separate Ventilation Systems for Development and Emplacement

F. *Site Generated Waste Handling* – Site-generated low-level wastes, mixed wastes, hazardous wastes, and sanitary wastes are managed.

G. *Off-site Rail Transportation within Nevada* – Rail transportation casks are moved to the repository.

H. *Support Operations and Services* – Structures and systems are operated to support the operations listed above.

5.3.3.1 Waste Receipt Operations

Transportation casks loaded with SNF are delivered to the MGDS on railcars or legal weight trucks. A loaded transportation cask carrier and its off-site prime mover are externally inspected for contraband and sabotage at the repository security boundary. The cask carrier is then transferred by the off-site prime mover to either the truck or rail parking area within the RCA. The off-site prime mover leaves the transportation cask carrier and exits the RCA. At the parking area, the off-site prime mover may pick up a cask carrier awaiting off-site shipment. Upon receipt at the parking area, the cask and carrier will be inspected for radiological contamination.

5.3.3.2 Carrier Staging Operations

A loaded transportation cask carrier is picked up from the parking area and delivered to the CSS to prepare for cask removal. Here the personnel barrier is retracted or removed, the impact limiters are separated from the cask, and the cask is reinspected for radiological surface contamination. Minor decontamination is performed as required. More substantial decontamination is done in the CMF.

The prepared transportation cask and carrier remain in the CSS until the WHB is available for removal of the cask the carrier. The personnel barriers and impact limiters are later reinstalled on the clean empty cask, returning from the WHB, in preparation for off-site shipment.

5.3.3.3 Waste Handling Operations

The site prime mover transfers the cask carrier to the WHB. In this building the casks are removed from the carrier, waste materials are transferred from the casks to disposal containers, filler material may be added to selected spent fuel assembly (SFA) canisters, and the disposal containers are welded closed and delivered for underground transportation. These operations are described below.

A. *Cask Receiving and Preparation* – A transportation cask is unloaded from a truck or rail carrier and placed on a railcar in a vertical position using a bridge crane.

A loaded cask requiring external decontamination or an empty cask requiring maintenance (i.e., recertification, repair or reconfiguration) is transferred on the cart to the CMF. After decontamination or maintenance, the cask is returned to the WHB. If the returned cask is empty, it is loaded back on a carrier and removed from the WHB by the site prime mover.

Loaded transportation casks are prepared for unloading, which includes operations such as cleaning the top of the cask, checking the pressure of the cask cavity, analyzing the cavity gas for contamination, and introducing a small negative pressure into the cask cavity. Following cask preparation, the loaded transportation cask is unloaded as described below in paragraphs B. and D.

B. *Canistered Waste Transfer* – A loaded rail transportation cask is moved on a cart to a shielded area where the lid is removed. The cask is then positioned under a cell port and the port plug is removed from above with a crane. The canister is lifted from the open cask, through the cask port, and into a hot cell. In the hot cell, the crane places the canister directly into a DC. The port plug is reinstalled. Following removal of the canister, the empty transportation cask is moved to where the lid is reinstalled and the cask is decontaminated, as necessary. The clean, empty cask is then transferred to where cask preparation and shipping operations are performed.

C. *Disposal Container Welding and Transfer* – In a hot cell, a crane moves a DC to an automated welding station, where the DC lids are installed and the welds are inspected. The closed DC (or waste package) is next moved to a device that places the container in a horizontal position. The horizontal DC, moved with a gantry, is decontaminated and placed on a subsurface waste package transporter cart. The cart is pushed into the waste package transporter, which is now ready to be taken underground for emplacement. A lag storage area is provided for in-process staging of DCs before or after welding.

D. *Uncanistered Waste Transfer* – After preparation, a truck transportation cask is moved on a cart to a shielded area where the lid is removed. The cask is then positioned under a cell port, the port plug is removed from above with a crane, and a contamination control barrier is installed. Bare SFAs are lifted, one at a time, from the open truck cask, through the cask port and into a hot cell. In the cell, the crane places each SFA into a staging rack. When the cask is empty, the contamination control barrier is decontaminated and removed, and the port plug is reinstalled. The empty transportation cask is moved to where the lid is reinstalled, and the cask is decontaminated as necessary. The clean empty cask is then transferred to where cask preparation and shipping operations are performed.

When enough SFAs have collected in the SFA staging rack to fill a DC, a DC is positioned under a transfer port. Each SFA is then lowered by crane from the SFA staging rack down through the port and into the DC. The loaded DC is moved to an area where an inner lid is seal welded in place by a laser. The sealed DC is transferred by cart to the DC welding area.

E. *Canister Filler Addition* – The addition of filler material may be required for approximately 117 SFA canisters as a moderator displacement technique to ensure long-term criticality control. This operation is performed by cutting the canister lid off, filling the voids between SFAs with carbon steel shot, and welding the canister lid back on. The operations are conducted remotely in a hot cell, and the cutting and welding are performed with a laser.

F. *Cask Preparation and Shipping* – The empty cask is transferred by cart to a preparation area after the waste has been removed. The cask arrives closed and decontaminated. Cask preparation includes visual inspections, cask closure inspections, health physics inspections, and, if necessary, purging of the cask cavity with an inert gas. These operations are safely conducted by direct contact because the casks do not contain waste materials. If the cask requires maintenance (i.e., recertification, repair, or reconfiguration), it is transferred to the CMF on a cart. Following cask maintenance, the cask is returned to the WHB. The clean empty transportation cask is lifted from the cart and loaded on a truck or rail carrier. The cask and carrier are transferred to the CSS by the site prime mover.

5.3.3.4 Underground Emplacement Operations

The waste package transporter, containing the loaded DC (i.e., waste package) and railcar unit, is pulled to an underground emplacement drift with an electric transport locomotive. This transporter is a specially configured railcar that includes a shielded cask with doors. Here the waste package and emplacement railcar are removed from the transporter and positioned in the emplacement drift with a battery-powered locomotive. These operations are described below.

A. *Waste Package Underground Transfer* – The transport locomotive attaches to the loaded transporter at the WHB loading dock. The locomotive hauls the transporter through the north waste ramp to the Waste Handling Main, into the Waste Handling Main, and to the designated emplacement drift and emplacement entry area. During pre-emplacement operations the emplacement entry area is prepared for emplacement.

The prime mover then positions the transporter in front of the emplacement drift door. The transporter door opens and continuity with the emplacement drift rails is established. A self-contained mechanism pushes the waste package beyond the opening. The transporter is retracted, and the emplacement drift door is closed. The empty transporter is pulled away from the emplacement entry area and transported back to the surface.

B. *Cask Return to Surface* – The transport locomotive parks the transporter at the WHB loading dock in preparation for loading a new waste package.

C. *Waste Package Emplacement* – When the empty transporter clears the emplacement entry area, a battery-powered, remote-operated transport locomotive is brought on a rail carrier, positioned at the emplacement entry area, and inserted into the emplacement drift. The emplacement locomotive advances, attaches to the car, moves the car to its emplacement location in the drift, and retreats back to the emplacement entry area. The emplacement drift door closes, completing the emplacement operation. Post-emplacement operations follow to clear the emplacement entry area or prepare it for the next waste package. The emplacement drift is ventilated until all waste packages of that drift are emplaced.

5.3.3.5 Cask Maintenance Operations

Cask maintenance includes periodically recertifying casks to ensure the cask is safe, clean and properly configured, routinely reconfiguring casks to accommodate different types of fuel assemblies (e.g., replacing the internal spacers and baskets), and repairing casks and cask components as needed to maintain cask certification. The operations required to accomplish recertification and/or reconfiguration are similar and are described below. Some of these operations may be skipped to repair a cask, depending on the nature of the irregularity.

A. *Preparation for Opening* – An incoming cask is received in the WHB and transported, in a vertical orientation on a cart, to the CMF. The cask is placed in a pit using a bridge crane, where a shroud and bottom protector are installed for contamination control. The cask is filled with water, the head is loosened, and the head removal adaptor is installed.

B. *Reconfiguration and Cleaning* – The cask is then transferred to the reconfiguration pool using a bridge crane. The head is removed and transferred to a pit for inspection, repair, and decontamination, as necessary. In the reconfiguration pool, the interior of the cask is inspected and then cleaned with a wet vacuum system. The spacers and baskets are removed from the cask by the pool bridge crane, cleaned, and then placed in an underwater storage rack. The interior of the empty cask is then inspected and cleaned again. Spacers and baskets are placed in the cask. If a cask reconfiguration was required, the design of the spacers and baskets placed in the cask differs from those removed. The cask is then lifted to the pool shelf with a crane, where the interior of the cask and any sealing surfaces are inspected.

C. *Decontamination* – The cask is lifted from the reconfiguration pool, and the shroud and bottom protector are removed as the cask is being placed in a pit. In the pit, the cask exterior is surveyed for contamination and decontaminated as necessary. Decontamination may be conducted with localized scrubbing or high-pressure washing with chemical solutions or tempered water.

D. *Component Repair and Closure* – Following decontamination, the water level in the cask is lowered to allow access to any sealing surfaces. Repairs to seals, fasteners, and any internal components are performed as required. The head is reinstalled, and the water is removed from the cask. The cask is vacuum dried, pressurized with an inert gas, and leak tested.

E. *External Repair* – The cask is removed from the pit to undergo dry tests and repairs to external surfaces. This activity includes welding, grinding, and component replacement. The recertified and/or reconfigured cask is placed on a cart and rolled to the WHB for off-site shipment.

5.3.3.6 Site Generated Waste Handling Operations

Secondary (i.e., site-generated) wastes include low level wastes, mixed wastes, hazardous wastes and sanitary wastes. The repository operations for handling these materials are described below.

A. *Low-Level Waste* – Liquid wastes are collected and routed through a piping system to the WTB. Recyclable liquids are treated with filtration, evaporation, and ion exchange. The treated water is piped to the waste generators for reuse. Non-recyclable liquids are neutralized, solidified, and packaged in drums. Solid wastes are transferred to the WTB in drums. These materials are size-reduced, compacted, or dewatered as necessary, and then packaged in drums with a solidification agent. After treatment, the drums of packaged low-level waste are shipped off site for disposal.

B. *Mixed Wastes* – Although the repository includes provisions to avoid the generation of mixed wastes, small quantities of solid and liquid mixed wastes are assumed to be generated from off-normal repository operations. If generated, this material will be packaged in drums at the point of generation, accumulated, and shipped off-site for treatment and disposal.

C. *Hazardous Waste* – Solid and liquid hazardous wastes are packaged in drums at the point of generation, accumulated, and shipped off site for treatment and disposal.

D. *Sanitary Waste* – Sanitary liquids are routed via sewer lines to an on-site sanitary waste treatment system. Sanitary solid waste is accumulated in dumpsters throughout the site. Garbage trucks periodically collect and transport the garbage to an off-site landfill.

5.3.3.7 Off-Site Rail Transportation Within Nevada

Two options are under consideration for transporting waste to the repository within Nevada. The first option uses a dedicated unit train (e.g., two locomotives and three to five cask carriers). This train, which is operated interstate by a commercial line-haul carrier (e.g., Southern Pacific and Union Pacific), enters Nevada on a main line, stops at a junction point, transfers to a connecting rail line, and continues to the repository. At the junction point, the transport authority is confirmed, crews are changed, and the train is switched to the connecting rail line.

In the second option, the train entering Nevada includes commercial freight cars as well as the cask carriers. The train stops at the junction and switches out the cask carriers. The cask carriers are then configured as a unit train. This unit train transports the waste to the repository via the connecting rail line. In this option, support facilities at the junction points are more extensive to accommodate additional equipment, interchange operations, and crew conveniences.

5.3.3.8 Support Operations and Services

Emplacement operations require a number of support operations and services. These operations are conducted with a variety of support structures, site support systems, and support systems within facilities. The operations are described below.

A. *Administration and Planning* – Administration and planning operations are supported by contractor/government and staff management, automated data processing, video conferencing, payroll, accounting, purchasing, visitor management, and food service. The facilities and equipment are primarily located in the Administration Building

B. *Engineering and Analysis* – Engineering and analysis includes responsibilities associated with health physics, emplacement/transportation planning and simulation, design engineering analysis, environmental analysis, energy conservation, etc. The main engineering workforce is housed in the Administration Building.

C. *Training and Certification* – Training uses classrooms, audiovisual aids, and mock-up facilities for field and on-the-job training. Personnel are certified and re-certified, as required, and the records are maintained on the Administration Building central computer. The facilities and associated training systems are located at various facilities throughout the site including the Administration Building, Training Auditorium, and Mock-up Building.

D. *Emergency Response* – The emergency response capability ensures adequate response to, and mitigation of, the consequences from off-normal events at the repository. Emergency response consists of the required facilities, systems, and trained personnel. The primary site facilities are the Fire Station, emergency response centers, and Medical Facility. The emergency response centers include a variety of special on-site and off-site capabilities to respond to subsurface, radiological, environmental, medical, and security events.

   Emergency response support systems are coordinated through existing site safety systems including communications/public address, fire protection/detection, security, radiological and hazardous monitoring, medical, and weather systems. Automatic and manually entered hazardous alarms are time tagged, identified, and prioritized. Alarm data is automatically routed to the appropriate control room, annunciator station, fire station, medical facility, emergency response center, and law enforcement agency.

E. *Physical Security* – Security maintains safety and the authorized access of people and equipment at the repository site and facilities. The security operation uses trained security and emergency response personnel, fences, barriers, guard houses, control rooms, offices, and equipment. The security equipment includes vehicles, weapons, control, and monitoring systems.

The control and monitoring systems include site/emergency communications, badge/vehicle access and accounting, automated data processing systems, video and electronic detection equipment, central monitor and control, and alarm systems. The system integrates surface facility, subsurface facility, and site security stations on the redundant data network with assigned priority to the emergency response system.

F. *On-Site Transportation* – On-site transportation directs and coordinates the on-site movement and maintenance of the shipping cask transportation vehicles. This operation includes the installed rail and road equipment, transporters and associated instrumentation, communications, safety equipment, and central control facilities. The control stations are in the Administration Building, collocated with the off-site transportation control area.

G. *Site Maintenance* – Site maintenance maintains repository facilities, systems, equipment, instruments, and vehicles. The system schedules and performs the maintenance, maintains records of failures and repairs, manages spares inventories, reports on failure histories and trends, and issues advisories for preventive maintenance procedures. Certain failures are logged automatically. Most equipment failures and the associated repair data is recorded by manual input on in-place or portable workstations. The major maintenance facilities include the TMB, Motor Pool and Facility Service Station, and Central Shops.

H. *Warehousing* – Warehousing maintains the inventory and records for general purpose site equipment and materials. This operation consists of warehouse space, material handling and packaging equipment, and inventory systems. The materials are stored at the Central Warehouse. The Administration Building automated data processing systems maintains the central records for all site inventories. Inventories are also maintained at the Waste Handling and Cask Maintenance Buildings for special equipment associated with maintaining the cask fleet and material handling equipment. The Administration Building staff maintains the central inventory and maintenance records and manages the purchasing activities.

I. *Secondary Waste Management* – The secondary waste management system handles all on-site generated wastes, maintains waste generation records, issues empty containers, coordinates waste minimization and recycling activities, and provides compliance reports. Administrative waste management functions are conducted in the Administration Building and records are maintained on the WTB automated data processing system. Refer to Section 5.3.3.6 for a description of the waste treatment operations.

J. *Utilities* – Utilities include water, electric power, diesel and gasoline fuels, and industrial air. Well water is used to produce potable water, well/fire water, tower cooling water, and chilled water, which is distributed to users throughout the repository. Electric power, provided from off site, is distributed to repository users through a system of transformers and switchgear. Uninterruptible and standby power is provided as required for critical safety and security systems. Liquid fuels are delivered by truck to support vehicle and standby generator operation. Industrial air is generated centrally at two locations and piped to users. Sanitary sewage is collected and treated in a septic system and underground waste water is collected and routed to a waste water pond. Other specialized utility systems are provided within the facilities.

K. *Communications* – Communications include data and voice and video signals throughout the repository, NTS, and off site. This operation uses fiber optic communications networks, a back-up microwave or cellular communication system, and a satellite earth station.

L. *Monitoring and Control* – Monitoring and control includes a number of networked computer systems used to collect, manage, synthesize, and display data from repository operations, and, where appropriate, control operations or notify repository personnel. The following systems are provided:

- Utility monitor and control systems
- Facility monitoring and control systems
- Emergency control, material control, and accountability
- Radiation monitoring
- Site effluent monitoring
- Off-site transportation monitoring and control.

Each system includes the appropriate level of reliability and secure access. Workstations are provided throughout the repository work areas. Central computers and servers are provided in the Administration Building.

M. *Ventilation Systems* – Ventilation systems are provided in all facilities to maintain the proper environmental conditions for the equipment as well as for the health, safety, and comfort of operating personnel. In general, the ventilation systems use electricity for heating and chilled water from central water chillers for cooling.

HVAC systems for nuclear surface facilities confine radioactive and hazardous materials as close to the point of origin as practicable and prevent uncontrolled releases to rooms and areas normally occupied by personnel. This confinement is accomplished through a series of successive confinement zones of varying pressures. Each successive zone is at a lower pressure and has a higher potential for contamination. Exhausts from the lowest pressure zone are routed through HEPA filters and discharged from the facilities at monitored stacks. Non-nuclear surface facilities have commercial-quality HVAC systems.

The subsurface facilities are ventilated by two separate and independent systems during the period when both emplacement and development are ongoing. A description of the emplacement area ventilation system follows. The development area ventilation system is described in Section 5.3.2. Airflow in the subsurface emplacement ventilation system enters the emplacement area through the north ramp and exits through the emplacement exhaust shaft. The air is drawn through a fan at the top of the shaft and is exhausted to the atmosphere. If abnormal levels of radiation are detected in the emplacement area, the exhaust airflow is diverted through a HEPA filtration system to ensure that contaminated particulates do not escape from the facility. Individual emplacement drifts are ventilated until all waste packages are emplaced in that drift. When the last waste package is emplaced in a drift, the doors are closed, and ventilation is cut off in that drift. Ventilation would be re-established only if access to the drift was required.

5.3.4 Caretaker

The caretaker phase is a waiting period of 76 years from the end of the emplacement phase, during which the option to retrieve emplaced waste is preserved. Caretaker operations are primarily limited to the maintenance of repository subsurface facilities. During this period the performance confirmation operations described in Section 5.3.7 also occur.

All surface facilities, except those required to conduct maintenance, are placed in a cold shutdown condition. The accessible portions of the underground (i.e., drifts not containing emplaced waste) are routinely inspected and repairs are made to the ground support as required. Data on the uninhabitable emplacement drifts is provided from the performance confirmation operations. If this program indicates that the emplacement drifts require maintenance, the drifts are cooled, the waste packages are removed to an empty emplacement drift, and repairs are made.

Caretaker operations require some of the same support operations and services described for the emplacement phase in Section 5.3.3.8, although the level of activity and staffing levels are significantly reduced. This activity includes operation of the subsurface utilities (e.g., ventilation system, lighting, electric power distribution, pumping, monitoring systems, and personnel transportation systems). Note that during caretaker operations, the subsurface ventilation system is reconfigured such that only one fan system is used.

Section 9.1 provides additional descriptions of caretaker operations.

5.3.5 Retrieval

The waste emplaced at the repository may be retrieved any time after the start of emplacement and before closure to remove public health and safety concerns or to recover the waste as a valuable resource. All or part of the emplaced waste packages could be retrieved.

When (and if) retrieval is required, a period of mobilization is needed to modify, expand, or upgrade the repository facilities, as required to conduct the retrieval operations. The following changes to the repository may be required:

- Special equipment is added to operate in emplacement areas that have not maintained their integrity.
- Surface facilities are modified to cut open waste packages, repackage the waste for shipment or remediation, or process the waste for recovery of a valuable resource.

- Lag storage facilities are added to stage the retrieved waste.
- Underground equipment, which has a useful life of 10 to 20 years, is replaced.

Waste package retrieval, under normal conditions, is essentially the reverse of the waste package emplacement operations described in Section 5.3.3. Prior to retrieval, the drifts are ventilated, inspected to confirm that no debris is obstructing equipment operation, and monitored until the drift temperature is within prescribed limits. At the surface, the waste may be repackaged and reemplaced, shipped off site, or processed on site for resource recovery.

Subsurface waste package retrieval may be hampered by a failure of the rock support, deterioration of the shotcrete or deterioration of drift inverts, causing track failure. Descriptions of off-normal subsurface retrieval operations dealing with these conditions, as well as a more detailed description of normal subsurface retrieval operations, are provided in Section 9.2.

5.3.6 Performance Confirmation

The performance confirmation phase includes data collection, performance assessment using the collected data to analyze the performance of the repository, and taking corrective action if required. These activities begin during site characterization, prior to construction.. The laboratory testing ends at start of closure. In situ monitoring may end at closure or continue in postclosure. Each activity is described below. Section 9.3 provides additional descriptions.

5.3.6.1 Data Collection

Data is collected with in situ monitoring, laboratory and field testing, and in situ experiments to monitor the geological and radiological environments of the repository. The types of measurements, collection methods, and quantity of measurements are determined as the current assessment operations and the MGDS design progresses.

In Situ Monitoring

The natural and engineered barriers are monitored in the emplacement drifts assigned to performance confirmation. Waste package and rock surface temperature and radiation measurements are taken. In addition, video cameras are used to inspect for corrosion, other abnormal waste package conditions, and drift conditions.

Measurements are taken on all waste package types. Measurements are also taken in several emplacement drifts to confirm that the confirmation drift data adequately represents conditions throughout the repository. Instrumentation packages are attached to an overhead rail system and remotely operated near the waste packages. In situ instrumentation is avoided because of the hostile environment and serviceability constraints in the emplacement drifts.

The natural barrier is monitored by measuring and profiling temperatures of the geologic media, stress and strain in the rock, water density, chemistry, and movement. Measurements are made in drill holes parallel to emplacement drifts or in empty drifts adjacent to emplacement.

Laboratory Tests

Conceptually, one waste package is retrieved every ten years for evaluation and repackaging in the WHB. The waste package is opened, testing and sampling is conducted, the waste is repackaged and returned to the emplacement area. The waste package supports and welds are inspected for cracks and corrosion, deterioration is photographed and logged, and samples are taken for further examination. Waste package surface temperatures and radiation levels are also noted and compared to the measured in situ levels. If leakage is detected, the waste package is repaired or replaced.

When a waste package is to be evaluated during the caretaker phase, crews are trained and the necessary surface facilities are restarted. After conducting these tests, the facilities are decontaminated and closed. The duration for each operating period is as follows: seven years for standby, two years for restart and waste package disassembly, and one year for decontamination.

Note that requirements for retrieval frequency and laboratory testing have not been established. Ultimately, the waste packages may need to be opened only if non-destructive testing suggest that additional data is required.

Field Tests

Repository ventilation exhausts, site groundwater, and perimeter air quality are continually monitored for radiation levels, composition, and particulates. Wells at the periphery of the repository are also monitored for radiation levels and water chemistry. Other measurements at the repository include seismic activity, ambient temperature, barometric pressure, and relative humidity.

In Situ Experiments

Monitoring of the natural barrier and the monitoring described above is conducted to determine the performance of the natural barrier. Temperature, humidity, and water flow profiles are trended from measurements taken at selected locations throughout the repository. Portable or permanent instrumentation packages are used.

5.3.6.2 Performance Assessment

As in situ monitoring, laboratory, and field test data become available, performance assessment models used during repository design are updated. Actual thermal profiles are compared to predicted profiles and geologic parameters modified where necessary to further refine models.

Using the updated performance assessment models, performance of the engineered barrier and natural barrier is estimated together with performance of the total system. Long-term radiological consequences are also estimated. Any deviation from earlier predictions is carefully examined.

Using environmental and performance data, the environmental performance bounds are assessed. The results are compared to the EPA standards developed prior to approval of the repository for waste receipt.

5.3.6.3 Corrective Action

If the performance assessment indicates that the system is not performing properly, appropriate action is taken. The risk of exceeding the limits is assessed and mitigation actions are planned from predetermined alternatives. For example, if the expected rate of waste package corrosion is exceeded, the following actions may be considered:

- Increase frequency of inspections
- Remove waste package for laboratory testing
- Relocate waste packages to other drifts
- Retrieve additional waste packages.

5.3.7 Closure

Permanent closure operation includes closure of the subsurface facilities, decommissioning of the surface facilities, site reclamation, and establishment and maintenance of institutional barriers.

5.3.7.1 Subsurface Closure

Closing subsurface openings involves removing underground equipment, preparing the openings to receive backfill, backfilling the openings, installing repository seals, and implementing postclosure monitoring, if required. Included in the definition of equipment to be removed prior to closure are utilities and support services, as appropriate (size and type would be considerations), and unsuitable materials. Preparing the openings to receive backfill includes installing utilities and equipment specifically for the backfilling operation.

Backfilling involves obtaining material from the surface stockpile or other source, processing it (screening and, if necessary, crushing) to obtain the required grading, placing the processed material into a stockpile for subsequent loading, and transferring it to the underground for emplacement. The function of such backfill is access prevention.

Placement of seals involves preparing the underground openings to receive the seals, obtaining and transferring seal material, and constructing the seals. Currently, it is assumed that seals are to be placed only in shafts, ramps, and boreholes to ensure proper waste isolation and repository performance. Backfill may be placed on both sides of each seal.

Options for using a special type of backfill, to be placed over the waste packages in the emplacement drifts to enhance waste isolation, are currently being studied. Such backfill is not currently included in the baseline design, but will be included if the requirement for it is established.

5.3.7.2 Surface Decommissioning

As part of the closure activities, the surface facilities are decommissioned and removed from service. Decommissioning includes decontamination, removal/salvage of valuable equipment and materials, and dismantlement.

Decontamination ensures that residual contamination, both radioactive and hazardous, is within permissible levels for unrestricted use, or disposal operations. Decontamination activities include the survey, identification, and characterization of contaminated areas and facilities. Decontamination activities also include determination of methods for removal, degree of treatment needed, packaging, in situ immobilization, and transportation either to an on-site or off-site disposal or storage location.

Decontamination activities for hazardous materials and substances are not anticipated but could occur. It is expected that potential radiological contamination could occur anywhere unconfined radioactive materials (i.e., exposed intact spent fuel assemblies) are handled or where contamination is present on incoming containers within the WHB and CMF. In addition, contamination is expected to be generated within the WTB. Hot cells, decontamination stations, HVAC ducts, and HEPA filters potentially require decontamination or packaging for removal.

Facility dismantlement includes the dismemberment, distribution, or removal from the site of facility systems, in whole or in part, for the purpose of salvage, disposal, interim storage, long-term storage, reuse at another location, or safety. All facilities not part of the Institutional Barrier System functions are dismantled and removed from the site area. Almost all of the surface facilities require demolition of reinforced structures after removal of fixtures and equipment. Consideration for salvage, recycle, and reuse of equipment, materials, and fixtures is planned.

Removal of facilities is required to perform final site restoration activities. Facility removal activities include the preparation and transportation of intact facilities and facility sections to off-site locations.

5.3.7.3 Site Reclamation

Site reclamation includes restoring the site to as near to its pre-construction condition as possible in accordance with the *National Environmental Policy Act of 1969*. Reclamation may require the recontouring of all possible disturbed surface areas, surface backfill, soil buildup and reconditioning, site revegetation, site water course configuration, and erosion control implementation.

5.3.7.4 Institutional Barriers

Institutional barrier systems are incorporated, including land records, and passive and active systems designed to inhibit human disturbance and disruption of the repository site. Active controls include site monitors, warning devices, patrols, and an education institution that informs future generations. Passive controls include surface markers and obstacles.

5.3.8 Postclosure

After closure, the system of institutional barriers is managed and monitored. During postclosure the Engineered Barrier Segment may be monitored to ensure waste isolation, and the data collected is periodically analyzed. If this monitoring is required, monitoring devices will be installed prior to closure and maintained in postclosure.

6. SITE DESCRIPTION

This site description is intended to be an overview of the site and its regional setting. Specific design related site information are covered in the individual sections of Volume II. Since the basis for the design presented in this report is a combination of the respective design requirements documents and the *Controlled Design Assumption Document* (CRWMS M&O 1995a), much of the site information presented in this chapter came from these documents. Where appropriate, more recent information is incorporated to add to the site description.

6.1 GENERAL SETTING

This section presents an overall depiction of the Yucca Mountain area by describing in detail its general setting, physiography, meteorology, stratigraphy, structural geology and tectonics, and hydrology.

6.1.1 Previous Work

The Yucca Mountain area has been studied by U.S. Department of Energy (DOE) as a potential geologic repository site for the disposal of high-level nuclear waste for a number of years. The process and schedule for the siting was specified by Congress in the Nuclear Waste Policy Act of 1982. In May 1986, DOE recommended, and the President approved, the Yucca Mountain site as one of three candidate sites for detailed study. In the Nuclear Waste Policy Amendments Act of 1987, Congress identified the Yucca Mountain Site as the only site to be characterized. Since that time, the area has been investigated with numerous bore holes, trenches, geophysical surveys and the ESF development for the purpose of site characterization and gathering data for design. These site characterization activities are located in the Site atlas (EG&G 1995).

6.1.2 Location and Access

Yucca Mountain is located in Nye County, Nevada, about 160 km (by road), northwest of Las Vegas (Figure 6.1.2-1). Access from Las Vegas is via U.S. Highway 95 to the Mercury turnoff, then northwest on the Jackass Flats road from Mercury. An alternate access is via U.S. Highway 95 to Lathrop Wells, then north on the Lathrop Wells road. The Yucca Mountain area Field Operations Center is located at the junction of the Jackass Flats and Lathrop Wells roads. From the Field Operations Center, the Yucca Mountain project site is reached via "H" road. All accesses to the area are controlled by the Nevada Test Site.

6.1.3 Land Control

The Yucca Mountain area is situated on land that lies within the Nevada Test Site, Nellis Air Force Range, and the U.S. Bureau of Land Management (BLM) administered lands (Figure 6.1.2-1). The Nevada Test Site is reserved for use by the DOE. The western portion of Area 25 on the Site has been informally reserved for the Yucca Mountain Project. The Nellis Air Force Range, withdrawn from the public domain for use by the Air Force, is managed by the BLM. The remaining area is public domain land administered by the BLM.

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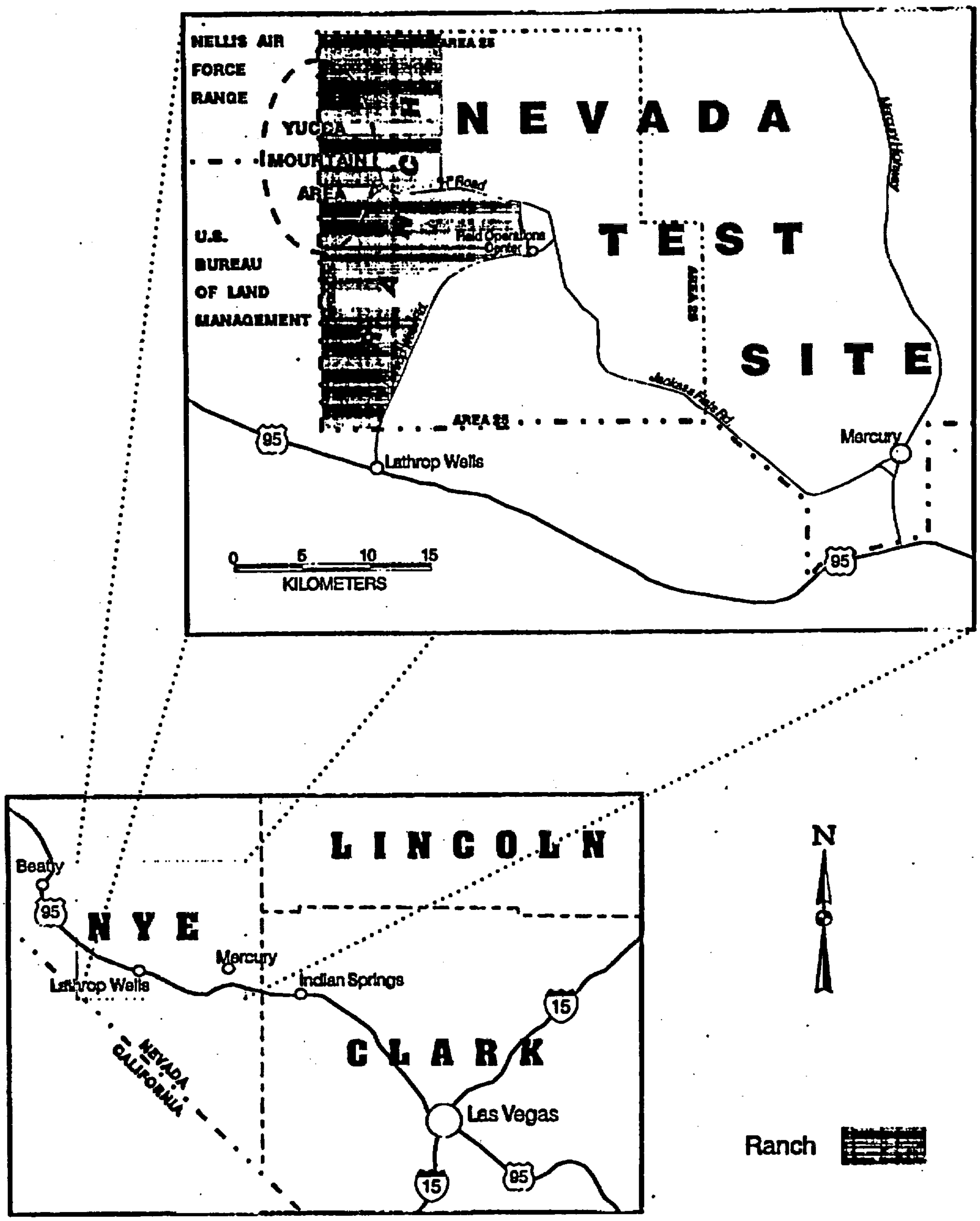

Figure 6.1.2-1. Location and Access Map

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6.1.4 Population

The 1990 U.S. Census population of Nye County was 17,781. Adjacent Lincoln County had a population of 3,775, and Clark County, which contains Las Vegas, had a population of 741,459. Metropolitan Las Vegas is now estimated to contain over 1 million people. In the more immediate area of Yucca Mountain, Beatty, Lathrop Wells, Mercury, and Indian Springs are all minor population centers. Located about 40 km south of Lathrop Wells is the town of Pahrump. In 1990, its population was 7,424, but has more than doubled since then.

6.2 PHYSIOGRAPHY

The physiography of the region around Yucca Mountain is an important indicator of the nature and magnitude of geologic processes that have occurred during the history of the region. A study of these processes, such as tectonics and erosion, results in a better understanding of future changes, and in particular, the changes likely to occur over the life of the repository. The following subsections present a summary of the physiographic setting of the Yucca Mountain area, a description of the geomorphic processes that have shaped the region, and projection of future processes.

6.2.1 Previous Work

A comprehensive discussion of the physiography of the region and Yucca Mountain is presented in the Site Characterization Plan (DOE 1988a).

The general region of Yucca Mountain is surveyed on five U.S. Geological Survey topographic maps. These include Bare Mountain and Big Dune, Nevada, at a 1:62,500 scale with 40- and 80-foot contour intervals respectively, and Busted Butte, Lathrop Wells, and Topopah Spring NW, Nevada, at a 1:24,000 scale with a 20-foot contour interval.

Special topographic map coverage for the Yucca Mountain area includes 1:12,000 scale maps with a 20-foot contour interval, developed from U.S. Geological Survey 1:24,000 scale digital line graph data. Orthophotographic coverage was developed for the Yucca Mountain area from 1:24,000 scale aerial photographs taken in July 1990 (EG&G 1995). The orthophotos were developed at a scale of 1:6,000. Digital elevation contour maps were also developed at a scale of 1:6,000 with 10-foot contour intervals as well as 160-foot spacing digital elevation models. Thirty of the 1:6,000 scale maps were developed for a 1,400 square km area around Yucca Mountain.

Orthophotographs were also developed at a scale of 1:12,000 from 1:40,000 scale color aerial photographs taken in July 1990 (EG&G 1995). Digital elevation contour maps with 20-foot contour intervals and digital elevation models at 250-foot intervals were also developed. Thirty-six 1:12,000 scale maps were developed for a 440 square km area around Yucca Mountain.

Detailed topographic contour maps with 2-foot contour intervals were developed at a scale of 1:1,200 from 1:6,000 scale aerial photographs taken in August 1991 (EG&G 1995). These maps are presented in 90 sheets and cover in area of about 57 square kms.

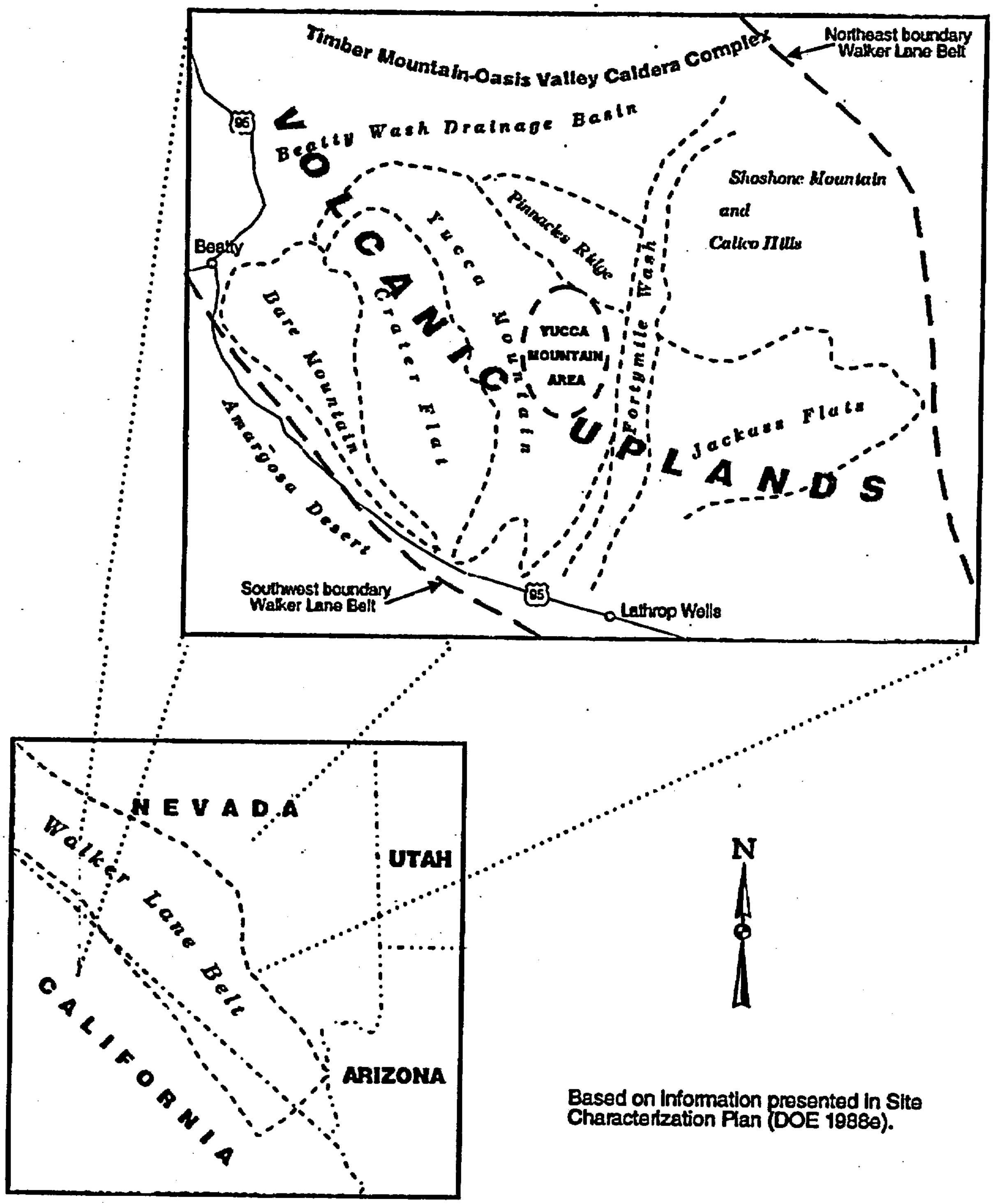
No metric topographic maps have been developed for general use on the project. For repository design, digital metric topographic map data was developed by using the computer-generated topographic surface from the 1:12,000 scale USGS digital maps with 20-foot contour interval, then recontouring the surface to a 20-meter contour interval (CRWMS M&O 1995n). Metric topographic maps have been identified as repository design data need 1.1 (CRWMS M&O 1995o).

6.2.2 Regional Physiography and Geomorphology

The Yucca Mountain area lies in the southern part of the Great Basin subprovince of the Basin and Range physiographic province. The Great Basin is generally characterized by long and narrow, north- to northeast-trending mountain ranges separated by intermontane structural basins. These characteristic basin and range landforms are the result of late Cenozoic high-angle normal faulting. The region around Yucca Mountain shows basin and range features, which are further complicated by local volcanism and the tectonic fabric of the Walker Lane belt (DOE 1988a).

The Walker Lane belt (Figure 6.2.2-1) is a complex zone of northwest-trending strike-slip displacement (DOE 1988a). It subparallels the western margin of the Great Basin subprovince from the area of Pyramid Lake in northwest Nevada to the Mojave Desert in southern Nevada. The Yucca Mountain area is located in an area of volcanic terrain within the Walker Lane belt, which is characterized by shallow-dipping volcanic uplands developed on the southern flank of the associated Timber Mountain-Oasis Valley caldera complex (Figure 6.2.2-1). The volcanics consist of tuffs and flow rocks of the late Tertiary, southwestern Nevada volcanic field (USGS 1995a). Ridge summits are broad and relatively flat with minor topographic relief. In many areas, these surfaces end abruptly at steep, caprock-protected slopes aproned with blocky talus. The flanks of the uplands are deeply dissected with radial and structurally controlled drainage systems (DOE 1988a).

Within the volcanic uplands area (Figure 6.2.2-1), the physiographic characteristics of the land surface are varied. Yucca Mountain itself is an irregularly-shaped volcanic upland 6 to 10 km wide and about 40 km long. It extends from Beatty Wash and Pinnacles Ridge in the north to the Amargosa Desert in the south, and from Crater Flat in the west to Fortymile Wash in the east. It consists of a series of subparallel ridges controlled by high-angle, generally north trending faults. The fault blocks are tilted slightly eastward so that the eastern flanks of the ridges are gentle and dissected, while the western, fault-controlled flanks generally have great topographic relief, steep slopes with talus developed, and are linear in plan view. Collectively, the subparallel ridges form what is referred to as Yucca Mountain. The repository site is located beneath a ridge known as Yucca Crest. The highest point on Yucca Mountain is at about 1,930 m, which is about 650 m above the adjacent lowlands of Crater Flat (DOE 1988a).



Based on Information presented in Site Characterization Plan (DOE 1988e).

Figure 6.2.2-1. Physiographic Setting

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Yucca Mountain is bounded on the north by Pinnacles Ridge (Figure 6.2.2-1), the southern part of which is structurally and lithologically similar to Yucca Mountain. Northward, Pinnacles Ridge changes rapidly to a deeply eroded and irregular highlands formed on the southern flank of the Timber Mountain-Oasis Valley caldera complex. To the east of this area lie the Calico Hills and Shoshone Mountain, which are also highlands formed along the southern flank of this caldera. To the west and east, Yucca Mountain is bound by lowlands of Crater Flat and Jackass Flats. Both these areas drain to the Amargosa Desert in the south. To the west of Crater Flat is Bare Mountain, a large upfaulted block. Along the western margin of Jackass Flats is the Fortymile Wash, which drains a large area within the Timber Mountain-Oasis Valley caldera complex. In its southern reaches, the Fortymile Wash has cut a trench 150 to 600 m wide and up to 25 m deep. To the north of Yucca Mountain and Pinnacles Ridge is one of the largest drainage systems in the area, the Beatty Wash drainage basin. It drains a large area along the southern margin of the Timber Mountain-Oasis Valley caldera complex (DOE 1988a).

6.2.3 Landforms of Yucca Mountain

Yucca Mountain landforms (Figure 6.2.3-1) are very characteristic of eroded and tilted volcanic uplands. Yucca Crest, which overlies the repository site, trends north-south with some irregularity in its trend. The ridge profile is asymmetrical, with a gently rounded top, relatively steeply-sloping west flank and gently-sloping east flank. The western flank of the ridge has well-developed talus slopes that merge into colluvial deposits at the base in Solitario Canyon. Drainage lines developed on this slope are steep, short, and shallow, and join together in the wash of Solitario Canyon. This canyon is wide and asymmetrical with a more gently-sloping, ridged west flank.

The eastern flank of Yucca Crest is more gentle, reflecting the gentle eastward dip of the strata, and is dissected by drainage lines that are linear. In the area closest to Yucca Crest, the washes generally trend to the east, which is parallel to the dip of the strata. As these drainage lines coalesce towards the east to form larger washes, they change their general orientation to east-southeast. Several of the major washes, such as Drill Hole Wash, have developed at this orientation. To the north of Drill Hole Wash, the orientation of the washes rotates to more southeast, reflecting the change in the strike of the strata and reflects the influence of structural control from northwest trending faults through this area.. Washes north of Drill Hole Wash tend to be long, sinuous, and narrow, and generally follow faults.

The developed ridges on the east flank of Yucca Crest are narrow and gently rounded, except where resistant caprock forms cliffs and rugged surfaces. The slopes are steep with a small convex profile developed near the top where the caprock is absent. Mid slopes are often covered with a thin veneer of talus that coalesces at the base. Where the wash bottoms are sufficiently wide, a concave profile may be developed at the base, covering the bedrock. Wash bottoms are sharp and V-shaped near the Yucca Crest, and widen out towards the base of the east flank where thick alluvial deposits have formed.

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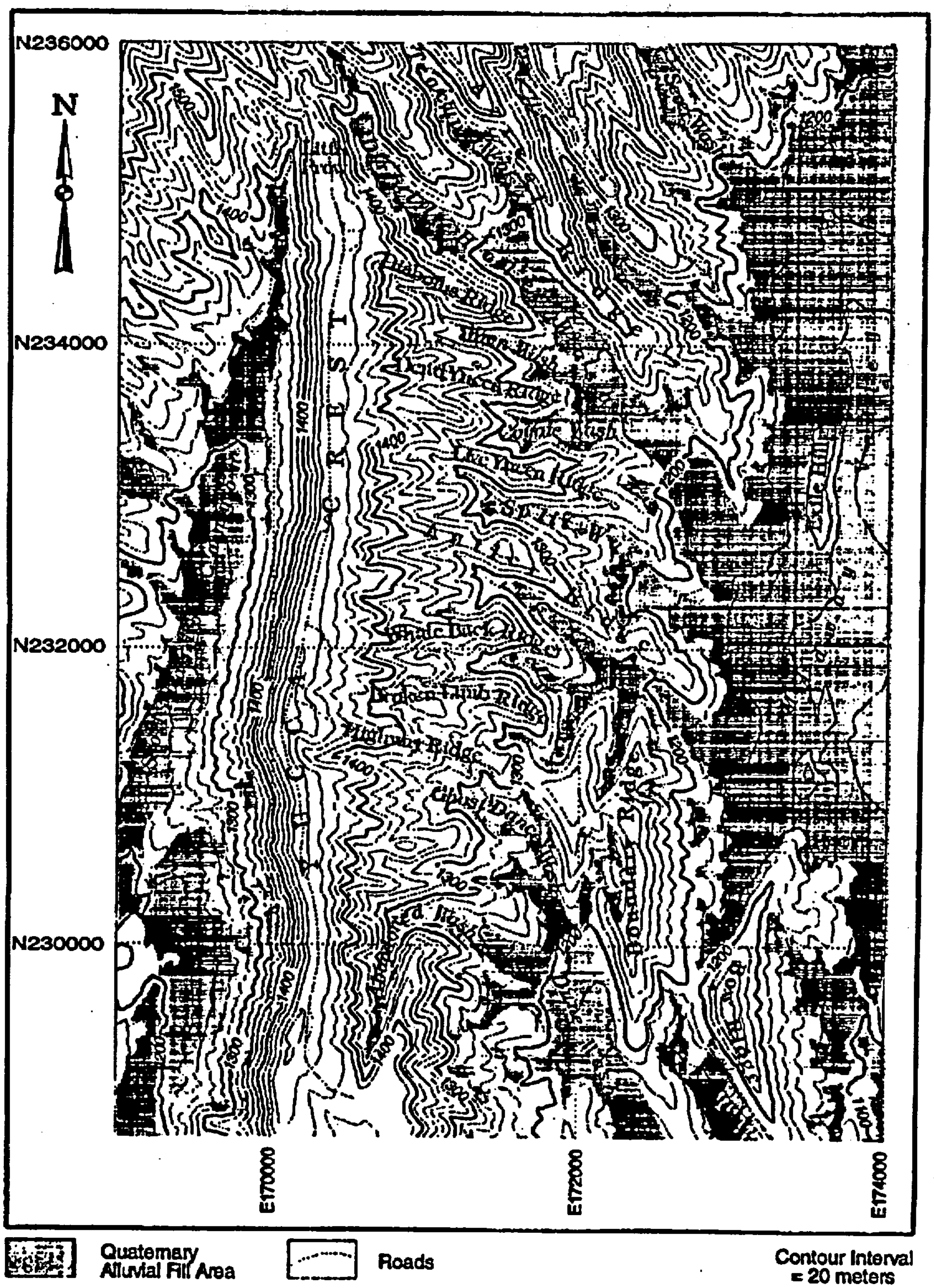

Figure 6.2.3-1. Topographic Map Showing Local Physiographic Features

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The drainages off the east flank of Yucca Crest meet in Midway Valley and join Fortymile Wash just east of the edge of the map in Figure 6.2.3-1. Midway Valley is floored by gentle piedmont slopes with incised washes and low, protruding ridge remnants, such as Exile Hill.

6.2.4 Geomorphic Process

The geomorphic processes that shaped the landscape of Yucca Mountain have been largely controlled by geologic structures, rock type, and climate. These factors have combined to produce a structure-dominated landscape of high relief, with rugged uplands separated by gently sloping lowland basins. Erosional processes are concentrated generally in the uplands and depositional processes are concentrated in the lowlands, with the intervening piedmonts serving as transport surfaces.

The single most important controlling factor in the development of the landscape in the southern Great Basin is the faulting produced by extensional tectonics during the late Cenozoic Era. However, in the area of Yucca Mountain, the Quaternary Period was a relatively quiet time with very little, if any, active extensional tectonics. Vertical tectonic adjustment during the late Tertiary and Quaternary Periods has been estimated (Scott 1990) at 0.1 to 0.5 mm per year between 13 and 11.5 million years ago, decreasing to 0.01 to 0.03 mm per year between 11.5 million years ago and Quaternary (2 million years ago). During the Quaternary, the rate further decreased to 0.006 to 0.0015 mm/per year. Based on this data, it can be concluded that vertical tectonic movement will not adversely affect the type and rates of geomorphic processes at Yucca Mountain during the next 10,000 years.

The volcanic bedrock of Yucca Mountain has also influenced the landforms. The weather resistant nature of the welded vitric beds at the top and bottom of the ashflow units encourages the formation of cliffs and ridge caps. The intervening welded volcanic ashflows are less resistant but still form steep ridge slopes. The nonwelded portions of the geologic section form more rounded slopes and low areas, except where they are partially protected by overlying resistant beds.

The influence of climate on the development of the landscape has been significant in that the arid to semi-arid climate of the past and present have tended to preserve the landscape. Weathering in arid environments is typically slow and is mainly limited to the steeper bedrock slopes of the ridges. The flow of surface water down the canyons and washes is intermittent and generally restricted to flash flood episodes. The valley fill between the uplands and lowlands has developed soil and desert varnish, both indicative of the slowness of erosion and sediment transport.

The subject of extreme erosion was examined in a Yucca Mountain Site Characterization Project Topical Report, which concluded that there is no evidence of extreme erosion at Yucca Mountain (YMP 1993). This conclusion was based on the following evidence:

- Early and middle Quaternary time hillslopes and basin alluvial deposits are common, while late Quaternary deposits are generally confined to the present washes.

- The evolution of Fortymile Wash indicates that the overall process in this drainage system during the Quaternary has been aggregation, not downcutting.

- Temporary episodes of Quaternary Period downcutting in Fortymile Wash have not migrated upstream into its tributaries.

Canyon downcutting at the Yucca Mountain site was estimated to be only 0.8 cm/ka during the past 12 million years. Erosion is estimated to have been very low, measuring 0.19 cm/ka, 40 times less than the average for the United States. Erosion has also been significantly less than the worldwide average for the same period (YMP 1993).

Similar estimates of erosion were presented in a technical basis report (YMP 1995b). Hillslope erosion rates in the Yucca Mountain area ranged from 0.1 to 0.6 cm/ka, averaging 0.19 cm/ka. Present day hillslope erosion at Yucca Mountain occurs primarily as debris flows that are initiated when summer thunderstorms saturate the ground sufficiently to result in a mass movement of the thin mantle covering. Debris flows are localized and infrequent, as evidenced by the presence of middle Pleistocene colluvium and the absence of erosion scars on the hillslopes (YMP 1995b).

Incision rates were calculated for Yucca Mountain alluvial deposits to range from 42 to 222 cm/ka, but the true long-term downcutting rate is believed to be closer to the minimum of 42 cm/ka (YMP 1995b). It is highly unlikely that the wash incised to bedrock during each downcutting episode; headcutting from the main wash did not migrate upstream into tributaries; and the overall behavior of Fortymile Wash during the Quaternary has been aggregation, not degradation. Bedrock channel incision rates were estimated for the small canyons on the east flank of Yucca Crest to be 0.8 cm/ka or less. The drainage system of Fortymile Wash and its tributaries was established in Miocene time and has changed little in basic course since then.

6.3 METEOROLOGY

The climate in southern Nevada is one of the hottest and driest in the United States. Yucca Mountain's climate is classified as mid-latitude desert, characterized by temperature extremes, a large range in annual temperatures, and annual precipitation of less than 150 mm. All evidence suggests that the region has been arid to semiarid during the Quaternary Period, the past 2 million years. It has been inferred that during the full glacial time in the Pleistocene Epoch, the climate was still semi-arid with temperatures only 7 to 10°C cooler than the present (DOE 1988a). Precipitation during this time was estimated to be 30 to 40 percent higher than the present. It is generally agreed that the area became progressively more arid during the Quaternary Period as the Sierra Nevada range was uplifted, producing a rainshadow effect (DOE 1988a).

6.3.1 Previous Work

Historical meteorological data are taken from the 17-year climatological summary of regional data from the Yucca Flat weather station, as summarized in the *Reference Information Base* (YMP 1995a). The Yucca Flat weather station was operated by the National Weather Service from January 1962 to May 1978, and is located approximately 40 km northeast of Yucca Mountain at an elevation of 1,196 m. In the recent past, meteorological data have been collected from the site and presented in several documents, 1986 to 1990 (USGS 1994e) and 1992 and 1993 (USGS 1995d).

6.3.2 Temperature

According to the data from the Yucca Flat weather station, the lowest daily temperatures occur during the months of November through March when the average daily maximum temperature ranges from 11°C in January to 16°C in November. The average daily minimum temperature ranges from -7°C in December to -2°C in March. The lowest recorded temperature during this period was -26°C in December 1967, and the highest was 31°C in March 1966 (YMP 1995a).

The hottest months at Yucca Flat are June, July, and August, when the average daily maximum temperature ranges from 32°C in June to 36°C in July. The average daily minimum temperature ranges from 10°C in June to 14°C in July. The highest temperature recorded at Yucca Flat reached 42°C in July and August 1972, and the lowest was -2°C in June 1971 (YMP 1995a).

Extreme daily temperature ranges are characteristic of the area. The greatest daily range of 22°C is in September and the smallest range of 17°C is in January (YMP 1995a).

6.3.3 Precipitation

Precipitation in the Yucca Mountain area is associated with two distinct atmospheric patterns. In the winter months and early spring (November through April), the Pacific air masses move towards the area from the west. Though Yucca Mountain lies within the rain shadow of the Sierra Nevada mountains, about 50 percent of the precipitation comes from this pattern. Average precipitation during these months ranges from 10 mm in April to 27 mm in February. The greatest monthly record was 102 mm in January 1969. The greatest daily precipitation was 38 mm in February 1976. Some of the precipitation during this period is in the form of snow. Average snowfall during these months ranges from 10 mm in April to 74 mm in January. The greatest monthly snowfall recorded at Yucca Flat was 739 mm, which fell in January 1974. The greatest daily snowfall of 254 mm was also in that month (YMP 1995a).

In late summer (July, August, and September), a low pressure area dominates the southwestern United States and gives birth to intense thunderstorm activities. These storms can bring flash floods to the area when they release significant amounts of precipitation in a relatively short period of time. Because of these thunderstorms and flooding potential they bring, siting of repository surface facilities must avoid areas subject to flooding. One of the most intense storms on record at Yucca Flat occurred on July 21, 1984, when 65 mm of precipitation fell within a 24-hour period (DOE 1988a). Prior to that storm, the greatest daily precipitation was 55 mm, which fell in August 1977. A very intense storm occurred on March 11, 1995 (DOE 1996) when 51 to 152 mm of precipitation fell in the area of Yucca Mountain. This storm resulted in the highest flows in the last 25 years in Fortymile Wash and Amargosa River. Average precipitation during the summer months ranges from 11 mm in August to 16 mm in September. Precipitation in the months between winter and summer (May, June, and October) averages 9 mm per month (YMP 1995a).

6.3.4 Humidity

The same processes that restrict precipitation in the area also provide for low relative humidity throughout the year. On Yucca Flat, the average monthly relative humidity in the summer months

(June through August) ranges from 13 percent during the heat of the day (4:00 pm) in June to 43 percent at night (4:00 am) in August. In the winter months (November through March), the average monthly relative humidity drops to 25 percent during the day (4:00 pm) in March and reaches 71 percent at night (4:00 am) in January (YMP 1995a).

6.3.5 Barometric Pressure

On the average, barometric pressure during the year varies from about 879 to 885 millibars between summer and winter. The lowest recorded pressures between 1962 and 1978 was 858 millibars and the highest recorded pressure was 901 millibars (YMP 1995a).

6.3.6 Wind

Since Yucca Mountain consists of high ridges and linear, narrow canyons that tend to channel air movement, local wind direction and velocities can be considerably different than in neighboring areas. Wind direction in the area is influenced by two types of atmospheric activity. Regionally, large scale pressure systems govern seasonal variations in wind direction. Winds from this activity blow from the north in the fall, winter, and early spring, and shift to predominantly south to southwesterly in late spring and early summer (DOE 1988a). This annual average wind cycle is affected locally by the terrain and the heating and cooling of the ground surface, which produces diurnal wind reversals. Upslope winds from this latter activity occur during daylight hours in almost all months of the year, and at night, downslope winds predominate.

Wind speeds associated with the various flow patterns in the Yucca Mountain area are highest during the mid-afternoon hours and reach minimum speeds shortly after sunset. This air movement pattern reflects the pattern of heating and cooling, with the maximum movement occurring during the heating period. Average wind speeds recorded in Yucca Flat range from 10 km per hour in November and January, to 15 km per hour in April. Wind speeds of over 85 km per hour can occur during any month of the year and reached speeds of over 97 km per hour in most months (DOE 1988a).

Tornados are considered to be rare in Nevada, but have been observed within 250 km of Yucca Mountain. The most intense of these tornados observed in the vicinity was classified as F-0 on the Fujita tornado intensity scale, which is based on extent of damage. A F-0 tornado is very weak, with winds between 65 to 115 km per hour, a path length of less than 1.6 km, and a path width of less than 16 m. Tornados have not been observed on the Nevada Test Site (DOE 1988a).

Dust devils, which are small whirlwinds containing sand and dust, occur frequently around the Yucca Mountain area and can locally disrupt visibility. Dust devils may develop wind speeds in excess of F-0 tornado intensity, but they are short-lived and dissipate rapidly. They typically spiral upward from 30 to 90 m, but may reach as high as 900 m. Dust devils usually occur during the summer months when there is unstable air at ground level (YMP 1995a).

6.3.7 Severe Weather

Thunderstorms, lightning, and flash floods are perhaps the most important of the severe weather conditions that could affect repository development and operations. Precipitation and flooding are discussed in separate subsections in this section.

Lightning is commonly associated with thunderstorms in the area. In Nevada, cloud-to-cloud lightning occurs 10 times more often than cloud-to-ground lightning. Strikes that result in measurable damage average 18 per year statewide (DOE 1988a). Lightning statistics for Yucca Mountain are not known.

Hail storms have occurred infrequently during thunderstorms but could be quite damaging. Between 1955 and 1967, Nevada had seven occurrences of hailstorms with hailstones at least 19 mm in diameter. One hail storm per year is likely in the Yucca Mountain area (DOE 1988a).

Other severe weather characteristics of the area include tornados, extreme winds and temperature, sandstorms, and fog. Most of these conditions are discussed in previous subsections in this section.

Disruptions due to poor visibility from sandstorms or fog could occur, but would be infrequent. Conditions right for sandstorms of the magnitude that would disrupt activities occur very seldom. Conditions conducive to fog development occur about twice a year from November through March (YMP 1995a).

6.4 STRATIGRAPHY

The stratigraphic setting of the Yucca Mountain area has been characterized for the purpose of siting the repository, evaluating the effects of structural and stratigraphic features, and assessing its pre- and postclosure performance. The host rock, within which the repository may be sited, and the surrounding rock have an important bearing on repository design and performance assessment.

At Yucca Mountain, there are three stratigraphic nomenclatures in common use: lithostratigraphic, thermal/mechanical, and hydrogeologic. The lithostratigraphic nomenclature is based on lithologic characteristics. The thermal/mechanical nomenclature is based on thermal and mechanical characteristics that are important to design. The hydrogeologic stratigraphy is based on hydrologic characteristics and is discussed in Subsection 6.6.3, Hydrogeologic Units, under Section 6.6, Hydrology.

6.4.1 Previous Work

Previous geologic mapping in the Yucca Mountain area was performed in the 1970s and 1980s by several U.S. Geological Survey geologists. The earliest work was mostly concentrated on the Timber Mountain-Oasis Valley caldera complex and the surrounding area including Yucca Mountain. During this period, Scott and Bonk (USGS 1984b) prepared their preliminary map of Yucca Mountain in which they defined the local stratigraphy based on petrologic and weathering characteristics of surface exposures. After the Yucca Mountain site was designated in 1987 as the only site for characterization, more concentrated work was performed in the immediate area of

Yucca Mountain. This stratigraphic work incorporated surface exposure observations, and subsurface information from core and the Exploratory Studies Facility underground excavation. This latest work was summarized by Buesch et al. (USGS 1995a), who presented a revised stratigraphic nomenclature for the Paintbrush Group that links together the diverse stratigraphic nomenclatures currently in use. The detailed stratigraphic nomenclature for the project is presented in the *Reference Information Base* (YMP 1995a).

For underground engineering design, the stratigraphic nomenclature of most interest is the thermal/mechanical stratigraphy. This was first proposed by Ortiz et al. (SNL 1985a) to group rocks with similar thermal and mechanical properties. The stratigraphy was based on the observation by Lappin et al. (SNL 1982) that thermal and mechanical properties can be correlated directly to grain density and porosity. The stratigraphy of Ortiz et al. includes 16 thermal/mechanical units identified megascopically in terms of their welding and lithophysal cavity content. The TSw2 unit, or Topopah Spring welded, lithophysae-poor rocks, was identified as the host horizon for the repository.

6.4.2 Stratigraphic Setting

Yucca Mountain is situated within the southwestern Nevada volcanic field and is on the southern flank of the Timber Mountain-Oasis Valley caldera complex (Figure 6.4.2-1). This was a major center of volcanic activity during the upper Miocene and lower Pliocene between 15 and 11.5 million years ago (Scott 1990). During this time, thick deposits of lava-flow, ashflow, and air-fall tuffs were formed. The principal volcanic rocks exposed on the surface comprise the Paintbrush Group (Figure 6.4.2-1). The two principal units within the Paintbrush are the Tiva Canyon Tuff, formed 12.7 million years ago, and the underlying Topopah Spring Tuff, formed 12.8 million years ago (Sawyer et al.1994). Along the southern flank of the Timber Mountain-Oasis Valley caldera complex, lava rocks make up most of the Paintbrush Group, while in more distal areas, it is composed principally of ashflow rocks. These volcanic deposits at Yucca Mountain are estimated to be close to 2,000 m thick. The Paintbrush Group contains most of the rocks encountered in the Exploratory Studies Facility and all of the rock in the repository development.

6.4.3 Lithostratigraphy

Rocks that are important to repository design are contained for the most part within the Paintbrush Group, which is comprised of welded and nonwelded ashflow deposits of Miocene age. The formations within the Paintbrush Group include in descending order, the Tiva Canyon Tuff, Yucca Mountain Tuff, Pah Canyon Tuff, and Topopah Spring Tuff. Overlying this group in local areas near Exile Hill are younger, nonwelded ashflow and air-fall tuffs. Below the rocks of the Paintbrush Group is the Calico Hills Tuff. The general stratigraphy of the area is illustrated in Table 6.4.3-1 and is described in detail in the *Reference Information Base*, a project Q document, (YMP 1995a) and the *Draft Stratigraphic Compendium*, a project non-Q document (CRWMS M&O 1994c). Specific lithostratigraphic descriptions for the Paintbrush Group are contained in Buesch et al. (USGS 1995a).

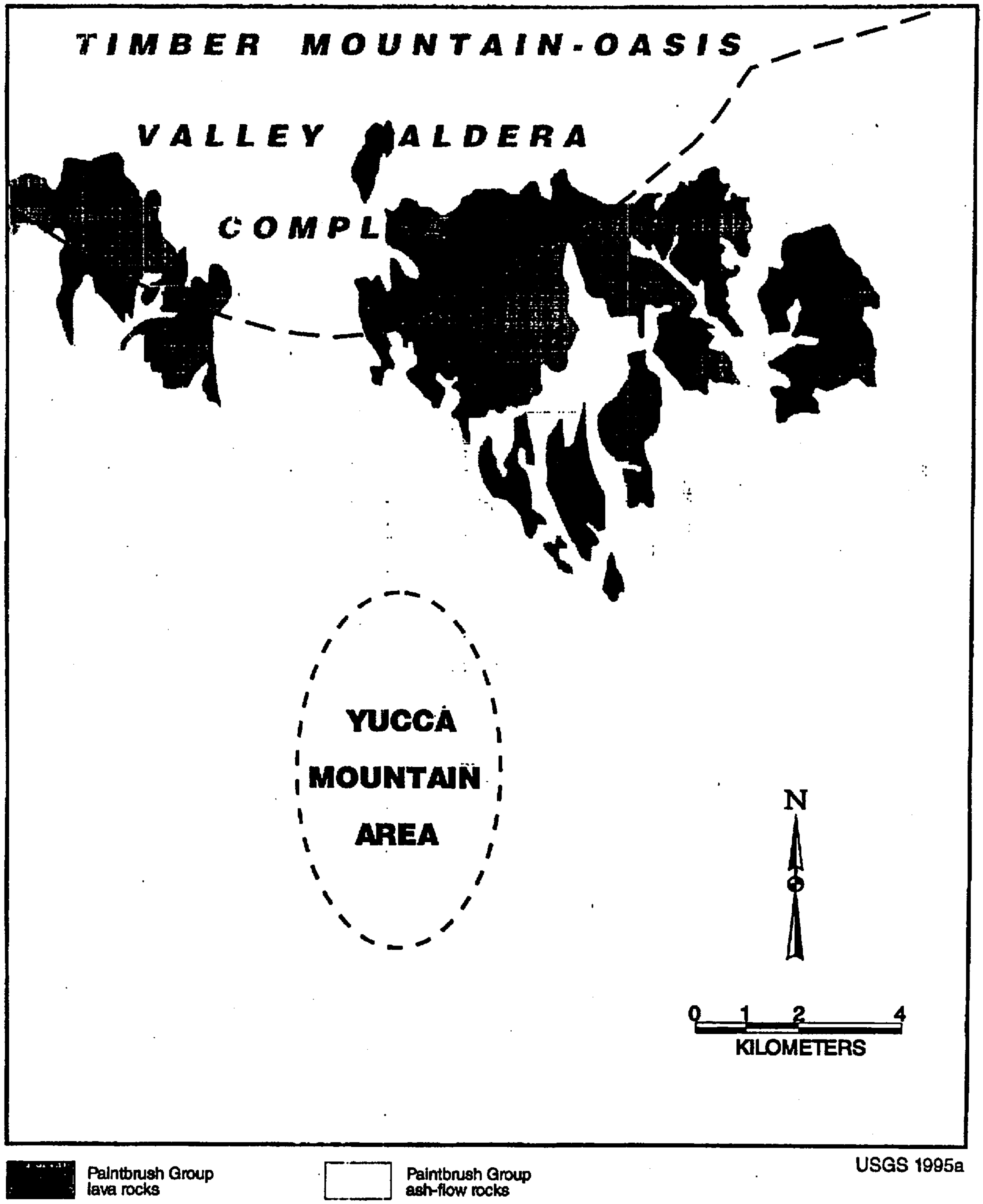

Figure 6.4.2-1. Yucca Mountain Area and the Timber Mountain-Oasis Valley Caldera

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Table 6.4.3-1. Stratigraphic Nomenclature for Yucca Mountain

Lithostratigraphic Units[1]		Thermal/ Mechanical Units[2]	Hydro-Geologic Units[3]
Timber Mountain Tuff (Tm)	Rainier Mesa member (Tmr)	Undifferentiated overburden (UO)	Unconsolidated Surficial Materials (UO)
	pre-Rainier Mesa bedded tuff (Tmrbt1)		
Tuff unit "X" (Tpk)	tuff unit "X" (Tpki)		
	post-Tiva Canyon bedded tuff (Tpbt5)		
PAINTBRUSH GROUP (Tp)			
Tiva Canyon Tuff (Tpc)	crystal-rich member (Tpcr) vitric zone (Tpcrv) - nonwelded subzone (Tpcrv3) - moderately welded subzone (Tpcrv2) - densely welded subzone (Tpcrv1) nonlithophysal zone (Tpcrn) lithophysal zone (Tpcrl)	Tiva Canyon welded (TCw)	Tiva Canyon welded (TCw)
	crystal-poor member (Tpcp) upper lithophysal zone (Tpcpul) middle nonlithophysal zone (Tpcpmn) lower lithophysal zone (Tpcpll) lower nonlithophysal zone (Tpcpln) - hackly subzone (Tpcplnh) - columnar subzone (Tpcplnc) vitric zone (Tpcpv) - densely welded subzone (Tpcpvv) - moderately welded subzone (Tpcpvm) - nonwelded subzone (Tpcpvn)	Paintbrush Tuff nonwelded (PTn)	Paintbrush nonwelded (PTn)
	pre-Tiva Canyon bedded tuff (Tpbt4)		
Yucca Mountain Tuff (Tpy)	Yucca Mountain Tuff (Tpyt)		
	pre-Yucca Mountain bedded tuff (Tpbt3)		
Pah Canyon Tuff (Tpp)	Pah Canyon Tuff (Tppt)		
	pre-Pah Canyon bedded tuff (Tpbt2)		
Topopah Spring Tuff (Tpt)	crystal-rich member (Tptr) vitric zone (Tptrv) - nonwelded subzone (Tptrv3) - moderately welded subzone (Tptrv2) - densely welded subzone (Tptrv1) nonlithophysal zone (Tptrn) lithophysal zone (Tptrl)	Topopah Spring welded, lithophysae-rich (TSw1)	Topopah Spring welded (TSw)
	crystal-poor member (Tptp) upper lithophysal zone (Tptpul) [upper pt]		
REPOSITORY HOST HORIZON	upper lithophysal zone (Tptpul) [lower pt] middle nonlithophysal zone (Tptpmn) lower lithophysal zone (Tptpll) lower nonlithophysal zone (Tptpln)	Topopah Spring welded, lithophysae-poor (TSw2)	
	vitric zone (Tptpv) - densely welded subzone (Tptpv3) - moderately welded subzone (Tptpv2) - nonwelded subzone (Tptpv1)	Topopah Spring welded, vitrophyre (TSw3) Calico Hills nonwelded (CHn)	Topopah Spring basal vitrophyre (TSbv) Calico Hills nonwelded (CHn)
	pre-Topopah Spring bedded tuff (Tptbt1)		
Calico Hills Tuff (Tac)	Calico Hills Formation (Tac)		
	pre-Calico Hills bedded tuff (Tacbt1)		

1) Based on USGS 1995a
2) Based on SNL 1985a
3) Based on SNL 1995b

6.4.3.1 Zonation of the Paintbrush Group Ashflow Tuffs

The volcanic rocks of the Paintbrush Group are typical, compositionally-zoned, ashflow sheets that emanated from the Claim Canyon segment of the Timber Mountain-Oasis Valley caldera complex (USGS 1976) in the north (Figure 6.4.2-1). These rocks covered a widespread area and were formed during violent, multiple flow, eruptions that were emplaced in rapid succession so that the mass cooled as one unit (USGS 1966). The two thickest formations of the Paintbrush Group, Tiva Canyon Tuff and Topopah Spring Tuff, are very similar in their composition, character, and distribution. These units, as well as other similar volcanic units, display a distinct, vertical systematic chemical, mineralogical, petrologic, and structural zonation. From bottom to top, the ash composition grades from crystal-poor rhyolite to crystal-rich quartz latite (USGS 1995a). Welding varies upward from non-welded to moderately welded tuff at the base, through the densely welded interior, to a capping of moderately-welded to nonwelded tuff. The densely welded interior may have a vitrophyre developed at the base and top of the zone, with the welded rocks between devitrified. The central portion of the welded interior, which contains subzones of lithophysae development, is affected by vapor phase crystallization.

Lithophysae development is prominent within specific zones of the densely-welded sections in the Tiva Canyon Tuff and Topopah Spring Tuff sections. Lithophysae are hollow, bubble-like structures composed of concentric shells of finely crystalline alkali feldspar, quartz and other minerals (USGS 1995a). In section, they are typically comprised of a central cavity with a thin lining of vapor-phase minerals, surrounded by a thicker rim of fine-grained crystals, which is in turn surrounded by a thin border of very fine-grained crystals. Most cavities are only a few centimeters across, but some may be as large as a meter. Lithophysae develop during emplacement of the tuff flow deposit and represent vapor concentrations from trapped gasses released from the cooling mass. Commonly associated with the lithophysae are spots 10 to 50 mm in diameter. They are comprised of fine-grained crystals with a thin very fine-grained border and occasionally a core of crystals or a lithic clast. Their origin may be similar or related to the formation of lithophysae (USGS 1995a).

The lithostratigraphic subdivisions of the Paintbrush Group at Yucca Mountain are identified by macroscopic textural features. The main identifying features include the type and abundance of phenocrysts, welding, crystallization, lithophysae, and fracture characteristics (USGS 1995a). Phenocryst content is the fundamental criteria for subdividing the Tiva Canyon and Topopah Spring Tuff formations into members. The upper member in these two formations is the crystal-rich member, which is characterized by 10 to 15 percent phenocrysts, whereas the lower crystal-poor member has 3 to 10 percent phenocrysts (USGS 1995a).

Within these two members, there are numerous zones and subzones that are subdivided based on welding, crystallization, lithophysae, and fracture characteristics (USGS 1995a). Welding and crystallization in ashflow tuffs typically follow a general pattern that reflects their deposition and cooling history, and the Tiva Canyon and Topopah Spring Tuffs follow these patterns. The lower-most zone of the ashflow deposit is known as the vitric zone. This unit can be subdivided into a nonwelded base, grading upwards through partially and moderately welded to densely welded at the top. The densely welded subzone is often-times present as a densely-welded vitrophyre.

The interior section of the ashflow tuffs is comprised of densely-welded, devitrified tuff with vapor-phase crystallization and lithophysae development. The repository host horizon lies within this interior unit in the Topopah Spring Tuff. Lithophysal zones developed where trapped gasses and vapors concentrated within this interior densely-welded section. Vapor-phase crystallization took place through much of the densely-welded section. Capping the interior section is the crystal-rich vitric zone. It is a mirror image of the crystal-poor vitric zone at the base.

6.4.3.2 Post-Paintbrush Group Rocks

Near Exile Hill where the portal of the Exploratory Studies Facility is located, there are subcrops of the younger nonwelded, ashflow and air-fall tuffs that post-date the Paintbrush Group. These include the Rainier Mesa member of the Timber Mountain Tuff, and the unit known informally as Tuff Unit "X" (SNL 1995a). They were deposited about 11.6 million years ago (Sawyer et al. 1994) after a long period of faulting, uplift and erosion (Scott 1990). These units are underlaid with bedded tuffs and were deposited in topographic lows between major fault blocks. These units were both encountered in the Exploratory Studies Facility north ramp excavation.

6.4.3.3 Paintbrush Group Rocks

The Tiva Canyon Tuff is the youngest formation in the Paintbrush Group. It was formed 12.7 million years ago from an eruption from the Claim Canyon caldera, which is a part of the Timber Mountain-Oasis Valley caldera complex (Sawyer et al. 1994). It is a multiple-flow, compound cooling unit that displays the composition zoning discussed in Section 6.4.3.1. Most of the outcrops on Yucca Mountain consist of units from this formation, which is estimated to have been about 100 m thick (Scott 1990). It forms the ridges on the eastern flank of Yucca Crest and the upper part of the cliff face on the western flank. The unit is mostly composed of welded tuff, except for the top and bottom, which is composed of non-welded to moderately welded tuff. Directly below the Tiva Canyon is the pre-Tiva Canyon bedded tuff, which is an air-fall deposit emplaced prior to the main Tiva Canyon pyrochatic flow units.

Underlying the Tiva Canyon is a series of relatively thin, simple cooling unit ashflow tuffs and associated bedded tuffs. These include the Yucca Mountain Tuff and Pah Canyon Tuff, which are discontinuous across the area (USGS 1995a). These ashflow tuffs are mostly nonwelded, but may be more welded where they locally thicken. These units outcrop on the western cliff face of Yucca Crest and in small local areas in the deep washes on the eastern flank. The Yucca Mountain is up to 30 m thick at the project site and the Pah Canyon is up to 70 m thick, but is absent in the far south.

The Topopah Spring Tuff underlies the Pah Canyon Tuff and was formed 12.8 million years ago (Sawyer et al. 1994). It is about 350 m thick at Yucca Mountain (USGS 1995a). As discussed previously, it is compositionally zoned similar to the younger Tiva Canyon Tuff and has a central welded interior with moderately to nonwelded tuff at the top and bottom. At the base of the welded interior, there is a very thick vitrophyre zone (Tptpv3). The Topopah Spring Tuff contains the host horizon for the repository within part of its central welded interior. The repository host horizon is shown in Table 6.4.3-1 and consists of the lower part of the upper lithophysal zone (Tptpul), middle nonlithophysal zone (Tptpmn), lower lithophysal zone (Tptpll), and lower nonlithophysal zone

(Tptpln). Like the Tiva Canyon, there is a bedded tuff unit at the base of the Topopah Spring Tuff, which consists of air-fall deposits.

6.4.3.4 Pre-Paintbrush Group Rocks

Below the Topopah Spring Tuff is the Calico Hills Tuff, which was formed 12.9 million years ago (Sawyer et al. 1994). This unit consists of relatively massive, homogenous, nonwelded ashflow tuffs separated into five units of ash-fall beds that overlie an interval of bedded tuff and a basal volcaniclastic sandstone (USGS 1994a). The Calico Hills unit contains zeolites, which may be important to waste isolation (CRWMS M&O 1994b). Below the Calico Hills is the Prow Pass Member of the Crater Flat Tuff.

6.4.4 Thermal/Mechanical Stratigraphy

The concept of developing a stratigraphic nomenclature that directly addresses engineering properties of the rock at Yucca Mountain was first introduced by Lappin et al. (SNL 1982). They proposed that the rocks of Yucca Mountain could be subdivided into units with similar thermal and mechanical characteristics, based on correlation to grain density and porosity. This stratigraphy was later refined by Ortiz et al. (SNL 1985a), who identified 16 thermal/mechanical units at the Yucca Mountain site, including the Tram Member of the Crater Flat Group. Their groupings reflected to a large extent the general degree of welding and, in the case of the Topopah Spring rocks, the volume of lithophysal cavities. The thermal/mechanical units correlate generally with groups of lithostratigraphic units, or in one case, parts of a lithostratigraphic unit (Table 6.4.3-1).

The uppermost thermal/mechanical unit identified is the undifferentiated overburden unit. This is a collection of various rock types that overlie the welded, devitrified Tiva Canyon Tuff. The overburden unit contains alluvium, colluvium, nonwelded and vitric portions of the Tiva Canyon Tuff, and other tuff units such as the Rainier Mesa member of the Timber Mountain Tuff, Tuff Unit "X," and their associated bedded tuff units.

Most of the Tiva Canyon Tuff is contained in the Tiva Canyon welded (TCw) thermal/mechanical unit. This unit includes rock between and including the densely welded subzone (vitrophyre) of the vitric zone of the crystal-rich member and the densely welded subzone of the vitric zone of the crystal-poor member (vitrophyre). This unit is exposed on the top of Yucca Crest and the ridges on the eastern flank.

Below the TCw is the Paintbrush Tuff nonwelded (PTn) unit. This unit consists of partially welded to nonwelded, vitric and occasionally devitrified tuffs. Included in this unit are the nonwelded tuffs at the base of the Tiva Canyon Tuff, the Yucca Mountain Tuff, the Pah Canyon Tuff, the nonwelded tuffs at the top of the Topopah Spring Tuff, and the associated bedded tuffs.

The Topopah Spring welded thermal/mechanical unit (TSw) underlies the PTn. This unit is subdivided into three subunits based on their volume of lithophysal cavities. The top subunit, TSw1, is lithophysae-rich and includes the top vitrophyre (crystal-poor member, vitric zone, densely welded subzone), the nonlithophysal zone, and the upper lithophysal zone. This upper subunit ranges from about 49 to 113 meters thick. The middle subunit, TSw2, is lithophysae-poor and consists of the middle nonlithophysal, lower lithophysal, and lower nonlithophysal zones. The TSw2 unit ranges from 175 to 229 meters thick. At the base of the Topopah Spring welded unit is the vitrophyre subunit (TSw3), which is about 7 to 25 meters thick.

Underlying the TSw units is the Calico Hills nonwelded unit (CHn). This unit consists of the lower nonwelded to partially welded portion of the Topopah Spring Tuff, the Calico Hills Tuff, the underlying pre-Calico Hills bedded tuff, and the upper nonwelded portions of the underlying Prow Pass Member of the Crater Flat Tuff.

Ortiz et al. (SNL 1985a) originally defined the TSw2 thermal/mechanical unit as the host horizon for siting the repository. Recent investigations by the M&O (CRWMS M&O 1995n) have identified that in addition to the TSw2 unit, the lower part of the overlying TSw1 unit may also be suitable. This is discussed more fully in Section 8.1, Repository Horizon Description.

6.5 STRUCTURAL GEOLOGY AND TECTONICS

Geologic structures and tectonics are among the important factors that influence repository design and its long-term performance. Study of the existing geologic structures and their analysis is a key to the structural disturbances that might be expected in the future. Seismic investigations that analyze past and current seismic events provide clues as to what can be expected in the future and provide for the development of appropriate seismic design standards.

6.5.1 Previous Work

The geologic structures identifiable on the surface were mapped by Scott and Bonk (USGS 1984b). This mapping has provided the framework for most of the structural investigations at Yucca Mountain. More recent detailed mapping by USGS (USGS 1994b; Spengler et al. 1993) has been carried out on some of the major faults in the area as well as on a more general verification of the structures mapped by Scott and Bonk.

6.5.2 Tectonic Setting

The geologic structures at Yucca Mountain are a result of large-scale plate tectonics as well as regional volcanic-related forces. The site is situated in the Basin and Range structural province, which is in the western deformed half of the North American continental plate. To the west is the Pacific plate, which is joined to the North American plate across a transform fault corresponding to the right-lateral strike-slip San Andreas fault system. Along the western part of the North American plate is the Cordilleran Orogenic belt, which has been subjected to numerous orogenic episodes from the Late Cretaceous Period to the present. Initial orogenic activities produced low-angle, east-directed thrust faults during the late Mesozoic and early Cenozoic Eras. Later in the Cenozoic Era, the crust was subjected to extension block faulting from the Miocene Epoch through the present. With extension comes thinning of the crust, which resulted in increased geothermal gradients and volcanism (DOE 1988a).

The Basin and Range structural province corresponds to the Great Basin subprovince of the Basin and Range physiographic province (Figure 6.5.2-1). The Yucca Mountain project site is situated in an area of the Basin and Range structural province known as the Walker Lane belt (Figure 6.5.2-1), a complex zone of northwest-trending right-lateral strike-slip displacement (DOE 1988a and Scott 1990). Major strike-slip faults near Yucca Mountain include the Las Vegas shear zone with at least 40 km of right-lateral movement, the Death Valley/Furnace Creek fault zones consisting of en echelon right-lateral faults with 10 to 80 km of displacement, and the left-lateral Pahranagat shear zone.

Although the strike-slip faults are the most dramatic and have the greatest displacement, the area is also characterized by the general north- to northwest-trending range-front normal faulting. This faulting has taken place from the Miocene Epoch to the present, and has produced the structural pattern so characteristic of the Basin and Range province. Extensional faulting may have developed as early as the late Eocene Epoch to the middle Miocene Epoch, but the dominant normal faulting occurred during the middle Miocene Epoch to the present (DOE 1988a).

6.5.3 Faults

The Yucca Mountain area lies within a large, east-tilted structural block with north-trending, west-dipping normal faults. Northwest-striking right-lateral and northeast-striking left-lateral strike-slip faults are also present. The surface faults in the Yucca Mountain area are illustrated in Figure 6.5.3-1, as mapped by Scott and Bonk (USGS 1984b). This large scale mapping (1:12,000) was preliminary and is currently being remapped a scale of 1:6,000 by USGS. The Primary Area of Mansure and Ortiz (SNL 1984a), which identifies the general potential repository area, is included in the figure for reference. Identified faults shown include the Bow Ridge, Dune Wash, Abandoned Wash, Ghost Dance, Solitario Canyon, Sundance, Drill Hole Wash, and Sever Wash faults. Between the Ghost Dance and Bow Ridge faults, there is a wide zone of closely-spaced faults known as the Imbricate fault system (Scott 1990). In the central area between the Solitario Canyon and Ghost Dance faults, where the main repository is sited, there are very few faults of significant offset. The only recognized faults in this area include the Sundance fault (USGS 1995c), an unnamed fault in the north between Sundance and Ghost Dance faults, northeast-directed splays of the Solitario Canyon fault, and a fault swarm in the south. These faults within the central area are all minor and are not considered to pose a problem to the repository design.

The easternmost, major normal fault shown in Figure 6.5.3-1 is the Bow Ridge fault. It is a down-to-the-west, steeply-dipping, normal fault that was encountered in the Exploratory Studies Facility North Ramp. Offset on this fault is estimated at about 130 m at the base of the Tiva Canyon Tuff (SNL 1995a). On the surface, the fault has been explored by trenching (USGS 1984c). In preparation for the Exploratory Studies Facility tunneling, the faults, and the geologic units in the hanging wall were also explored with drilling trenching and seismic refraction and reflection lines (SNL 1995a), which identified that the fault decreases in dip with increased depth. As encountered in the Exploratory Studies Facility, the fault is about 2 m thick and consists of brecciated rock (USBR 1995a; 1995b). At the surface in trench 14, the fault is filled with calcium carbonate, opaline silica, and fine-grained sediments that are of pedogenic origin (USGS 1993). The Bow Ridge fault forms the eastern boundary of a major structural block (Scott 1990).

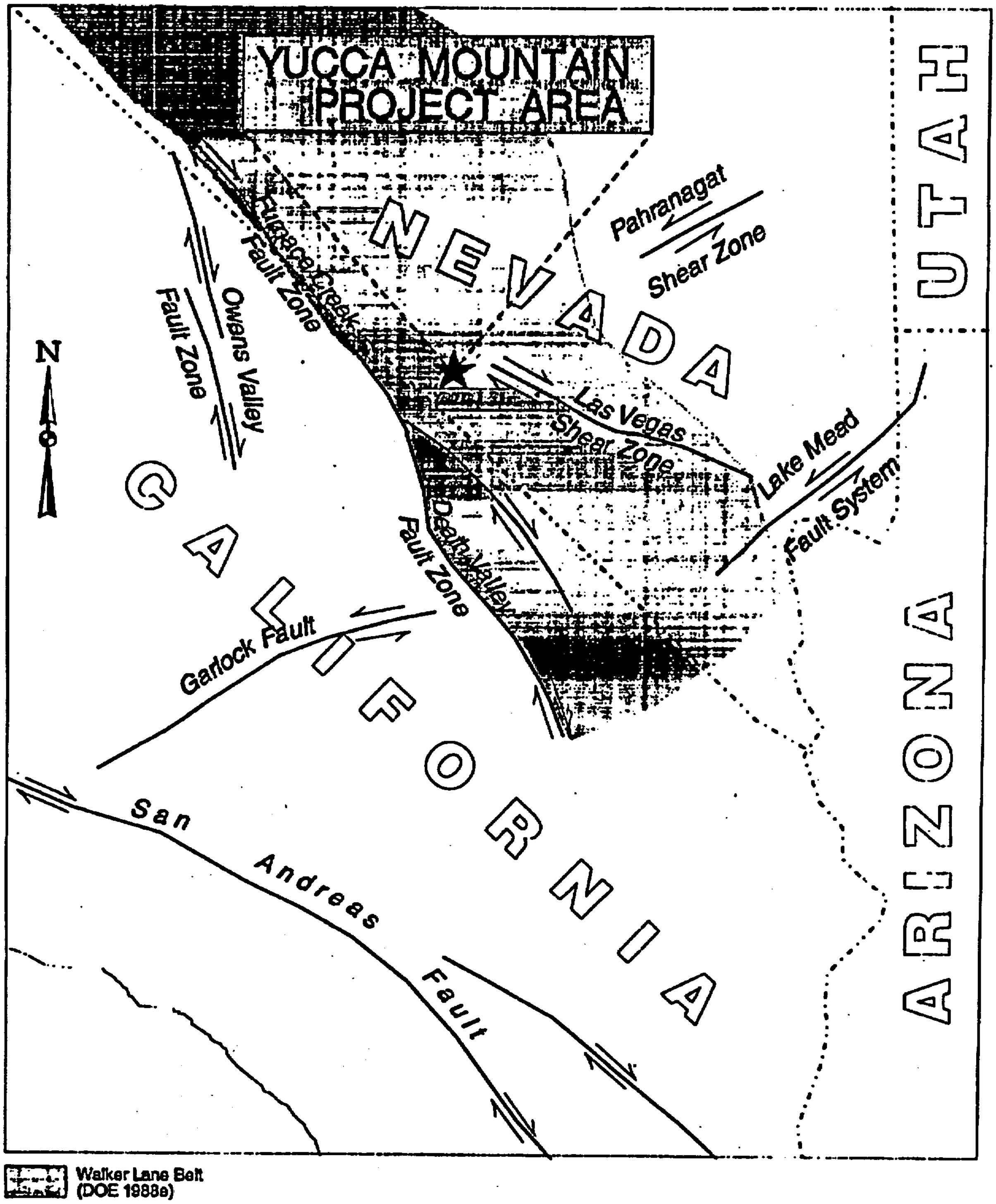

Figure 6.5.2-1. Major Strike Slip Faults in the Region Around the Yucca Mountain Project Site

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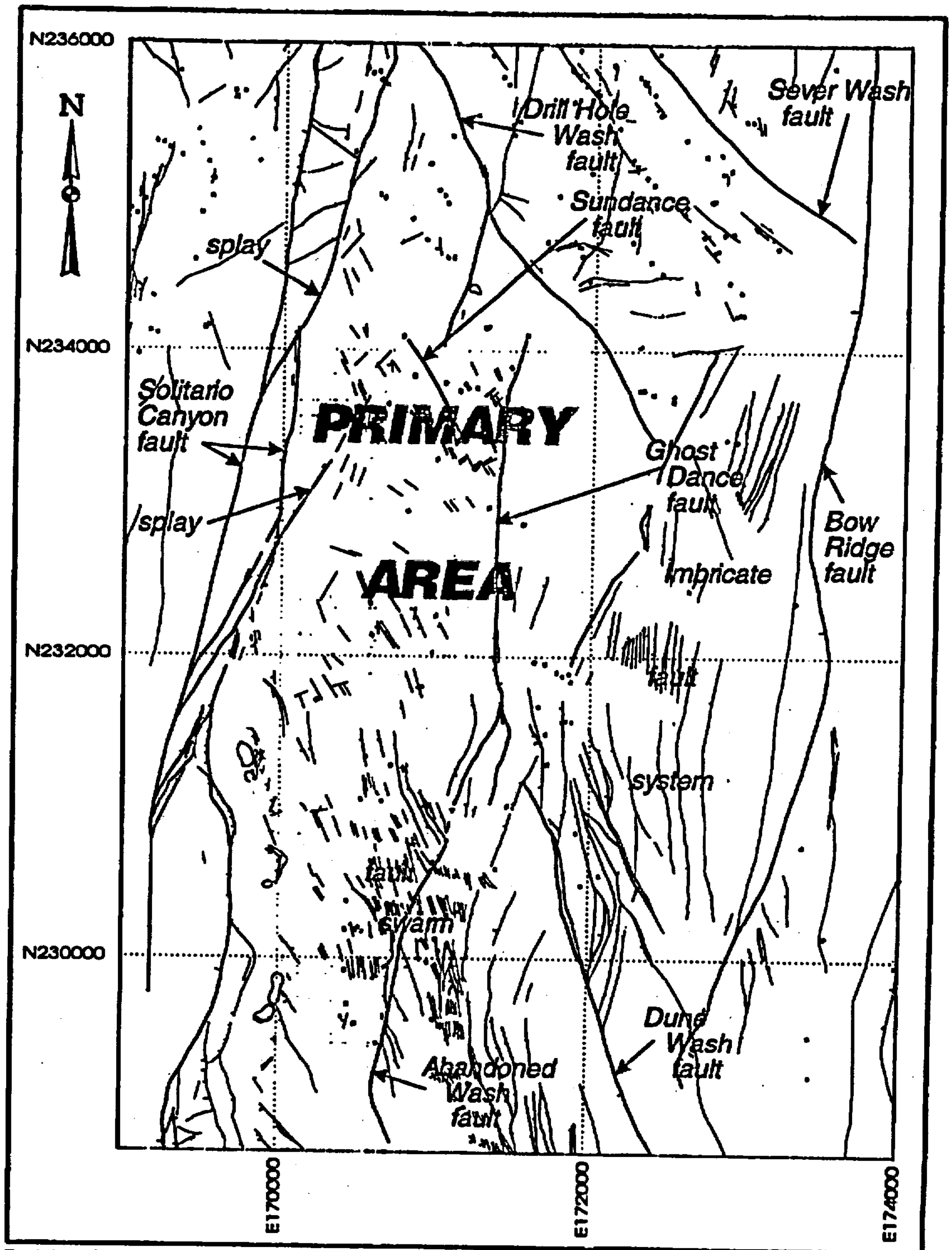

Fault locations based on USGS (1984b), with some modifications to reflect more recent information.
All fault classifications are shown as solid lines.

Figure 6.5.3-1. Surface Faults

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The Solitario Canyon fault (Figure 6.5.3-1) forms the western limit of the major structural block and the repository area. It is a complex, braided, high-angle, down-to-the-west normal fault. Offset on this fault is estimated to be over 400 m (SNL 1995a). The USGS is conducting detailed mapping of the Solitario Canyon fault and associated splays. This work is not yet complete. The westernmost trace of the fault, as mapped by Scott and Bonk (USGS 1984b), consists of a wide brecciated zone. Two small but prominent splays extend off the east side of the fault within the planned repository area. These faults displace rocks of the Topopah Spring Tuff by only a few meters where they join the Solitario Canyon fault, decreasing rapidly to the north where they do not appear to offset the younger Tiva Canyon Tuff (Scott 1990).

The area between the Solitario Canyon and Bow Ridge faults comprises a major structural block that exhibits characteristics typical of internal block deformation associated with extensional tectonics. The structural pattern within these blocks includes a largely unfaulted, uniformly eastward dipping area on the western leading edge of the block, and a complex-faulted, more steeply, eastward dipping area on the eastern trailing edge of the block. These faults along the eastern edge are closely-spaced, steep, west-dipping faults with minor, down-to-the-west offsets of a few meters or less. These faults are referred to as the Imbricate fault system (Scott 1990) and account for about 50 percent of the extension within this block.

The Ghost Dance fault (Figure 6.5.3-1), which is the only major fault that passes through the repository area, has been studied in much detail on the surface (Spengler et al. 1993). Recent pavement mapping and trenching on the Ghost Dance fault indicates that it has not moved in the past 20 to 30 thousand years. The Ghost Dance fault is a north-trending, near-vertical, normal fault with an offset of 30 m in the south, progressively decreasing to zero in the north. Near the northern limit of the fault, it dies out into highly fractured and brecciated rock on Diabolous Ridge (Figure 6.2.3-1). To the south, it bifurcates and may continue south as the Abandoned Wash fault on the west side and the Dune Wash fault on the east side. Detailed mapping along the fault trace where it crosses Antler, Whaleback, and Broken Limb Ridges (Figure 6.2.3-1) have revealed several additional subparallel, braided faults on the east and west side of the main trace (Spengler et al. 1993). These additional faults typically offset strata down to the west by 3 to 6 m and are commonly spaced 15 to 46 m apart for a distance of over 100 m from the main trace of the fault. Cumulative west-side-down displacement along these faults range from 21 to 47 m. To the west of the northern end of the Ghost Dance fault is a small unnamed normal fault that is parallel to the Ghost Dance fault (Figure 6.5.3-1).

The northwest-trending Drill Hole Wash (Figure 6.2.3-1) was identified by Scott and Bonk (USGS 1984b) as the location of a right-lateral strike slip fault (Figure 6.5.3-1). This fault is almost entirely concealed, so was predicted based on exposures on the ridge between Teacup Wash and Drill Hole Wash, geophysical surveys, topographic expression, and projecting unit contacts and thicknesses from drill holes within and across the wash (Buesch et al. 1993). It was predicted that t would have a down-to-the-west dip-slip displacement of less than 10 m (SNL 1995a). In the Exploratory Studies Facility North Ramp, some small faults were found in the tunnel and were identified as the Drill Hole Wash fault.

Detailed mapping of the Ghost Dance fault along the southern flank of Live Yucca Ridge identified a northwest-trending fault system that was subsequently named the Sundance fault system (USGS 1994b). This fault was presented as the southernmost northwest-trending structure and one that extended across the central portion of the planned repository. Later mapping work has minimized the significance of this fault (USGS 1995c). The recent mapping identified the Sundance as a fault zone about 750 m long, 75 m wide at its maximum extent, and with a maximum cumulative northeast side down vertical movement of 11 m. During the excavation of the Exploratory Studies Facility Topopah Spring Main Drift, a small fault was found near the projected location of the Sundance fault. It is thought that this small fault is the Sundance fault.

6.5.4 Fractures

Fractures in the Yucca Mountain area are of two types. The first type is cooling joints that formed during the cooling of the volcanic mass. Fractures that are interpreted to have formed during cooling are common throughout the Yucca Mountain area (Spengler et al. 1993; USGS 1992). The surface of the cooling joints is typically very smooth and planar or gently curving, and exhibit braided tubular structures. These cooling joint fractures occur in two conspicuous orientations around N40°E and N50°W, and appear to increase in abundance from south to north.

The second type of fractures is that associated with the major structures and tectonics. Fractures that are rough and more angular, as compared with cooling joints, are interpreted to be tectonic fractures (USGS 1992). Along the Ghost Dance fault and within the zone of parallel faults, there are northwest-trending fractures that extend out over 100 m from the main fault trace (Spengler et al. 1993).

The *Controlled Design Assumptions Document* (CRWMS M&O 1995a) states the joint orientations and frequency that are currently to be used for design. These were developed by Lin et al. (SNL 1993a) from examination of core and video camera logs from boreholes USW GU-3 and USW G-4. The joint orientations that they recognized in the Tiva Canyon Tuff and the Topopah Spring Tuff from these two boreholes are summarized in Table 6.5.4-1. Also shown are the joint orientations for the Topopah Spring Tuff, as stated in the *Controlled Design Assumptions*. Preliminary stereographic plots of joint orientations by lithostratigraphic units, as developed by the CRWMS M&O from the Exploratory Studies Facility mapping data, show general agreement to the sets as stated in the *Controlled Design Assumptions*.

Also included in the *Controlled Design Assumptions*, are estimates of joint frequency for the TSw2 thermal/mechanical unit, which was also derived from Lin et al. (SNL 1993a). Joint frequency is estimated to be 2.51/m for 70-80° joints and 11.28/m for 80-90° joints.

Table 6.5.4-1. Summary of Fracture Orientations

	Northwest to North-trending Sets with Steep Dips	Northeast-trending Sets with Steep Dips	Sets with Low-angle Dips
TIVA CANYON TUFF[1]			
USW GU-3	N-N30°W, 85°- 90°SW/NE	N50°W, 70°-90°NE/SW	—
	N50°W, 12°NE		—
	N18°W - N36°E, *NM*		—
USW G-4	—	N-N22°E, 65°- 90°NW	—
TOPOPAH SPRING TUFF[1]			
USW GU-3	N10°W, 75°-90°NE/SW	N45°E, 80°-90°SE/NW	N25°E, 10°SE
USW G-4	N12°W, 80°-90°NE/SW	N-N40°E, *NM*	—
CDA, (TDSS-017)[2]	N10°-12°W, 75°-90°NE/SW	N-N45°E, 80°-90°SE/NW	N25°E, 10°S
Cooling Joints[3]	N50°W	N40°E	—

1) From SNL 1993a
2) From *Controlled Design Assumptions*, Assumption TDSS-017 for Topopah Spring Tuff (CRWMS M&O 1995a)
3) From Buesch et al. (1993)
NM Not measured

6.5.5 Strata Dip

In the southern part of the repository area between the Ghost Dance and Solitario Canyon faults, the Tiva Canyon Tuff strata strikes generally north-south and dips about 6° to 9° to the east; however, in the northern part of this block, it rotates eastward to strike northeast and dips about 5° to 6° to the southeast (USGS 1984b). At the repository level within this southern part, the Topopah Spring strata dips about 7° and strikes N10°W, but in the northern part, it shallows to about 6 degrees and the strike rotates eastward to about N25°E near the Drill Hole Wash fault (Figures 8.1.3-2 and 8.1.3-3). To the north of Drill Hole Wash, the strata continues striking to the northeast, thus defining the axis of a gentle syncline centered along Drill Hole Wash.

To the east of Ghost Dance fault, the strata continues with generally the same strike and dip, but upon reaching the complex Imbricate fault system, the strata dip more steeply eastward between 20° and 40° (USGS 1984b).

6.5.6 In Situ Stresses

A summary of the in situ stresses from the *Controlled Design Assumptions*, Assumption TDSS-001 (Technical Data Assumption - Subsurface), is shown in Table 6.5.6-1 (CRWMS M&O 1995a). The principal stress direction is vertical, due to lithostatic load. At the repository level, the vertical stress is estimated to be 7.0 MPa (megapascals) on the average. Horizontal stresses are expected to be lower and range from 3.5 to 4.2 MPa, but they could range as high as 2.1 to 7.0 MPa. These in situ stress values are generally confirmed by a stress profile calculated for the Exploratory Studies Facility test area (YMP 1995a), which showed a vertical stress of 6.0 MPa at a depth of 300 m.

Table 6.5.6-1. Summary of In Situ Stresses at Repository Horizon[1]

Parameter	Average Value	Range of Values
Vertical Stress	7.0 MPa	5.0 - 10.0 MPa
Minimum Horizontal/Vertical Stress Ratio	0.5	0.3 - 0.8
Maximum Horizontal/Vertical Stress Ratio	0.6	0.3 - 1.0
Bearing of Minimum Horizontal Stress	N57°W	N50°W - N65°W
Bearing of Maximum Horizontal Stress	N32°E	N25°E - N40°E

1) From *Controlled Design Assumptions* Assumption TDSS-001 (CRWMS M&O 1995a)

Horizontal stress for the same depth ranged from 2.1 to 4.2 MPa, using a maximum to minimum horizontal stress ratio of 2:1.

In general, horizontal in situ stresses at the repository site are expected to be low; consequently, failure modes around underground openings during construction will be primarily controlled by geologic structures. Minimum and maximum horizontal/vertical stress ratios are close, indicating a weak horizontal stress anisotropy. Consequently, lateral stresses should be approximately the same and the effects similar for all drift orientations. Horizontal stress anisotropy may become significant only during thermal loading as horizontal stress shows a greater increase in a north-south direction along the probable long-axis of the repository (CRWMS M&O 1994d).

6.5.7 Seismicity

Seismicity in the region around the Yucca Mountain site is discussed in the Site Characterization Plan (DOE 1988a) and the Exploratory Studies Facility seismic design (CRWMS M&O 1994d). The pattern of regional seismicity in close proximity to the Yucca Mountain site (within 100 km) consists of the north-south-trending Nevada-California seismic belt and the diffuse east-west seismic belt encompassing the Yucca Mountain site. The Nevada-California belt corresponds in part to the Owens Valley, Furnace Creek, and Death Valley fault zones shown in Figure 6.5.2-1. This seismic belt is the most active in the area. The largest earthquake recorded in the region and the closest to Yucca Mountain was the 1872 Owens Valley shock, centered about 150 km west of Yucca Mountain and located within the Nevada-California seismic belt along the Owens Valley fault zone (DOE 1988a). The magnitude of this shock was estimated at 8.25 M (Richter magnitude) (DOE 1988a). Epicenter density is sparse in the East-West seismic belt except for clusters of aftershocks near weapons testing areas in the Nevada Test Site, induced earthquakes at Lake Mead, and a series of 1966 to 1967 shocks up to 6.1 M located at Clover Mountain near the Nevada-Utah border. Large quiescent areas in the region include the southern part of the Death Valley-Furnace Creek fault zone, the Las Vegas shear zone, and the vicinity of Yucca Mountain (DOE 1988a).

One recent earthquake occurred at Little Skull Mountain on the Nevada Test Site on June 29, 1992. The earthquake's epicenter was at a depth of 9.6 km below Little Skull Mountain, which is about 16 km southeast-ward from the Yucca Mountain repository site. The earthquake's magnitude was 5.6 M (CRWMS M&O 1994d). The type of movement associated with the shock was normal on northeasterly striking planes. Aftershocks of 4.4 and 3.1 M were associated with normal and strike-slip faulting (CRWMS M&O 1994d). At the project Field Operations Center, located about 6 km north of the epicenter, there was some structural damage to the buildings, but none that resulted in loss of use or structural capacity (Voegele 1993). Preliminary estimates of seismic accelerations at the Field Operations Center were approximately 0.10 g to 0.15 g (Voegele 1993). Located about 3 km west of the epicenter is the X-Tunnel, which is an experimental test facility that supported the U.S. Air Force Ballistic Missile Office deep basing studies in the early 1980's. Examination of this underground facility revealed little or no damage, which affirmed that the potential for damage to underground facilities is moderate and attenuated by depth below the ground surface (Voegele 1993). This conclusion was also supported in the seismic analysis for the ESF (CRWMS M&O 1994d), which determined that ground motion would be reduced by a factor of 0.5 to 0.7 for depths of 200 to 400 meters. Based on this observation, seismic hazard is not considered to be significant. The seismic design parameters are considered to be conservative and follow topical report standards.

The Little Skull Mountain earthquake was apparently triggered by the Landers earthquake of June 28, 1992 (Anderson et al. 1994; Gombert and Bodin 1994). The Landers earthquake was a 7.4 M shock that had its epicenter about 280 km south of the Little Skull Mountain epicenter. The Landers earthquake triggered 227 earthquakes throughout southeastern California and southwestern Nevada during the first 83 days following the event (Anderson et al. 1994).

6.6 HYDROLOGY

An understanding of the hydrologic regime of the Yucca Mountain site is important in the design of the surface facilities, repository siting, and for long term performance assessment. One of the primary advantages of the proposed Yucca Mountain repository site is that the intended emplacement is located entirely within the unsaturated zone above the water table (saturated zone). In the proposed repository area, the unsaturated zone is 500 to 700 m thick (YMP 1995b), and the proposed repository is approximately 300 m above the groundwater table.

6.6.1 Previous Work

Much of the information available on the groundwater hydrology of Yucca Mountain has come from regional studies that concentrated on the saturated zone. In 1957 when the U.S. Atomic Energy Commission began underground testing of nuclear devices at the Nevada Test Site, studies on the location and movement of groundwater were carried out to assess the potential for radionuclide contamination. Since about 1978, as a result of the interest in siting the repository above the groundwater table, more emphasis was placed on characterizing the unsaturated zone. Beginning in 1981, hydrologic test holes were drilled into the saturated zone at Yucca Mountain, and beginning in 1983, test holes were drilled specifically to investigate the unsaturated zone. Shallow boreholes, called neutron holes, have been drilled throughout the Yucca Mountain area to obtain water content profiles within the unsaturated zone to investigate meteoric infiltration. The most recent report on the hydrology was developed by the YMP (YMP 1995b).

6.6.2 Surface Hydrology

Although the Yucca Mountain area is in an arid to semiarid climate that is characterized by high evaporation, low precipitation, and infrequent storms, surface runoff does occur. The rugged relief, abundant exposed bedrock, development of caliche in the washes, and sparse vegetation all promote rapid runoff. Some runoff may occur from regional storms in the winter months, but the greatest runoff is associated with the localized thunderstorms in the summer. Dry washes provide channels that concentrate the runoff and may be the principal sources of potential groundwater recharge in the area. There are no springs or seeps within the Yucca Mountain area. There are also no natural lakes or standing bodies of water.

The western flank of Yucca Crest and the repository area is covered by the Drill Hole Wash drainage basin and Busted Butte Wash drainage basin (Figure 6.6.2-1). These areas drain into the Fortymile Wash, which in turn drains to the Amargosa River. On the west side of Yucca Crest is Solitario Canyon, which drains southward to Crater Flat, then the Amargosa River. All these tributaries of the Amargosa River and the river itself are intermittent and carry water only during periods of heavy runoff. Because of the potential for rapid runoff and the nature of the storms in the area, Yucca Mountain is subject to flash floods that are generally confined to the narrow washes. Flash floods commonly occur during the summer months as the result of short-lived, intense thunderstorms. These floods can be destructive over local areas. One especially intense storm occurred on March 11, 1995, which resulted in the highest flows in Fortymile Wash and Amargosa River in the last 25 years (DOE 1996, in prep). This represents the first documented instance during site characterization studies in which Fortymile Wash and Amargosa River have flowed simultaneously throughout their entire Nevada reaches.

The flood potential of the Yucca Mountain site has been investigated as part of the site characterization activities (USGS 1984d; YMP 1995b). The flood potential map (USGS 1984d) for the potential repository area is shown in Figure 6.6.2-1. It was estimated that in the Drill Hole Wash drainage basin, which drains most of the site of the repository, the maximum depths for 100-year and 500-year floods would be 1.2 and 3.4 meters, respectively. These floods would have velocities of 2.4 and 3.4 meters per second. The 100-year flood would stay within the existing stream channel, but the 500-year flood would overflow its banks. The regional maximum flood would inundate all flat alluvial areas in the watershed.

A more recent estimate of flood potential for the Exploratory Studies Facility North Portal and South Portal sites, Drill Hole Wash, and Coyote Wash were presented in a technical basis report (YMP 1995b). This presented estimates of the flood volume of the potential maximum flood for the four sites as follows:

North Portal site (Mid Valley Wash east of portal)	869 - 1897 m^3/s
Drill Hole Wash (upwash from confluence with Coyote Wash)	1189 m^3/s
Coyote Wash (near confluence with Drill Hole Wash)	187 m^3/s
South Portal site (wash east of portal)	98 - 301 m^3/s

The potential maximum flood for the rest of the area has not been determined.

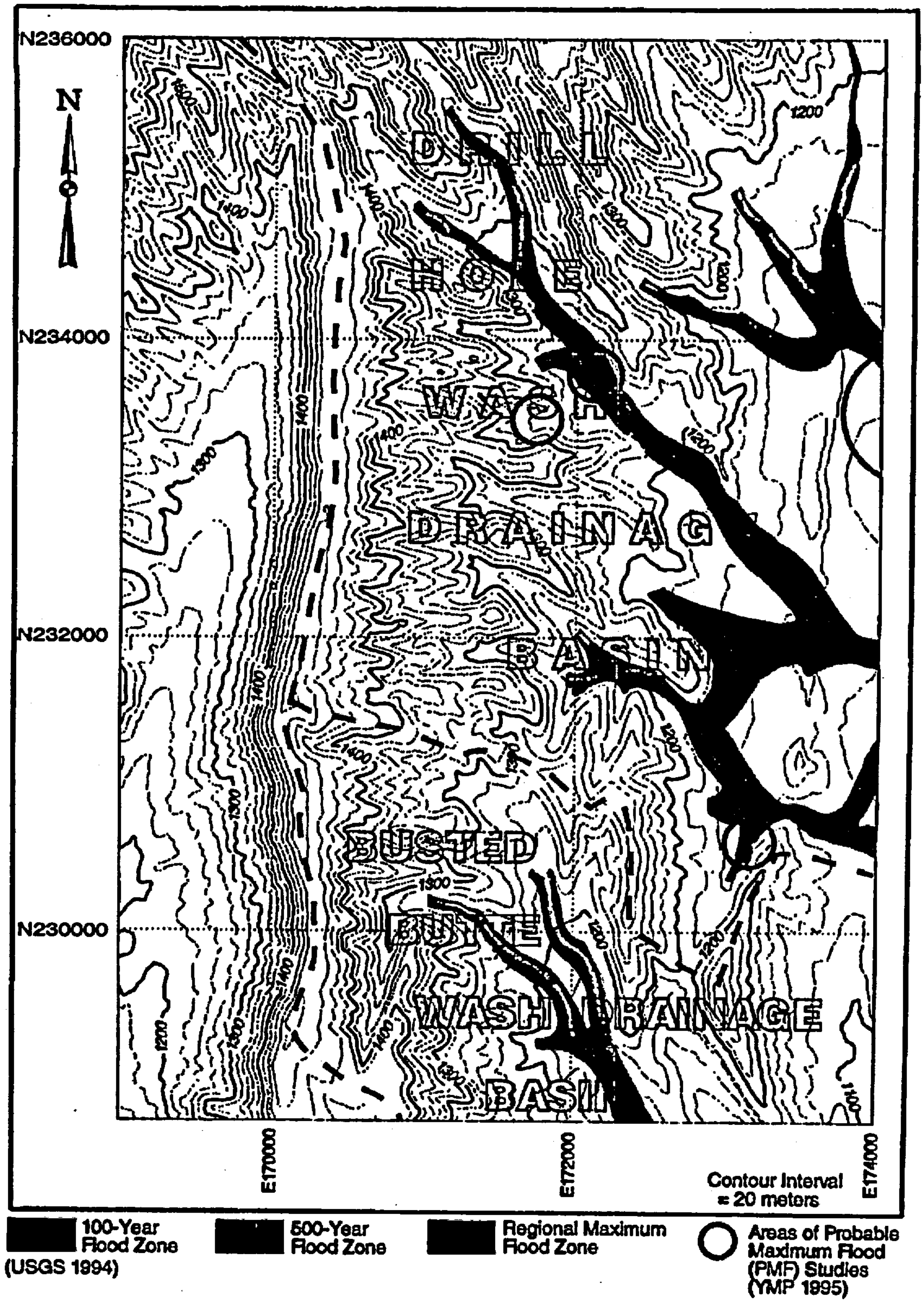

Figure 6.6.2-1. Flood Potential Map for the Drill Hole Wash and Busted Butte Wash Drainage Basins

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6.6.3 Hydrogeologic Units

The rock units of the Yucca Mountain site can be grouped into two gross hydrogeologic units, valley fill aquifer and the welded and bedded tuff aquifer (DOE 1988a). The valley fill aquifer is composed of colluvial, alluvial, and fluvial deposits that are concentrated in the washes and valleys. These deposits are of variable thickness and limited lateral distribution, so their influence on groundwater flow on a regional scale is minimal. The welded and bedded tuff aquifer consists of various nonwelded to welded ashflow tuffs and bedded tuffs. The most important regional aquifer is the paleozoic aquifer, which crops out to the north in Calico Hills and is at a depth of over 1,240 m in borehole p-1 in the eastern part of the area near Boundary Ridge (USGS 1986).

For Yucca Mountain, the welded and bedded tuff aquifer is subdivided into subunits that generally correspond to the thermal/mechanical units described in Section 6.4 and Table 6.4.3-1. These subdivisions are based on hydrologic properties, which group moderately and densely welded tuffs together and the nonwelded and bedded tuffs together (SNL 1995b). The welded tuffs are characterized by relatively low porosities, abundant fractures, and low matrix permeability. Estimates of saturated matrix hydraulic conductivity for the welded tuffs is on the order of 10^{-11} m/s (YMP 1995b). The nonwelded and bedded tuffs, in contrast, are characterized by greater porosities, fewer fractures, and greater matrix conductivities unless clays or zeolites are present. Estimates of saturated matrix hydraulic conductivity for the nonwelded tuffs is on the order of 10^{-7} m/s (YMP 1995b).

The proposed repository is sited within the unsaturated bottom portion of the TSw hydrogeologic unit (Table 6.4.3-1), approximately 300 m above the water table. Water flow to the repository and from the repository to the accessible environment depends mainly upon the hydrogeologic characteristics and flow mechanisms of the unsaturated zone and TSw unit.

6.6.4 Subsurface Unsaturated Zone Hydrology

The subsurface unsaturated zone includes the section of rock from the surface down to the water table, or saturated zone. The unsaturated zone has been investigated by numerous borings, from which the recovered core has been analyzed and in which down-hole testing has been performed.

Perched water has been observed within the unsaturated zone in several boreholes (SNL 1995b). Four of these boreholes are in the Drill Hole Wash proximity and included USW UZ-1, USW UZ-14, USW NRG-7/7A, and USW SD-9. The perched water was encountered about 100 m above the water table. Polymer drilling fluid from G-1 was detected in samples from UZ-1 and UZ-14, and may possibly be present in NRG-7/7A and SD-9. The drilling fluid from G-1 borehole at least contributed to the volume of perched water found at these sites. One borehole, USW SD-7, located further south near the southern end of the repository block, encountered perched water 59 m below the top of the Calico Hills and approximately 150 m above the water table. If perched water were encountered, it is not expected to pose construction problems requiring other than standard engineering measures (YMP 1995b).

Unsaturated groundwater flow occurs in both the matrix and in fractures. At lower degrees of saturation, the flow is primarily within the rock matrix. Significant flow occurs within the fractures only at relatively high degree of saturations.

6.6.5 Subsurface Saturated Zone Hydrology

Groundwater flow in the saturated zone under Yucca Mountain occurs in the lower volcanic rocks and the underlying Paleozoic carbonate strata. Direct observation of the groundwater table was obtained from 28 boreholes, 13 of which are shown in Figure 6.6.5-1. Primarily based on 1988 average water levels, Ervin et al. (USGS 1994c) presented a revised potentiometric-surface map for the region around Yucca Mountain. A rendition of their map is shown in Figure 6.6.5-1, which includes groundwater elevations for boreholes, corrected for hole deviation. General groundwater flow is from the northwest to the southeast. The Primary Area of Mansure and Ortiz (SNL 1984a), which identifies the general area of the potential repository, is included in Figure 6.6.5-1 for reference.

Ervin et al. (USGS 1994c) recognized in the Yucca Mountain area three distinct groundwater areas, which they referred to as the small-gradient area throughout the southeast, moderate-gradient area on the western side, and large-gradient area to the northeast (Figure 6.6.5-1). In the small-gradient area, the groundwater surface elevations range from 740 to 730 m. This area can be explained by flow through high-transmissivity rocks or low ground-water flux through the area. The ground water surface in the moderate-gradient area ranges from 775 to 780 m in elevation and appears to be impeded by the Solitario Canyon fault and a splay of that fault. The groundwater surface in the large-gradient area groundwater levels reach 738 to 1,035 m in elevation and is possibly the result of semi-perched groundwater. The National Academy of Sciences has postulated that the maximum rise of the water table in the event of possible future climatic changes, would be about 100 m, wich is well below the 300 m distance of the repository above the groundwater.

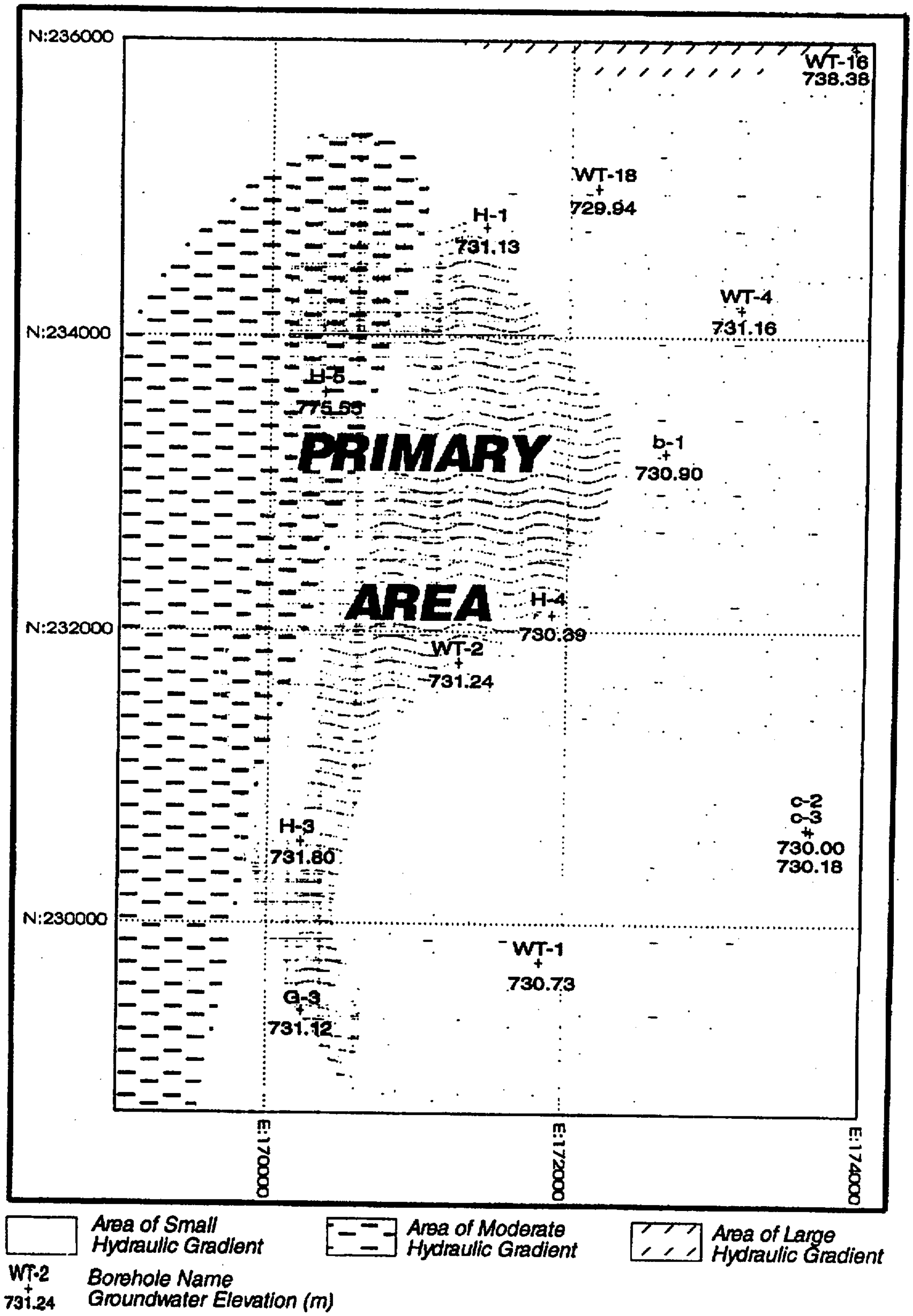

Figure 6.6.5-1. Groundwater Surface Map