RAYTHEON SERVICES NEVADA

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

TITLE I

DESIGN SUMMARY REPORT

FOR THE EXPLORATORY STUDIES FACILITY

REVISION 1

DRAFT H

VOLUME 5

APPENDICES

SEPTEMBER 3, 1991

Prepared by:

RAYTHEON SERVICES NEVADA

101 Convention Center Drive

Las Vegas, Nevada

9112020061 - Part 6

received with letter dtd
11/25/91

INTRODUCTION

These Appendices contain backup information with regard to work performed for the Reference Design Study represented by Revision 1 of the Title I Design Summary Report (DSR) for the Exploratory Studies Facility.

In several cases, the backup document is not included in total because it has been published and issued. In these instances, only enough of the front sheets are included to give the reader a "feel" for the nature of the document. The reader may consult the actual document for further information. The items not totally included are Appendices 5.1, 5.3, 5.4, 5.5, 5.10, 5.11, 5.12, 5.13, and 5.14.

Documents which do not reflect the latest Alternative Studies Option 30, "four ramps" configuration are included. The methodology presented in these documents is valid for the Reference Design Study and was utilized as backup information. These documents and studies shall be revisited during Title II design to update them, if appropriate, to the latest configurations and concepts.

102-8

Draft 8/29/91

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5.1 "Findings of the ESF Alternatives Study," SAND90-3232

SANDIA REPORT

SAND90–3232 • UC–814
Unlimited Release
Printed March 1991

Findings of the ESF Alternatives Study

A. L. Stevens, L. S. Costin

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-76DP00789

SAND90-3232
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Printed March 1991

Distribution
Category UC-814

FINDINGS OF THE ESF ALTERNATIVES STUDY

by

A. L. Stevens
L. S. Costin
Sandia National Laboratories
Albuquerque, NM

ABSTRACT

This report presents a summary of the conduct and findings of the Exploratory Shaft Alternatives Study. The study basis and findings are presented in sufficient detail to allow the Department of Energy to make an informed decision as to the Exploratory Shaft Facility/Repository design option to be used as the basis for resumption of ESF Title II design. As a result of the desire for a rigorous, logically defensible analysis and the complexity of the required evaluation, a multi-attribute utility analysis was used as the primary decision-aiding tool. Over 2500 regulations, requirements and concerns were considered under four broad objectives. The analysis resulted in the ranking of 34 options, in accordance with the extent to which each option could achieve the objectives. Additional findings regarding design features that were identified as key elements in an options ability to provide good overall performance are also discussed.

This work was performed under the Sandia National Laboratories Nuclear Waste Repository Technology Department Quality Assurance Plan as a quality-affecting activity. WBS 1.2.6.1.1

Findings of the Exploratory Shaft Facility Alternative Studies

Executive Summary

The purpose of this report is to present the findings of the Exploratory Shaft Alternatives Study with sufficient detail to allow the DOE executive to make an informed decision as to the Exploratory Shaft Facility/Repository design option to be utilized as the basis for resumption of ESF Title II design.

This report was prepared in accordance with the Yucca Mountain Site Characterization Project Exploratory Shaft Facility Alternatives Study Implementation Plan, Rev. 1, December 20, 1990, prepared by SNL. It is considered to accurately represent the findings of the study, although the final report is in the compilation process, and is expected to be available in draft form in the March/April 1991 time frame.

Due to the desire for a rigorous, logically defensible analysis and the complexity of the required evaluation, (34 ESF/Repository options and approximately 2500 requirements and concerns) which had to be considered, multi-attribute utility analysis was used as the primary decision-aiding tool.

The analysis resulted in the ranking of the 34 options, in accordance to the extent of the adequacy with which expert panels estimated that each option would achieve the objectives. It should be noted that all of the options were considered to be adequate, although some options were ranked distinctly lower than the others (e.g., 9 and 26).

It is recognized that there are substantial uncertainties with respect to the actual performance of any option. The quantitative differences indicated between options are derived from the consensus best-professional judgments of expert panels selected for the study. It should be recognized that conducting the analysis using other expert panels would likely produce different quantitative differences (smaller or larger) and might or might not produce a different ranking.

To aid in the decision process, isometric drawings which portray each of the 34 options are included in an appendix. In the interest of report brevity, prose descriptions of the options have been omitted. If desired, detailed presentations on specific options will be provided.

In addition, your attention is directed to the November 20 presentation to the NWTRB. This presentation material includes the results of the evaluations by the expert panels in tabular form.

The decision will result in the placing of key features of the selected option under configuration control but does not preclude future changes. Rather, the key features will be baselined, and changes to those key features will be accomplished in accordance with the change control process, after review by appropriate technical disciplines. Selected key features will only be changed with the approval of the decision making executive.

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ACKNOWLEDGMENT

A large number of people have participated in the Exploratory Shaft Facility Alternatives Study. As one measure, over 200 people (from DOE, the participant organizations, subcontractors, and consultants) have been trained in the use of Sandia National Laboratories (SNL) QA procedures in support of this effort. Numerous others have participated under the QA procedures of their own organizations. The results presented in this report would not have been achieved without the enthusiastic and exemplary contributions of all members in this team effort. Within this number there are several key members of the team whose contributions we wish to specifically acknowledge. For leadership of the major tasks of the study: Al Dennis, SNL - study management and report preparation; Earl Gruer, SNL - development of options; Stephen Bauer, SNL - evaluatin process; and Mike Parsons, T&MSS - identification of requirements. For development and implementation of the decision-aiding methodology used for the study: Lee Merkhofer, Applied Decision Analysis and Paul Gnirk, RE/SPEC. For support to the expert panels in the evaluation process: Ned Elkins, LANL - testing requirements and schedules, Bill Kennedy, RSN - ESF configurations and construction methods, Brian Lawrence, PBQ&D - repository configurations and construction methods, Jim Scott, RSN - construction and operational schedules and costs, Ray Finley, SNL - Task 4 support and conduct of reviews, and Mike Voegele, T&MSS - support to the program viability panel. For guidance and encouragement to the study teams: Ted Petrie, Bob Waters, Max Blanchard, and Dave Dobson, all of the Yucca Mountain Site Characterization Project Office.

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5.2 Letter, Gertz to Bullock dated 02/22/91, "Authorization for Conducting a Design Study to Develop a Reference Exploratory Shaft Facility (ESF) Design to be Used as Input to Title I Design Summary Report"

I-S

Department of Energy

Yucca Mountain Site Characterization
Project Office
P. O. Box 98608
Las Vegas, NV 89193-8608

WBS 1.2.6
QA: N/A

FEB 22 1991

FEB 25 9 28 AM '91

Richard L. Bullock
Technical Project Officer
for Yucca Mountain
Site Characterization Project
Raytheon Services Nevada
101 Convention Center Drive
Phase II, Suite P-250
Las Vegas, NV 89109

AUTHORIZATION FOR CONDUCTING A DESIGN STUDY TO DEVELOP A REFERENCE EXPLORATORY SHAFT FACILITY (ESF) DESIGN TO BE USED AS INPUT TO TITLE I DESIGN SUMMARY REPORT (WORK BREAKDOWN STRUCTURE 1.2.6)

Reference: Ltr, Blejwas to Petrie, dtd 1/9/91, w/encl

This letter hereby directs Raytheon Services Nevada to begin work on the subject project. For purposes of design, Option 30 of the Alternative's Study shall form the basis of configuration along with the following modifications considered for enhancement.

1. The test area at the main test level should be located in the northern part of the repository. Because this is where the minimum thickness occurs between Topopah Spring and water table, we wish to acquire early test data in this location.

2. To improve the aesthetics from the highway, ESF excavated rock coming from the south ramp shown in Option 30 should be transported and disposed of in a more aesthetically acceptable manner (i.e., not visible from the highway).

3. To facilitate underground operations and acquisition of scientific information about the rock above the Topopah Spring (should it be needed), a vertical shaft design should be included. The construction of this shaft will be deferred until it is required.

Please provide an Engineering Plan for the subject work by March 4, 1991. If you have any questions, please contact Edgar H. Petrie at 794-7961 or James T. Gardiner at 794-7583.

Carl P. Gertz
Project Manager

EDD:EHP-2080

cc:
G. K. Beall, SAIC, Las Vegas, NV, 517/T-36
K. J. Lobo, SAIC, Las Vegas, NV, 517/T-36
L. R. Hayes, USGS, Las Vegas, NV
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R. J. Herbst, LANL, Los Alamos, NM
T. E. Blejwas, SNL, 6310, Albuquerque, NM
J. H. Nelson, SAIC, Las Vegas, NV
R. F. Pritchett, REECo, Las Vegas, NV
R. E. Lowder, MACTEC, Las Vegas, NV

TITLE I DESIGN SUMMARY REPORT
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5.3 "Exploratory Shaft Facility Design Requirements," Volumes 1 & 2, YMP/CC-0013

YMP/CC-0013

U.S. DEPARTMENT OF ENERGY

OCRWM

YUCCA MOUNTAIN

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

Document No. YMP/CC-0013
Revision 07/29/91
CI No. N/A
Date 07/29/91
WBS No. 1.2.1 thru 1.2.7
QA Yes

PROJECT CCB CONTROLLED DOCUMENT

49

EXPLORATORY SHAFT FACILITY DESIGN REQUIREMENTS

CHANGES TO THIS DOCUMENT REQUIRE PREPARATION AND APPROVAL OF A CHANGE REQUEST IN ACCORDANCE WITH PROJECT AP-3.3Q

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

UNITED STATES DEPARTMENT OF ENERGY
YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT OFFICE

YMP-035-R0
4/22/91

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
DOCUMENT CHANGE NOTICE (DCN) RECORD

1 Document Title:

Exploratory Shaft Facility Design Requirements (ESFDR)

2 Document Number: YMP/CC-0013

The document identified in Blocks 1 and 2 has been changed. The changed pages attached to this DCN are identified in Block 7 opposite the latest DCN number in Block 3. The original issue of this document as modified by all applicable DCN's constitutes the current version of the document identified in Blocks 1 and 2.

3 DCN NO.	4 CR NO.	5 DOCUMENT Rev./ICN #	6 CR TITLE	7 AFFECTED PAGES	CHANGE	ADD	DELETE	8 DATE
001	91/068	5/31/91*	Revision to ESFDR Document					5/31/91
			Minor editorial changes	Marked by bar	X			
			Supplement Appendix B w/Testing Requirements	Appendix B		X		
			Appendix C				X	
*NOTE:	Submitted as YMP/CC-0013, Revision 1. Change Control Board approved as date revision to accommodate dynamic changes to the document.							
002	91/076	7/01/91	Revision to ESFDR Document					7/01/91
			Minor editorial changes	Marked by bar	X			
			Add'l testing requirements added	Appendix B		X		
003	91/095	7/29/91	Revision to ESFDR Document					7/29/91
			Changes to Appendix B	Marked by bar	X			
			Add Appendix J	Appendix J		X		

INFORMATION COPY

Y-AD-057
9/90

YUCCA MOUNTAIN PROJECT CHANGE DIRECTIVE (CD)

1 CR No. 91/068
Page 1 of 2

SECTION I. IDENTIFICATION

2 Title of Change:

Revision of Exploratory Shaft Facility Design Requirements (ESFDR) Document

3 Change Classification:

☐ Class 1 ☐ Class 3
☒ Class 2

SECTION II. DISPOSITION

4 CR Disposition:

☒ Approved ☐ Disapproved
☐ Approved with Conditions

5 Conditions: *(if applicable)*

None

(See Change Documentation Continuation Page ___)

6 Implementation Direction: *(if applicable)*

1. This Change Request (CR) is Approved for CCB control as the Exploratory Shaft Facility Design Requirements Document and is assigned Controlled Document Number YMP/CC-0013, Revision 5/31/91. A date revision is being given to this document to accommodate the dynamic changes anticipated to this document.

2. The CCB Secretary shall ensure that the Cover Page and the Title Page for Document YMP/CC-0013, Revision 5/31/91, are prepared.

(See Change Documentation Continuation Page 2)

SECTION III. CONCURRENCE

7 Quality Assurance Organization Concurrence

Name: D. G. Horton Org.: PQA
(print) *(print)*
Signature: [signature] for DG Horton Date: 5/31/91

8 Disposition Authority

Name: M. B. Blanchard Title: CCB Chrprsn
(print) *(print)*
Signature: [signature] Date: 5/31/91
For M.B Blanchard

9 Effective Date:

5/31/91

6 Implementation Direction (continued)

3. The Document Originator shall provide a Print Ready Copy of YMP/CC-0013, Revision 5/31/91, to the CCB Secretary. The Document Number and Revision Number will be identified on each page of the Publication Ready Document YMP/CC-0013. The Document Originator shall also provide a Document Change Notice (DCN) identifying changes made to Revision 5/31/91 of document YMP/CC-0013.

4. The CCB Secretary shall ensure that YMP/CC-0013, Revision 5/31/91, is prepared in accordance with this Change Directive (CD). The CCB Secretary shall prepare a Controlled Document Issuance Authorization (CDIA) to transmit this CD and YMP/CC-0013, Revision 5/31/91, to the Project Document Control Center (DCC) in accordance with AP-1.5Q.

5. Per AP-3.3Q, each Project Participant and Project Office Division Director will complete an Affected Document Notice (ADN) as notification of completion of implementation planning for this CD.

6. The CCB Secretary shall ensure that the Configuration Information System (CIS) and the CCB Document Register are updated to reflect this Approved addition of Document YMP/CC-0013, Revision 5/31/91.

7. Any changes to Document YMP/CC-0013, Revision 5/31/91, will require submittal of a CR to the Project CCB.

8. Upon release of YMP/CC-0013, Revision 5/31/91, all Project Participants will be required to use YMP/CC-0013, Revision 5/31/91, in performing duties applicable to this document.

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Y-AD-057
9/90

YUCCA MOUNTAIN PROJECT CHANGE DIRECTIVE (CD)

1 CR No. 91/076
Page 1 of 2

SECTION I. IDENTIFICATION

2 Title of Change:

Revision to Exploratory Studies Facility Design Requirements Documents (ESFDR)

3 Change Classification:

☐ Class 1 ☐ Class 3
☒ Class 2

SECTION II. DISPOSITION

4 CR Disposition:

☒ Approved
☐ Approved with Conditions
☐ Disapproved

5 Conditions: *(if applicable)*

None.

(See Change Documentation Continuation Page ___)

6 Implementation Direction: *(if applicable)*

1. This Change Request (CR) is approved to revise the Exploratory Shaft Facility Design Requirements Document, YMP/CC-0013, Revision 7/1/91.

2. The CCB Secretary shall ensure that the Cover Page and the Title Page for document YMP/CC-0013, Revision 7/1/91, are prepared.

3. The Document Originator shall provide a Print Ready Copy of YMP/CC-0013, Revision 7/1/91, to the CCB Secretary. The document number and revision number will be identified on each page of the Publication Ready Document

(See Change Documentation Continuation Page 2)

SECTION III. CONCURRENCE

7 Quality Assurance Organization Concurrence

Name: D. G. Horton *(print)* Org.: PQA *(print)*

Signature: [signature] Date: 7/9/91

8 Disposition Authority

Name: M. B. Blanchard *(print)* Title: CCB Chrprsn *(print)*

Signature: Robert V Barton Date: 7/10/91

9 Effective Date:

7/10/91

YUCCA MOUNTAIN PROJECT
CHANGE DOCUMENTATION CONTINUATION PAGE

6 Implementation Direction (continued)

YMP/CC-0013. The Document Originator shall also provide a Document Change Notice (DCN) identifying changes made to Revision 7/1/91 of document YMP/CC-0013.

4. The CCB Secretary shall ensure that YMP/CC-0013, Revision 7/1/91, is prepared in accordance with this Change Directive (CD). The CCB Secretary shall prepare a Controlled Document Issuance Authorization (CDIA) to transmit this CD and YMP/CC-0013, Revision 7/1/91, to the Project Document Control Center (DCC) in accordance with AP-1.5Q.

5. Per AP-3.3Q, each Project Participant and Project Office Division Director will complete an Affected Document Notice (ADN) as notification of completion of implementation planning for this CD.

6. The CCB Secretary shall ensure that the Configuration Information System (CIS) and the CCB Document Register are updated to reflect this approved revision of document YMP/CC-0013, Revision 7/1/91.

7. Any changes to document YMP/CC-0013, Revision 7/1/91, will require submittal of a CR to the Project CCB.

8. Upon release of YMP/CC-0013, Revision 7/1/91, all Project Participants will be required to use YMP/CC-0013, Revision 7/1/91, in performing duties applicable to this document.

YMP-034-R0
4/22/91

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
CHANGE DIRECTIVE (CD)

1 CR No. 91/095
Page 1 of 2

SECTION I. IDENTIFICATION

2 Title of Change:
Revision to Exploratory Studies Facilities Design Requirements Document

3 Change Classification:
☐ Class 1 ☐ Class 3
☒ Class 2

SECTION II. DISPOSITION

4 CR Disposition:
☐ Approved ☐ Disapproved
☒ Approved with Conditions

5 Conditions: *(if applicable)*

Change Request (CR) 91/095 is approved with the following condition:

1. The Third Phase Submittal Description shall be removed from the Exploratory Studies Facility Design Requirements Document.

(See Change Documentation Continuation Page ___)

6 Implementation Direction: *(if applicable)*

1. Change Request (CR) 91/095 is approved with the condition listed in Block 5 of this Change Directive (CD) as CCB Controlled Document YMP/CC-0013, Revision 7/29/91, Exploratory Studies Facility Design Requirements Document (ESFDRD).

2. The CCB Secretary shall ensure that the Title Page and Table of Contents for Document YMP/CC-0013, Revision 7/29/91, are revised to reflect these changes.

3. The Document Originator shall provide a Print Ready Copy of YMP/CC-0013, Revision 7/29/91, to the CCB Secretary. The document number and revision

(See Change Documentation Continuation Page 2)

SECTION III. CONCURRENCE

7 Quality Assurance Organization Concurrence

Name: D. G. Horton (print) Org.: PQA (print)
Signature: [signature] for Date: 7-29-91

8 Disposition Authority

Name: M. B. Blanchard (print) Title: CCB Chrprsn. (print)
Signature: Maxwell B Blanchard Date: 7-29-91

9 CD Effective Date

QMP-03-09

6 Implementation Direction (continued)

date will be identified on each page of the Print Ready Document YMP/CC-0013. The Document Change Notice (DCN) shall be revised to reflect changes made to Revision 7/29/91, of document YMP/CC-0013.

4. The CCB Secretary shall ensure that YMP/CC-0013, Revision 7/29/91, is prepared in accordance with this CD. The CCB Secretary shall prepare a Controlled Document Issuance Authorization (CDIA) to transmit this CD and YMP/CC-0013, Revision 7/29/91, to the Project Document Control Center (DCC) in accordance with AP-1.5Q.

5. Per AP-3.3Q, each Project Participant and Project Office Division Directors will complete an Affected Document Notice (ADN) as notification of completion of implementation planning for this CD.

6. The CCB Secretary shall ensure that the Configuration Information System (CIS) an the CCB Document Register are updated to reflect this approved addition of Document YMP/CC-0013, Revision 7/29/91.

7. Any changes to Document YMP/CC-0013, Revision 7/29/91, will require submittal of a CR to the Project CCB.

8. Upon release of YMP/CC-0013, Revision 7/29/91, all Project Participants will be required to use YMP/CC-0013, Revision 7/29/91, in performing duties applicable to this document.

YMP/CC-0013, Rev. 5/31/91

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

EXPLORATORY STUDIES FACILITY (ESF)

DESIGN REQUIREMENTS

(ESFDR)

VOLUME I

Prepared by Yucca Mountain Site Characterization Project (YMP) Participants as part of the Civilian Radioactive Waste Management Program. The YMP is managed by the Yucca Mountain Site Characterization Project Office (YMPO) of the U.S. Department of Energy, Office of Civilian Radioactive Waste Management.

Compiled by:
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with support from
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101 Convention Center Drive, Suite 407
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Prepared for:

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P.O. Box 98608
Las Vegas, Nevada 89193-8608

 YMP CC-0013, Rev. 5 31 91

SUBMITTALS AND APPROVALS

This Exploratory Studies Facility Design Requirements (ESFDR) document for the YMP has been prepared and submitted by the Sandia National Laboratories (SNL), with support from the Technical and Management Support Services Contractor (T&MSS), and with YMPO approval by:

Edgar H Petrie — Date : 5/30/91

E. H. Petrie, Acting Director
Yucca Mountain Engineering and Development Division
Yucca Mountain Site Characterization Project Office

N Voltura for DGHORTON — Date : 5/30/91

D. G. Horton, Director
Yucca Mountain Quality Assurance Division

Carl Gertz — Date : 5/31/91

C. P. Gertz, Yucca Mountain Site Characterization Project Manager
Yucca Mountain Site Characterization Project Office;
Associate Director
Office of Geologic Disposal

The technical content of this document was developed by various Participants who remain responsible for the technical adequacy of the data they provided. Unless otherwise noted, all included data are considered to be "best available," and are adequate for the resumption of ESF design studies. Specific authorization for use of the data to finalize design packages for construction must be obtained from the YMPO.

Sandia National Laboratories (SNL) has primary responsibility for assuring that the technical data other than that indicated as "best available" are developed in accordance with YMP procedures.

YMP/CC-0013, Rev. 7/1/91

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APPENDICES

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BACKGROUND

In accordance with the Nuclear Waste Policy Act (NWPA), Public Law 97-425, January 7, 1983, the Office of Civilian Radioactive Waste Management (OCRWM) of the U.S. Department of Energy (DOE) was charged with identifying and nominating at least five sites for submission to the President as being suitable for further study in selection of the first high-level radioactive waste repository site.

As required by Section 112 of the NWPA, each nomination was accompanied by an Environmental Assessment (EA) that included an evaluation of the effects of site characterization activities. Site characterization is defined in the NWPA as the following:

> "...activities, whether in the laboratory or in the field, undertaken to establish the geologic condition and the ranges of the parameters of a candidate site relevant to the location of a repository, including borings, surface excavations, excavations of exploratory shafts, limited subsurface lateral excavations and borings, and in situ testing needed to evaluate the suitability of a candidate site for the location of a repository, but not including preliminary borings and geophysical testing needed to assess whether site characterization should be undertaken."

The DOE recommended three of the five sites to the President for characterization. Presidential approval of the Yucca Mountain site, in Nevada, occurred on May 28, 1986. On December 22, 1987, the Nuclear Waste Policy Act Amendments (NWPAA) identified Yucca Mountain as the site to be characterized.

Evaluation of the suitability of Yucca Mountain as a geologic repository is the responsibility of the YMPO, which is managed by the Office of Civilian Radioactive Waste Management (OCRWM) Office of Geologic Disposal. The Exploratory Studies Facility (ESF) is one aspect of the site characterization process which will provide the necessary data for a number of suitability analyses. An exploratory facility is allowed by the Code of Federal Regulations, Title 10, Part 60 (10 CFR 60) for the conduct of in situ exploration and testing at the depths at which wastes would be emplaced. This testing must be well underway prior to submittal of a license application for authorization to construct a repository. The in situ testing is required to establish and confirm geologic conditions and the ranges of parameters relevant to the demonstration of the adequacy of the site, in accordance with the requirements of 10 CFR 60.

PRIMARY GUIDELINES

The primary guidelines for the YMP ESF are as follows:

- All ESF workings will be restricted to the unsaturated zone. The candidate host rock will be a section of the welded interior of the Topopah Spring Member of the Paintbrush Tuff. The design of the ESF will consider the need to obtain significant and unique information about site properties during underground shaft and/or ramp construction.

YMP/CC-0013, Rev. 5/31/91

- The ESF will be constructed with the necessary and adequate facilities and so that the ESF testing will focus on the information necessary to support the site characterization program and license application.

- Construction of the ESF will provide access for detailed studies of the potential host rock as well as the overlying and underlying geologic strata.

The ESF Design Requirements (ESFDR) document provides the functional requirements, performance criteria, constraints, and assumptions for all systems and subsystems within the scope of the ESF. The applicable guidance and requirements contained in the ESF document hierarchy were utilized and incorporated into the ESFDR. For example, the flowdown from the higher documents consist of the Waste Management System Requirements, Volume IV (WMSR IV, an OCRWM document) into the System Requirements (SR) and on into the ESFDR. The ESFDR also has requirement inputs from the Site Characterization Program Baseline (SCPB) (see Appendix B) plus interface requirements from the Repository Design Requirements (RDR) (see Appendix A.1). Additionally, the ESFDR incorporates the input and the concerns of the NRC and the Nuclear Waste Technical Review Board (NWTRB) which includes, but is not limited to, three concerns that were expressed by the NRC regarding the acceptability of ESF Title I Design as it pertains to the Site Characterization Plan and the start of new characterization activities at the Yucca Mountain Site. The three NRC concerns are:

1. The ESF design, construction, and operations should not compromise the ability of the site to isolate waste.

2. The ESF design, construction, and operations should not compromise the ability to characterize the site.

3. The ESF design, construction, and operations should provide representative data.

It is the responsibility of each YMP Participant to comply with all applicable higher level requirements as identified in this document for design and construction of the ESF.

The ESFDR translates the OCRWM requirements into the site specific requirements, from which the YMP Participants' responsibilities are assigned to ensure that all of the design criteria, requirements, and responsibilities are met.

EXPLANATION OF ESFDR VOLUME 1 NOTATIONS AND ORGANIZATION

The structure of the ESFDR follows the applicable guidance of the Office of Civilian Radioactive Waste Management (OCRWM) DOE/RW/0051, REV. 1, Systems Engineering Management Plan. This document requires that the site specific design requirements document (ESFDR) include the following:

 YMP/CC-0013, Rev. 5/31/91

- DEFINITION OF SUBSYSTEM ELEMENTS.
- APPLICABLE REGULATIONS, CODES, AND SPECIFICATIONS.
  (This category is shown as APPLICABLE REGULATIONS, CODES, STANDARDS, AND DOE ORDERS in the ESFDR.)
- FUNCTIONAL REQUIREMENTS.
- PERFORMANCE CRITERIA.
- INTERFACE CONTROL REQUIREMENTS.
- CONSTRAINTS.
- ASSUMPTIONS.

This document conforms to this outline within each subsystem section.

Each section of the ESFDR contains the following structure and information: (Section titles are shown in all capital letters for emphasis.)

The DEFINITION OF SUBSYSTEM ELEMENTS division is further divided into two parts, <u>Definition</u> and <u>Boundaries and Interfaces</u>. The definition identifies the general purpose of the section. The boundaries and interfaces identify the complementary sections of the ESFDR which may affect the satisfaction of the requirements in the section of interest.

The APPLICABLE REGULATIONS, CODES, STANDARDS AND DOE ORDERS division identifies those regulatory documents associated with the subject of the section. This division is only found in the primary part of the sections; subsections do not contain this division.

The FUNCTIONAL REQUIREMENTS (FR) division contains definitions of what the subsystem, identified in the section, must accomplish. These FRs are listed in numeric order as statements of purpose.

The PERFORMANCE CRITERIA (PC) division contains criteria statements on how well a specific subsystem must perform its functional requirement and, in some cases, the means for evaluating its performance. These criteria are listed in numeric-alphabetic order as a means of identifying the functional requirement to which they are subordinate. As an example, performance criteria 1a through 1f would be subordinate to Functional Requirement 1. Letters are not used for a single performance criteria.

The INTERFACE CONTROL REQUIREMENTS (IR) division either documents or identifies the source documentation of the external, site, waste package, repository, and internal physical interfaces of the subject subsystem. This division is only found in the primary sections; subsections do not contain this division.

The CONSTRAINTS (C) division contains statements on the limitations that are placed on the subsystem by the design process, interrelated subsystems, and/or environmental conditions within which the subsystem must function. The constraints are listed in alphabetic order.

The ASSUMPTIONS (A) division contains site specific condition statements which may limit the design or needs of the subsystem to a certain alternative, action, route, or piece of equipment. The assumptions are listed in numeric order.

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Each subsystem statement, whether FR, PC, C, or A, is followed by a bracketed citation which identifies the source of authority for the statement. Specific examples of these citations and their meanings are as follows:

- [10 CFR 60.123]--This citation identifies the statement's source is Paragraph 123 of 10 CFR Part 60.
- [SR3.B]--This citation identifies a quote of Constraint B in Section 3.0 of the Yucca Mountain Mined Geologic Disposal System Requirements (SR-ESF) Document developed to support ESF.
- [SRY.E]--This citation identifies a quote of Constraint E in Section YMMGDS of the Yucca Mountain Mined Geologic Disposal System Requirements (SR-ESF) Document developed to support ESF.
- [6.0FR1]--This citation identifies the statement derived from a higher level statement in section 1.2.6.0 of the ESFDR, Functional Requirement 1.

Any reference made to State regulations will mean State of Nevada unless otherwise noted.

Each PC subsystem statement citation is followed by a series of capital letters in brackets. Each letter identifies the functional system allocation of the associated statement. The definition of each letter code used is as follows:

D--Development activity: ESF construction related tasks and functions.

O--Operations activity: ESF operations related tasks and functions.

W--Waste containment and waste isolation: ESF tasks and functions that may affect nuclear waste isolation capability of the repository.

S--Safety: ESF operational and public safety related tasks and functions.

P--Performance confirmation: ESF performance confirmation related tasks and functions.

M--Maintenance: ESF maintenance tasks and functions.

T--Testing: ESF testing related tasks and functions.

I--Training (instruction): ESF personnel training related tasks and functions.

10 CFR 60 REQUIREMENTS

Appendix E of the WMSR Volume IV lists requirements from 10 CFR 60 which, according to the Nuclear Regulatory Commission (NRC) staff, must be considered in the ESF design. These include requirements which are not applicable to shafts and ramps, but which have been included as a DOE management decision. All requirements have been considered in the sense that nothing in this document

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would later preclude the DOE's complying with the requirements. However, some of the listed 10 CFR 60 requirements do not directly influence the ESF design and consequently do not appear in the ESFDR. These requirements fall into four categories:

1. The 10 CFR 60 requirements that regulate the handling and control of radioactive material do not appear in the ESFDR because it is anticipated that radioactive waste will not be used during ESF testing. These requirements are:

   - 10 CFR 60.111(a), Protection against radiation exposures and releases of radioactive material

   - 10 CFR 60.131, General design criteria for the geologic repository operations area (a) Radiological protection

   - 10 CFR 60.143, Monitoring and testing waste packages

   Should the DOE decide to transport radioactive waste to the ESF and test it, the above requirements plus others from 10 CFR 71, Section 113 of the NWPA, and appropriate state regulations will be added to the ESFDR.

2. Similarly, the 10 CFR 60 requirements for structures systems and components that protect the public's radiological health and safety do not appear in the ESFDR because such structures would not be needed where there is no radioactive material. These requirements are:

   - 10 CFR 60.21, Content of License Application except for 10 CFR 60.21(a)(11). This includes the Safety Analysis Report.

   - 10 CFR 60.131, General design criteria for the geologic repository operations area. (b) Structures, systems, and components important to safety.

   - 10 CFR 60.133(g), Underground Facility Ventilation (ventilation when radioactive particles are present underground).

   - 10 CFR 60.133(h), Engineered Barriers (none will be present).

3. The following requirements of 10 CFR 60 do not appear in the ESFDR because they are covered elsewhere and are not directly relevant to the ESF design. These requirements are:

   - 10 CFR 60.4, Communications and records. (b) Retention of records.

   - 10 CFR 60.16, Site characterization plan required (These requirements have been satisfied)

   - 10 CFR 60.17, Contents of the Site Characterization Plan (These requirements have been satisfied)

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- 10 CFR Part 60.24(a), Updating of application and environmental report

- 10 CFR 60.151, Quality Assurance Applicability

- 10 CFR 60.152, Quality Assurance Implementation

- 10 CFR 60.111(b), Retrievability of Waste

- 10 CFR 60.112, Performance Objective of Geologic Repository after Permanent Closure

- 10 CFR 60.113(a), Performance Objectives of Engineered Barrier Systems

- 10 CFR 60.113(a)(2), Requirements for the minimum groundwater travel time to the accessible environment. The relationship of the ESF and the disturbed zone boundary is covered in 10 CFR 60.15(c).

- 10 CFR 60.113(b),(2),(3) and (4), Factors that may persuade the Commission to specify or approve some other radionuclide release rate, containment period or groundwater travel time.

- 10 CFR 60.122, Siting Criteria (The ESFDR uses 10 CFR 60.122(c)(1), to constrain drainage and surface water impoundments. Flooding potential of ESF accesses is covered in 10 CFR 60.133(d).

- 10 CFR 60.133(c), Retrieval of Waste

4. Finally, the ESFDR has been revised to eliminate all requirements applicable to the actual Performance Confirmation Program because these belong in the SCPB. The ESFDR now contains only Performance Confirmation Plans (PCPs) design requirements and allows this interface to be maintained. These requirements are:

   - 10 CFR 60.133(e)(1), Underground openings (design is to support the retrievability option).

   - 10 CFR 60.140, Performance Confirmation Program (PCP), General requirements

   - 10 CFR 60.141, Performance Confirmation Program (PCP), Confirmation of geotechnical and design parameters

   - 10 CFR 60.142, Performance Confirmation Program (PCP), Design Testing

The remaining 10 CFR 60 requirements are quoted and cited throughout the ESFDR serving as performance criteria or constraints. The quotes and citations enable one to trace the flow of 10 CFR 60 requirements from one document to another. Any deviation from verbatim 10 CFR 60 quotes will be indicated by the new text change being enclosed within brackets.

Beneath some 10 CFR 60 requirements, the ESFDR provides sub-tier requirements, criteria or constraints that orient a Part 60 provision to the circumstances to which it will be applied. These sub-tier statements elaborate on 10 CFR 60, but many do not transform the regulation into a numerical criterion nor do they add much detail. Moreover, in some cases a 10 CFR 60 requirement stands alone without a sub-tier supplement.

DESIGN ACCEPTABILITY ANALYSIS (DAA)

These Exploratory Studies Facility Design Requirements (ESFDR) do not provide the detail that the NRC staff desires. For the most part, the ESFDR, much like the Design Acceptability Analysis, considers the applicable 10 CFR 60 requirements qualitatively. The NRC staff, however, objected to the DAA because;

> "The approach adopted in the DAA raises questions about completeness and rigor of the design acceptability analysis, as <u>detailed design criteria</u> were not developed for <u>all</u> applicable requirements." (NRC, 1989, page 4-98, emphasis added).

The DAA is affected by the 10 CFR 60 considerations discussed above under 10 CFR 60 Requirements. Therefore, these 10 CFR 60 considerations apply to the DAA in that they may not be considered applicable for use in the ESF at this time (See Appendix K for more information).

It is believed the above consideration of 10 CFR 60 requirements adequately deals with the NRC's objection, and this will allow the NRC staff to reconsider their objection and accept the ESFDR even though "detailed design criteria ... for all applicable [10 CFR 60] requirements" have not been developed.

UNDERGROUND TESTING SUPPORT

The title of Section 1.2.6.8 was changed from Underground Tests to Underground Test Support to more accurately reflect the nature of the requirements contained in the section. Requirements applicable to the development of the test program and to the development and execution of individual tests were deleted because they belong in the SCPB. Section 1.2.6.8 now contains only facility design and support requirements for testing.

The Integrated Data System (IDS) will not be designed from requirements in the ESFDR but will be designed using its own set of design requirements. The IDS will require ESF facility support. This will require an interface during ESF design. The title and content of Section 1.2.6.8.1 was revised to reflect this.

EXPLANATION OF ESFDR VOLUME 2 NOTATIONS AND ORGANIZATION

The ESFDR Volume 2 contains Volume 1 support information arranged as appendices A through K. The contents of individual appendices are as follows:

- Appendix A.1--This appendix contains general descriptions of the repository/ESF interfaces. This appendix identifies the need for

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modifications and redesigns of the ESF accesses to satisfy the functional requirements of the repository underground facility. The appendix cannot be detailed or specific at this time since the ESF configuration is yet to be determined. However, it mentions Option #30 (modified) from the ESF Alternatives Study (AS) as YMPO's choice to resume ESF design. Appropriate generic text describe the Repository/ESF interface relationship. This appendix will continue to be developed and expanded to support the interface relationship as directed by DOE.

- Appendix A.2--This appendix contains drawings that show interfaces between the ESF and repository.
- Appendix A.3--This appendix contains sealing requirements imposed upon the ESF by the repository.
- Appendix A.4--This appendix contains thermal loads to be used for ESF design.
- Appendix A-5--This appendix contains seismic loads to be used for ESF design.
- Appendix B--This appendix contains general descriptions and requirements of the underground tests to be performed in the ESF and the requirements of the Integrated Data System (IDS). The tests are divided into two categories: (1) the suite of tests that will be recommended in any option being considered by the ESF Alternatives Study; (2) the suite of tests that are dependent on the configuration and location of the ESF. These will be addressed when an option has been approved. A list of the tests described is contained in the table at the beginning of the appendix.
- Appendix C--This appendix will list drilling requirements for the ESF.
- Appendix D--This appendix is reserved for future use.
- Appendix E--This appendix contains a listing of some known regulations, codes, standards, and DOE Orders which are applicable to the ESF.
- Appendix F--This appendix contains cross reference listings which allows the reader to determine the relationships between the ESFDR and 10 CFR 60. The listing of 10 CFR 60 contains all of those shown in WMSR Appendix E.
- Appendix G--This appendix contains the logic tree whose purpose is to map graphically the systems, functions and requirements for the ESF.
- Appendix H--This appendix contains the ESF Responsibility Matrix whose purpose is to identify the YMP Participant(s) responsible for designing and implementing per any given requirement in Volume 1 and those Participants who will provide support to the responsible Participant. Those requirements that have not been verified for traceability to a reference authority will have a NV in column 3.

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Those requirements that require qualification will have a TBD (to be determined) in column 3. Those requirements that have bounds, conditions or values that must be verified will be designated with a TBV (to be verified) in column 3. Requirements listed as TBD are to be sufficiently qualified by the organizations listed to remove the TBD. Requirements with values listed as TBV are to be verified by the organizations listed.

- Appendix I--This appendix contains a listing of information related to ESF performance assessment requirements and the current status of the performance assessment related requirements included in Volume 1 of the ESFDR.

- Appendix J--This appendix contains the relevant environmental requirements associated with the support of ESF design.

- Appendix K--This appendix contains the requirements developed by the DAA and shows the location of a corresponding statement in the ESFDR.

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT QUALITY ASSURANCE

All activities associated with the ESF shall be performed to applicable Quality Assurance requirements, and specific approved Quality Assurance Grading Report criteria for ESF items and activities. The basic Quality Assurance policy is established by the YMP Quality Assurance Requirements Document (DOE/RW 0214) and shall be implemented to provide assurance of quality in all phases of the ESF YMP. The latest revision of DOE/RW 0214 includes all Quality Assurance elements identified in the Code of Federal Regulations, Title 10, Part 50, Appendix B, and requires that each participating organization develop Quality Assurance program plans and procedures for all YMP activities.

ESFDR QUALITY ASSURANCE

The review and approval of this document was performed in accordance with QA programs that meet the requirements of 10 CFR 60, Subpart G. The review and approval process was performed in accordance with Sandia National Laboratories Procedure DOP 3-13, "Independent Technical and Management Reviews of Documents," and YMP Quality Management Procedures QMP-06-04, "YMPO Document Development, Review, Approval, and Revision Process." The assignment of quality assurance criteria to individual items and activities described in this document will be accomplished by Quality Assurance grading for specific items and activities. This document does not assign quality assurance criteria. All revisions of the ESFDR for resumption of design shall be performed under QA controls in accordance with DOE/RW 0214 criteria. The ESFDR is expected to be revised on an as-needed basis. Indicated changes, if any, resulting from program redirection or WMSR Vol. IV changes will be incorporated during the revisions.

ESFDR REQUIREMENTS TO BE VERIFIED/VALIDATED

Section

Some of the requirements contained in 1.2.6.0 through 1.2.6.9 and the Appendices may need to be verified or validated. Reference Appendix H and the explanation

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of the contents of Appendix H contained in this introduction for additional information.

ESFDR NUMERIC VALUES

The numeric values and units shown in this document are as they appear in the source material. Conversion to any other system or format is left to the user. The principal source of data in this document is the controlled Reference Information Base (RIB), DOE 1989, YMP Reference Information Base, latest issue YMP/CC-0002.

ESFDR VALUES STATED AS GOALS

Performance criteria and constraints expressed as goals are included to provide the designer insight into the importance of parameters that are significant in satisfying the requirements specified in 10 CFR 60. In the design process, it is expected that analyses will be performed to test the validity of these goals. If such analyses predict that the identified goals cannot be met with reasonably available technology, it will be necessary to evaluate the predicted values to ensure that they are acceptable from the repository performance perspective. If the predicted values are acceptable, associated ESFDR goals will be revised accordingly.

CHANGE PROCESS

All changes to this document must have concurrence of the YMPO. Changes required to this document will be evaluated to determine the area(s) of responsibility. Changes which are the responsibility of the Participant organizations will be completed by the responsible Participants.

ESFDR ORGANIZATION DIAGRAM

- **EXPLORATORY STUDIES FACILITY 1.2.6.0**
  - **SITE(S) 1.2.6.1**
    - MAIN SITE(S) 1.2.6.1.1
    - AUXILIARY SITE(S) 1.2.6.1.2
    - ACCESS ROADS 1.2.6.1.3
    - SITE DRAINAGE 1.2.6.1.4
  - **SURFACE UTILITIES 1.2.6.2**
    - POWER SYSTEM 1.2.6.2.1
    - WATER SYSTEM 1.2.6.2.2
    - SANITARY SYSTEM 1.2.6.2.3
    - COMMUNICATIONS SYSTEM 1.2.6.2.4
    - SURFACE WASTE-WATER SYSTEM 1.2.6.2.5
    - COMPRESSED AIR SYSTEM 1.2.6.2.6
    - SOLID WASTE DISPOSAL SYSTEM 1.2.6.2.7
  - **SURFACE FACILITIES 1.2.6.3**
    - VENTILATION SYSTEM 1.2.6.3.1
    - TEST SUPPORT FACILITIES 1.2.6.3.2
    - SITES PREPARATION FOR SURFACE STRUCTURES 1.2.6.3.3
    - PARKING AREAS 1.2.6.3.4
    - STORAGE FACILITIES 1.2.6.3.5
    - SHOP 1.2.6.3.6
    - WAREHOUSE 1.2.6.3.7
    - OTHER TEMPORARY STRUCTURES 1.2.6.3.8
    - COMMUNICATIONS/DATA BUILDING(S) 1.2.6.3.9
  - **SHAFT ACCESS 1.2.6.4**
    - COLLAR 1.2.6.4.1
    - LINING 1.2.6.4.2
    - STATIONS 1.2.6.4.3
    - FURNISHINGS 1.2.6.4.4
    - HOIST SYSTEMS 1.2.6.4.5
    - SUMP 1.2.6.4.6
  - **RAMP ACCESS 1.2.6.5**
    - PORTAL 1.2.6.5.1
    - LINING 1.2.6.5.2
    - STATION 1.2.6.5.3
    - RAMP FURNISHINGS 1.2.6.5.4
    - 1.2.6.5.5 (NOT USED)
    - SUMP 1.2.6.5.6
  - **UNDERGROUND EXCAVATIONS 1.2.6.6**
    - OPERATIONS SUPPORT AREAS 1.2.6.6.1
    - TEST AREAS 1.2.6.6.2
  - **UNDERGROUND SUPPORT SYSTEMS 1.2.6.7**
    - POWER DISTRIBUTION SYSTEM 1.2.6.7.1
    - 1.2.6.7.2 (NOT USED)
    - LIGHTING SYSTEMS 1.2.6.7.3
    - VENTILATION DISTR SYSTEMS 1.2.6.7.4
    - WATER DISTRIBUTION SYSTEMS 1.2.6.7.5
    - UNDERGROUND WASTEWATER COLLECTION SYSTEM 1.2.6.7.6
    - COMPRESSED AIR DISTR SYSTEM 1.2.6.7.7
    - FIRE PROTECTION SYSTEM 1.2.6.7.8
    - MUCK AND MATERIAL HANDLING SYSTEMS 1.2.6.7.9
    - SANITARY FACILITIES 1.2.6.7.10
    - MONITORING AND WARNING SYSTEMS 1.2.6.7.11
  - **UNDERGROUND TEST SUPPORT 1.2.6.8**
    - INTEGRATED DATA SYSTEM SUPPORT 1.2.6.8.1
    - TEST SUPPORT 1.2.6.8.2
  - **ESF DECOMMISSIONING AND CLOSURE 1.2.6.9**
    - SURFACE FACILITIES 1.2.6.9.1
    - ACCESSES & UNDERGROUND FACILITIES 1.2.6.9.2

Figure 1

ESFBS 009/5-31-91

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TITLE I DESIGN SUMMARY REPORT
REVISION 1
DRAFT H
VOLUME 5, APPENDIX

5.4 "Reference Information Base," Version 4, Revision 4, YMP/CC-0002

U.S. DEPARTMENT OF ENERGY

OCRWM

YUCCA MOUNTAIN

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

Document No. YMP/CC-0002
Revision 4
CI No. N/A
Date 04/08/91
WBS No. 1.2.1.3.3
QA Level N/A

PROJECT CCB CONTROLLED DOCUMENT

CONTROLLED COPY NO. 108 THIS IS A RED STAMP

THE YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

REFERENCE INFORMATION BASE

VERSION 4, REVISION 4

CHANGES TO THIS DOCUMENT REQUIRE PREPARATION AND APPROVAL OF A CHANGE REQUEST IN ACCORDANCE WITH PROJECT AP-3.3Q

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

UNITED STATES DEPARTMENT OF ENERGY
YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT OFFICE

The
Yucca Mountain Project
Reference Information Base

Version 4
Revision 4

Released April 1, 1991

YUCCA MOUNTAIN PROJECT REFERENCE INFORMATION BASE
VERSION 4
INTRODUCTION

The Reference Information Base (RIB) is a Project approved, controlled document that provides summary data and information to the Project. It is an evolving document that represents the best currently available technical information. Since this version of the RIB does not yet contain adequate information to complete many activities, including Title II ESF design, updates will be required. Information concerning the reference site, design, performance, and socioeconomic and environmental characteristics of the proposed Mined Geologic Disposal System at Yucca Mountain, Nevada, will be entered in the developing RIB.

The purpose of the RIB is to identify reference information to Project participants and to establish the consistent use of data for Project activities. With the exception of standard handbook information, use of the RIB is required for all technical data used in design and analysis activities that may be used in the licensing process. Project personnel are responsible for ensuring that the RIB information is used appropriately, and that the use of the RIB is documented, tracked, and controlled so that the impacts of future RIB changes can be evaluated. Use of sources other than the RIB requires written authorization by the Project Manager or his designee.

Since the content of the RIB continues to evolve for design and analysis purposes, it is important that Project personnel recognize their responsibility for identifying needed additions and modifications to the RIB. Project personnel may propose a change to the RIB by submitting a RIB Change Request (RIBCR) in accordance with AP-5.3Q, "Information Flow Into the Project Reference Information Base". A RIBCR is used both to request data which is needed to conduct an activity and to submit data (from the Project Site and Engineering Properties Data Base (SEPDB) and other sources) for incorporation into the RIB. Approved changes, which are processed in accordance with Project configuration management procedures, are periodically released for updating the RIB content.

The RIB has three chapters: (1) Site Characteristics, (2) Design Configuration, and (3) Performance Assessment Results. Each chapter is divided into sections of general topic areas. The sections are further subdivided into Information Items. An Information Item is entered in the RIB following Project Change Control Board approval. The most recent revision of each Information Item is indicated in the Table of Contents. The Topic Index is the primary means of locating specific information within the body of the RIB. The use of Information Items and the Topic Index allows the RIB to change and expand without disrupting the structure of the document.

The basic unit of the RIB is the RIB Information Item. A RIB Information Item is a complete unit of closely related information for a single topic, which is summarized in several pages. Revisions of the RIB between release of base versions will be made by the addition or replacement of RIB Information Items. Each RIB Information Item consists of (1) header change control identification, (2) a list of topic index keywords ("Keywords"), (3) a descriptive summary ("Description and Methodology"), (4) a description of the quality assurance associated with the information ("Quality Assurance Information"), (5) a listing of information sources ("Sources"), and (6) tabular and graphic summary information pertaining to the technical topic.

Any reference to RIB information should include the base version, item revision number, chapter, section, and item number, which are given in the header of each page of an Information Item. For example, Yucca Mountain stratigraphic information is referenced in the initial release of the fourth base version as RIB Version 4, Revision 0 of Item 1.1.1. A new base version of the RIB will be released either annually or at the initiation of major Project phases.

Keywords are listed on the first page of each Information Item to identify the information topics included in the Item and to establish a connection to the Topic Index.

The descriptive summaries, "Description and Methodology" and "Quality Assurance Information", are as important as the tabular and graphic information because they give relevant background information such as important assumptions and usage limitations. Because of the summary nature of the RIB, sources of more detailed data on which the RIB information is based are identified and pointed to by the RIB. These sources include specific SEPDB data, reference design drawings, and other interpretive reports. These more detailed data may be used subject to the limitations described in the RIB. However, if the use of these data would lead to a different interpretation than is presented in the RIB, submittal of a RIB Change Request is required to propose that the new information be added to the RIB.

Users of the RIB should recognize that many of the existing Project data were collected under procedures for which satisfaction of the requirements of 10 CFR 60, Subpart G, has not been demonstrated. The descriptions assist the user in determining the suitability of the information for specific uses and indicate the relationship of the summary information to the listed sources.

Information in the RIB is derived from a variety of sources, including published reports, and information developed for the RIB in accordance with documented development strategies as described in AP-5.3Q. The nature of these sources is identified and traceable to the supporting documentation record identified by the RIB Control Number given in the header.

YMP REFERENCE INFORMATION BASE
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CHAPTER 1. SITE CHARACTERISTICS

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TITLE I DESIGN SUMMARY REPORT
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5.5 "Site Characterization Program Baseline," YMP/CM-0011

U.S. DEPARTMENT OF ENERGY

OCRWM

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

Document No. YMP/CM-0011
Revision 1
CI No. CI.11.0000/CI.13.0000
Date 4/5/91
WBS No. 1.2.3
QA Level Yes

PROJECT BASELINE DOCUMENT

YUCCA MOUNTAIN SITE CHARACTERIZATION PROGRAM BASELINE (SCPB) VOLUME 1

CHANGES TO THIS DOCUMENT REQUIRE PREPARATION AND APPROVAL OF A CHANGE REQUEST IN ACCORDANCE WITH PROJECT AP-3.3Q

UNITED STATES DEPARTMENT OF ENERGY
YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT OFFICE

INFORMATION COPY

Y-AD-057
9/90

YUCCA MOUNTAIN PROJECT CHANGE DIRECTIVE (CD)

1 CR No. 91/052
Page 1 of 2

SECTION I. IDENTIFICATION

2 Title of Change:
Submittal of the "Site Characterization Program Baseline, Rev. 1," for CCB Control

3 Change Classification:
☐ Class 1 ☐ Class 3
☒ Class 2

SECTION II. DISPOSITION

4 CR Disposition:
☐ Approved
☒ Approved with Conditions
☐ Disapproved

5 Conditions: *(if applicable)*

The next revision of this document should incorporate the following items:

1. The term "Exploratory Shaft Facility" should be replaced by "Exploratory Studies Facility" throughout the document.

2. The term "repository" should be replaced by "potential repository" throughout the document.

(See Change Documentation Continuation Page ___)

6 Implementation Direction: *(if applicable)*

1. This Change Request (CR) is approved for CCB Baselining as the "Site Characterization Program Baseline, Revision 1," and is assigned Controlled Document number YMP/CM-0011.

2. The Director, Regulatory and Site Evaluation Division is responsible for ensuring the above listed conditions are incorporated into the next revision of Document YMP/CM-0011.

(See Change Documentation Continuation Page 2)

SECTION III. CONCURRENCE

7 Quality Assurance Organization Concurrence

Name: D. G. Horton (print)
Org.: PQA (print)
Signature: N. Voltura for DG Horton
Date: 3/28/91

8 Disposition Authority

Name: M. B. Blanchard (print)
Title: CCB Chrprsn (print)
Signature: Robert [illegible] For Maxwell Blanchard
Date: 3/28/91

9 Effective Date: 3/28/91

6 Implementation Direction (continued)

3. The CCB Secretary shall ensure that the Cover Page and the Title Page for Document YMP/CM-0011, Revision 1, are prepared.

4. The Document Originator shall provide a Print Ready Copy of YMP/CM-0011, Revision 1, to the CCB Secretary. The Document Number and Revision Number will be identified on each page of the Publication Ready Document, YMP/CM-0011.

5. The CCB Secretary shall ensure that YMP/CM-0011, Revision 1, is prepared in accordance with this Change Directive (CD). The CCB Secretary shall ensure the Document Change Notice (DCN), indicating changes made in the document, is prepared. The DCN will be attached to the front of the Print Ready Copy of the document. The CCB Secretary shall also prepare a Controlled Document Issuance Authorization (CDIA) to transmit this CD, the DCN, and YMP/CM-0011, Revision 1, to the Project Document Control Center (DCC) in accordance with AP-1.5Q.

6. Per AP-3.3Q, each TPO and Project Office Division Director will complete an Affected Document Notice (ADN) as notification of completion of implementation planning for this CD.

7. The CCB Secretary shall ensure that the Configuration Information System (CIS) and the CCB Register are updated to reflect Revision 1 to YMP/CM-0011.

8. Any changes to document YMP/CM-0011, Revision 1, will require submittal of a CR to the Project CCB.

9. Upon release of YMP/CM-0011, Revision 1, all Project Participants will be required to use YMP/CM-0011, Revision 1, in performing duties applicable to this document.

Y-AD-059
9/90

YUCCA MOUNTAIN PROJECT
DOCUMENT CHANGE NOTICE (DCN) RECORD

1 Document Title:

Site Characterization Program Baseline

2 Document Number:
YMP/CM-0011

The document identified in Blocks 1 and 2 has been changed. The changed pages attached to this DCN are identified in Block 7 opposite the latest DCN number in Block 3. The original issue of this document as modified by all applicable DCN's constitutes the current version of the document identified in Blocks 1 and 2.

3 DCN NO.	4 CR NO.	5 DOCUMENT Rev./ICN #	6 CR TITLE	7 AFFECTED PAGES	CHANGE	ADD	DELETE	8 DATE
001	91/052	Rev. 1	Submit SCPB, Rev. 1 for CCB Control (complete revision of information related to ESF design)	All	X			4/5/91

Department of Energy
Yucca Mountain Site Characterization
Project Office
P. O. Box 98608
Las Vegas, NV 89193-8608

WBS 1.2.9
QA: N/A

MAR 20 1991

Distribution

RENAMING OF EXPLORATORY SHAFT EFFORT

As a consequence of the instructions from Dr. John W. Bartlett, Director of the Office of Civilian Radioactive Waste Management, on February 12, 1991, about the redirection of Yucca Mountain Site Characterization Project efforts associated with the Exploratory Shaft Facility design effort, it has become apparent that retaining the name of Exploratory Shaft would be somewhat misleading when the current design studies are focusing upon ramps, and a shaft is only being considered as a possible backup.

Therefore, after considerable discussion with many parties about selecting a new name, I have concluded that the most appropriate approach for now is to change the name of Exploratory Shaft Facility (ESF) to Exploratory Studies Facility (ESF). As you can observe, the acronym remains the same but "Shaft" becomes "Studies."

For all future communication, I request that you use this new name for this very important facility. We do not plan on modifying any completed documents or sending out errata sheets. I do request that all new communications within the U.S. Department of Energy's program now refer to this facility as the Exploratory Studies Facility. I thank you for your cooperation.

Carl P. Gertz
Project Manager

YMP:MBB-2814

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SITE CHARACTERIZATION PROGRAM BASELINE

REVISION 1

Submitted:

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Technical and Management
Support Services Project Manager

Date 3/26/91

Approved:

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Date 3/27/91

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The numbering scheme used in this table of contents reflects that the numbering of the Site Characterization Plan has been preserved to maintain consistency among related documents. Sections 8.5 and 8.6 have been intentionally excluded.

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8.0 INTRODUCTION

This chapter presents the Department of Energy's (DOE) plans for the site characterization program to be conducted at the Yucca Mountain site in the State of Nevada. Such a program is required by the Nuclear Waste Policy Act of 1982, by the regulations promulgated for geologic repositories by the U.S. Nuclear Regulatory Commission (NRC) in 10 CFR Part 60, and by the DOE's general guidelines for siting repositories, promulgated as 10 CFR Part 960. These legal requirements are summarized in the general introduction to this document, which also discusses the DOE's compliance with them.

The DOE expects to modify these plans as more information about the potential repository system becomes available. (NOTE: Throughout this document, the use of the term "repository" refers to a potential repository at the Yucca Mountain site, assuming the site is found to be suitable.) The data collected during site characterization will be used in the design of the repository and the waste package, as well as in the analyses of system performance. Characterization, design, and performance assessment activities will all be conducted during site characterization. These activities will depend on each other; for example, the data collected from the site will be used in designing the repository, while the design of the repository will be considered in determining the needed tests and analyses. The site characterization program will be modified, as needed, to meet newly developed design and performance requirements and in response to the data obtained from site characterization itself.

As site characterization proceeds, the results of investigations and any changes to plans will be reported to the NRC, the State of Nevada, and the general public through semiannual progress reports and technical reports. As the DOE revises its plans, it will do so in consultation with the NRC, the State of Nevada, and the general public. The DOE expects that this process will help to develop a consensus among the DOE, the NRC, the State of Nevada, and the general public that will lead to the early resolution of issues as part of the siting and licensing process.

The remainder of this introduction is devoted to two topics: the organization and content of Chapter 8 and the top-level strategy that describes the role the features of the site are expected to play in accomplishing the general objectives for the disposal system.

Organization and content of Chapter 8

Chapter 8, called Part B of the SCP, builds on the existing information about the site (the information that is reported in Chapters 1 through 5 of Part A) and on information about the conceptual designs of the repository and the waste package (the designs of the repository and the waste package are described in Chapters 6 and 7 of Part A, respectively). The information presented in Part A not only summarizes the current technical knowledge about the site, but also constitutes part of the basis for defining the information that needs to be obtained during site characterization. Chapter 8 describes the DOE's plans for the characterization of the Yucca Mountain site.

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The first three sections of Chapter 8 present the rationale for the site characterization program and develop from that rationale a detailed description of the tests to be conducted during the program. The discussion that follows describes the content of those sections.

The site characterization program has three principal purposes:

- To provide the data to be used to determine the suitability of a site.

- To provide the data needed for licensing.

- To provide the data for design of the repository and the waste package.

In planning a program to achieve these purposes, the DOE has adopted an approach that starts with the regulatory requirements that must be satisfied in siting and licensing the repository, identifies the performance and design information needed to address those requirements, and then develops specific investigations to obtain the needed information. This approach is embodied in an issue resolution strategy, which is discussed in some detail in Section 8.1. An important part of this strategy is an issues hierarchy (Section 8.1.1) that consists of key issues, issues, and information needs. The key issues and issues are based on the regulatory requirements that govern a repository. The information needs define the data and analytical techniques that are needed to resolve each issue. The DOE expects that satisfying the information needs will resolve the issues and that the resolution of the individual issues will lead to resolution of the key issues. Issue resolution is not likely to provide complete assurance that performance of the repository system will be acceptable. A reasonable assurance of acceptable performance is the general standard that will be met. The strategy described here and in Section 8.1 will be applied in an iterative manner to develop confidence throughout the licensing phases. The concept of reasonable assurance is discussed later in this section.

Another important part of the issue resolution strategy and the development of information needs for the issues is the "performance allocation" process, discussed in Section 8.1.2. Performance allocation consists of deciding which repository-system elements will be relied on in resolving an issue, identifying the functions that the elements will be expected to perform and the processes that will affect the performance of each element, making specific quantitative statements about the expected performance, and developing a testing program to obtain the needed information about the performance. The issue resolution strategy will guide the development of the programs for testing and analysis; it will help to make clear what tests and analyses are necessary. As the characterization of the site proceeds and more information becomes available, the strategy will be refined to support site selection and licensing.

Section 8.2 serves both as a summary of the overall strategy for resolving the issues and an introduction to the individual issues. It presents the issues to be resolved and their information needs. Section 8.3 then presents the complete strategies for issue resolution and describes the planned investigations to be conducted during site characterization. This section is

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organized into five sections around the major programs: site, repository, seals, waste package, and performance assessment.

The site program is discussed in Section 8.3.1. Organized by technical disciplines, this section describes the investigations, studies, and activities to be carried out to resolve the design and performance issues in the issues hierarchy. The site program is designed to reduce uncertainty about site properties and conditions and to reduce uncertainty in the conceptualization of the site physical system. Systematic hypothesis testing is being used to discriminate between alternative conceptual models by eliminating untenable or nonviable hypotheses.

The repository program is described in Section 8.3.2, which provides detailed resolution strategies for the repository design issues. The section identifies the site information and the design activities needed for issue resolution.

The seal program is covered in Section 8.3.3, which identifies the activities required to develop designs and demonstrate the performance of seals to be placed in shafts, ramps, drifts, and boreholes.

The waste package program is discussed in Section 8.3.4. This section presents the detailed issue resolution strategies for the issues that deal with the design of the waste package. The section identifies the site information and the design activities needed for issue resolution.

Section 8.3.5 presents the performance assessment program. Strategies to address the preclosure and postclosure performance issues and discussions of the analytic techniques needed for the safety and performance assessments for these strategies are presented. The section identifies the site information and the performance assessment activities needed for resolving the issues.

Much of the information presented in Section 8.3 is summarized in performance allocation and hypothesis testing tables. A careful study of these tables will provide an understanding of the information to be provided by the site program and the intended use of this information for resolving the design and performance issues.

The plans for surface-based activities and for subsurface excavations related to implementing the site characterization program described in Section 8.3 are presented in Section 8.4. This section also discusses the potential impacts on the integrity of the site as a result of conducting these activities. Section 8.4 is divided into three parts. The first section, 8.4.1, presents background information on the approach adopted by the DOE to guide the characterization program, gives the approach to incorporating the requirements of 10 CFR Part 60 into the development of the testing program, and discusses the concepts of flow in the unsaturated zone. The rationale for the planned testing is presented in Section 8.4.2, which also describes the surface testing and the underground test facility and evaluate whether construction or operation of facilities or the conduct of the tests is likely to adversely impact the results of site characterization activities. Section 8.4.3 evaluates the impact of the testing program on the

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integrity of the site by considering its potential impacts on the postclosure performance objectives.

Section 8.7 presents general plans for decontamination and decommissioning of the Yucca Mountain site in the event the site were found to be unsuitable for a repository. That section also contains general plans for mitigation of any significant adverse environmental impacts that may be caused by site characterization.

Top-level strategy

This section presents the "top-level strategy," that is, a brief explanation of the role the features of the Yucca Mountain site are expected to play in achieving the general objectives for the system. As a consequence of this role, which will be explained, the program for characterizing the site places considerable emphasis on the range of expected flow conditions in the unsaturated rocks in which the waste would be emplaced. The program also emphasizes the geochemistry and other characteristics of the unsaturated rocks. These characteristics could affect performance of the waste packages and radionuclide transport through the unsaturated rocks. In addition, the geohydrology of the saturated rocks deep beneath the site will be characterized. Reliance on these features requires the investigation of any disruptive processes and events that might alter the features. The top-level strategy also emphasizes pre-closure radiation safety and the effects of seismicity on the surface and underground facilities. This section discusses the basis for the emphasis on these features in the site characterization program.

The principal role of a disposal system is to isolate waste for a long period into the future. Therefore, the general objective for the entire system is to limit any radionuclide releases to the accessible environment. This objective will be achieved by selecting a site that contains natural barriers against radionuclide releases and by providing an appropriate system of engineered barriers. To provide additional insurance that the system will perform adequately, individual objectives have also been defined for the engineered and natural barriers to radionuclide release and for the design of the disposal system. The general objective for the engineered barriers is that they should limit the release of radionuclides to the natural barriers. The general objective for the natural barriers is that the time of travel of significant quantities of radionuclides through these barriers to the accessible environment should be very long. In particular, since ground water may transport radionuclides, the ground-water travel time should be very long. The general objectives for the design of the disposal system are that its operation should be safe and that its construction should not compromise its ability to meet the other general objectives.

These general objectives are compatible with the regulations promulgated by the NRC in 10 CFR Part 60. In the regulations, the NRC specifies postclosure performance objectives, including the environmental standards anticipated to be set by the Environmental Protection Agency for releases to the accessible environment, individual protection, and ground-water protection; requirements on the containment to be provided by the set of waste packages and on the rate of release of radionuclides from the engineered-barrier system; and an objective for the pre-waste-emplacement ground-water travel

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time. The regulations also specify design criteria for the disposal system to ensure the postclosure performance objectives would be met, and they set preclosure objectives for radiation protection. Detailed strategies that explicitly address the NRC regulations are presented in Sections 8.1, 8.2, and 8.3. The remainder of this section describes the top-level strategy to address the general objectives for the disposal system.

General objective for the disposal system

The major system elements that are expected to affect waste isolation at the Yucca Mountain site can be seen in Figure 8.0-1. As explained in detail in Chapter 3, the currently available information suggests that only small amounts of water are available to percolate slowly downward through Yucca Mountain. If the Yucca Mountain site is developed for a repository, water that moves through the unsaturated rock above the repository could continue down to the unsaturated rock unit in which the underground repository would be constructed. If any of this water could reach the emplaced waste, it might dissolve radionuclides and carry them in solution through the unsaturated rock below the repository to the saturated rock that underlies the unsaturated zone. After reaching saturated rock (Figure 8.0-1), the water joins the much larger, horizontal flow there. Radionuclides that are carried by the water could therefore be transported by the flow in the saturated zone and move toward the accessible environment.

To reach the emplaced waste, the water would have to penetrate the engineered-barrier system. For the purposes of defining the top-level strategy, the major elements of this system are the container and the waste form inside the container. There would also be an air gap between the container and the wall of the borehole in which the container would be emplaced.

This sequence of events--downward water movement, water penetration into the engineered-barrier system, downward transport of radionuclides to saturated rock, and horizontal transport--provides a way by which radionuclides could move from the Yucca Mountain repository to the accessible environment. According to the available evidence, the percolation flux at and below the repository horizon is very low. Furthermore, it appears that the percolation of water through the unsaturated rock units at this depth is primarily in the rock matrix rather than through fractures. If the water is retained within the rock matrix, as it appears to be, the water would not be expected to move from the rock across the air gap to the waste container; the water would, therefore, not be expected to reach the waste. Furthermore, the results of preliminary studies have suggested that the quantity of moving water is so small that any corrosion of the disposal container and dissolution of radionuclides would be limited even if the water could cross the air gap. The evidence also suggests that the movement of water in the rock matrix is very slow and that, therefore, the transport of any radionuclides dissolved in this water downward through the unsaturated rocks below the repository would be very slow. An additional characteristic of the unsaturated rock and the water is their geochemistry, which will determine the radionuclide dissolution and the retardation of radionuclide transport.

Therefore, the elements of the system that the DOE will investigate in the site characterization program to evaluate the system with respect to the general objective are

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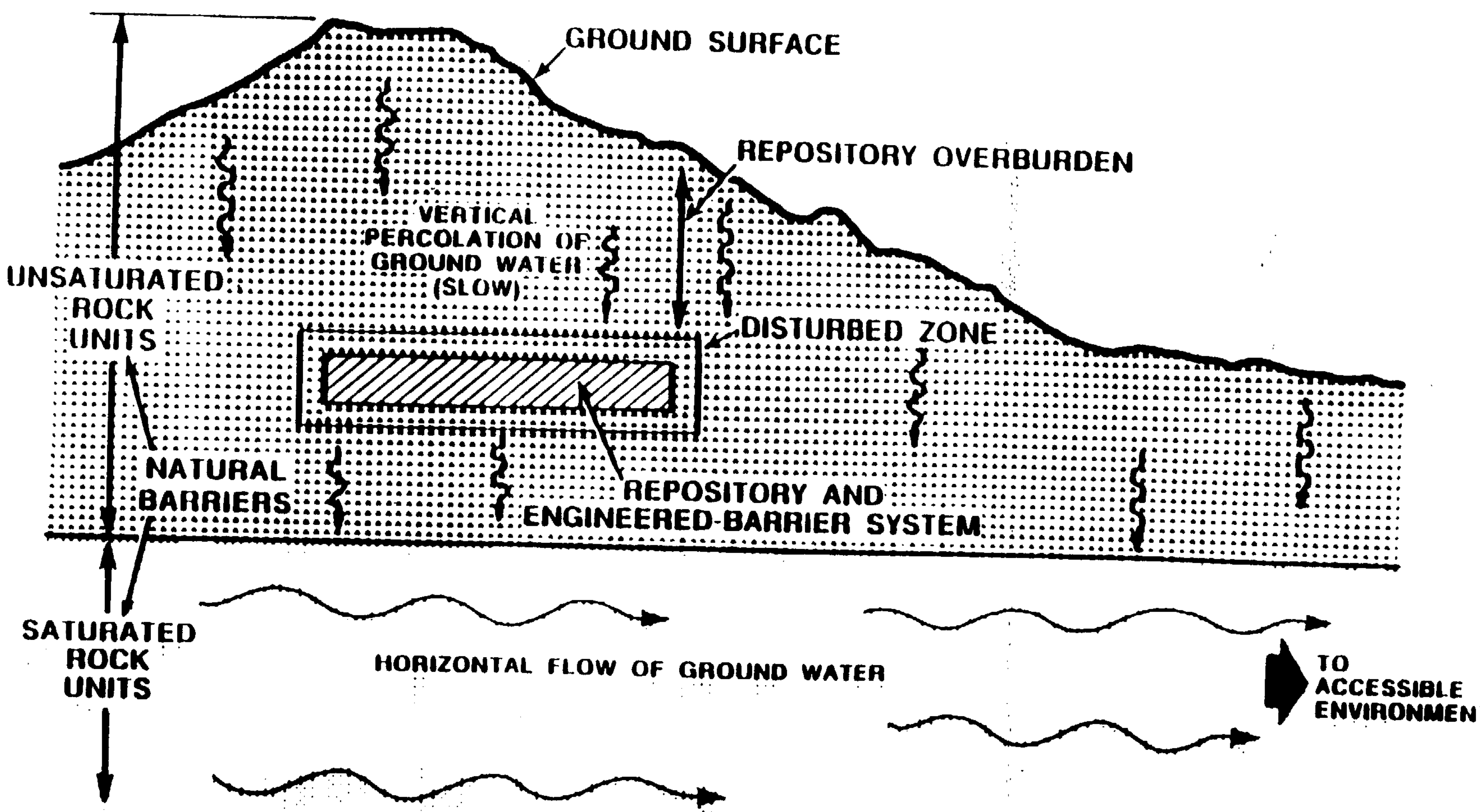

Figure 8.0-1 Major system elements exp[illegible]o affect waste isolation at the Yucca Mountain site

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- The unsaturated rock units.
- The saturated rock that lies below the unsaturated rock.
- The engineered-barrier system.

Concentrating on the characteristics of only one of these features, such as the slow movement of water through the unsaturated rocks below the repository, could reduce the cost of the site characterization program. The DOE has decided, however, that it is prudent to consider initially the characteristics of all three of these features. Future evidence may show, for example, that the current estimates of ground-water travel time are too long. If so, the DOE's strategy may need to focus on the other features. Choosing all of these features is a way of dealing with the uncertainties in each of them; it ensures that the site characterization activities, guided by the strategy, will collect the data needed to evaluate the site with respect to the general objective. Analyses conducted during site characterization may indicate that other features may need to be considered as well. Conversely, information obtained during site characterization may show that fewer features need to be taken into account. In either case, the top-level strategy can be revised appropriately.

One further sequence of events might contribute to a release under the current conditions at Yucca Mountain. If the waste containers were breached, radionuclides that exist in the waste in gaseous form might move upward through the air spaces in the unsaturated rock above the repository. They might then reach the accessible environment at the ground surface above the repository. The available information is not complete enough to decide definitively whether this sequence is capable of producing significant releases. It is not clear, for example, that the waste form can release gaseous radionuclides rapidly enough or in sufficient quantities to be important. The DOE will evaluate the potential for gaseous release to determine the significance of this mode of release. The elements of the system that may affect gaseous releases at the site are the unsaturated rock above the repository and the engineered-barrier system. The current evidence is not sufficient to indicate if the unsaturated rock would be effective. The available evidence does suggest, however, that the waste form is likely to allow only negligible amounts of volatile radionuclides to escape. The top-level strategy, therefore, focuses primarily on the ability of the engineered-barrier system to limit the rate of release of gaseous radionuclides.

General objective for performance of the engineered-barrier system

The general objective for the engineered-barrier system is to limit release of radionuclides to the natural barriers. In the top-level strategy, the DOE has chosen to focus on three particular components to evaluate the performance of the engineered-barrier system.

- The air gap between the container and the host rock.
- The container.
- The waste form.

The container is expected to provide the principal barrier to the release of radionuclides from the engineered-barrier system. This barrier will be designed to provide substantially complete containment of the wastes during the early period when the heat and radiation emitted by the waste are

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at their peak. The limited availability of water in the unsaturated zone is expected to contribute to the ability of the container to limit the release of radionuclides to the natural barriers. In addition, the container materials will be chosen to be compatible with the geochemistry of the water in order to limit degradation of the containers in contact with any water.

The air gap between the container and the host rock is expected to increase the ability to limit the release of radionuclides. That is, because the percolation flux is expected to be low and because the water is expected to be retained in the rock matrix, little water would be available to leave the rock and cross this air gap. Therefore, the amount of water available to contact the waste packages is expected to be even less than the small amount in the host rock.

The waste form is chosen as an additional barrier to limit the rate of radionuclide release from the engineered-barrier system. Because of the low probability of early container failure and because of the small quantities of water available for waste-form dissolution and the leaching of radionuclides, the spent fuel or glass matrix is expected to limit the rate of release.

General objective for the performance of the natural barriers

As explained above, one natural barrier within the geologic setting that can contribute to the isolation of the waste and to the overall system performance is the long ground-water travel time to the accessible environment. The DOE has chosen to focus on two barriers to determine the ground-water travel time:

- The unsaturated rock units below the repository.
- The saturated rock below the unsaturated rock.

The current evidence suggests that the travel time from the repository through the unsaturated units to the saturated zone is longer than 10,000 yr. Furthermore, many of the radionuclides important for waste isolation will have an even longer travel time than the ground water because of geochemical and mechanical retardation processes. Therefore, these units are expected to provide an effective barrier to radionuclide transport. According to the available evidence, the saturated rock units can add at least a few hundred years and possibly a few thousand years to the total time that radionuclides would take to move to the accessible environment.

General objectives for the design of the disposal system

The general design objectives to ensure safe operation without compromising the ability to meet the other general objectives have a number of implications for the site characterization program. In particular, the surface and underground facilities must be designed to withstand potential ground motion or surface rupture at the site. The available evidence suggests that the design can accommodate the range of seismic activity expected at the site. Information regarding the expected frequency and magnitude of earthquake-related activity at the site will be needed to support the detailed design.

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The design of the repository system must also address radiation protection of the surface and underground facilities. It is expected that standard techniques will be adequate to assess preclosure radiation safety. Although these assessments will not rely heavily on features of the site, some investigations will be conducted to support them.

Priorities for the site characterization program

Priorities for the testing program can be inferred from the choices made for the top-level strategy, that is, the elements identified and the expected role of these elements with regard to the general objectives suggest the priorities for the investigations in the site characterization program. The top-level strategy to address these objectives at the Yucca Mountain site leads to the following areas of emphasis:

- Unsaturated-zone flow characteristics.
- Site characteristics (e.g., geochemistry) affecting performance of the container and the waste form and transport of the radionuclides in the unsaturated zone and the geohydrologic characteristics of the saturated rocks that underlie the unsaturated zone.
- Unlikely processes or events that disturb site characteristics.
- Preclosure radiation safety and the effects of seismicity on the surface and underground facilities.

The top-level strategy focuses strongly on the investigations of the characteristics of the flow in the unsaturated zone, relying heavily on the current view that the percolation flux is low and that the water in the unsaturated zone is tightly confined within the rock matrix. If these concepts can be confirmed, then the general objective for the system and for the postclosure performance of the engineered and natural barriers are very likely to be met. Therefore, the investigations of these concepts have the highest priority in the program. As part of these investigations, the program will address alternative concepts including flow in fractures, lateral movement of water at rock interfaces in the unsaturated zone, and the effect on the flow of structural features such as faults. The ability of the unsaturated rock to hold water and limit contact of water with the waste packages will also be investigated.

Because of uncertainties in these concepts and to add confidence that the general objective will be met, other site characteristics will also be investigated. The top-level strategy also places emphasis on other characteristics of the site as discussed above. Therefore, at a somewhat lower level of priority, the program will give attention to the geochemistry and other characteristics of the unsaturated rocks that may affect the performance of the waste packages and the transport of radionuclides in the unsaturated rocks and the geohydrology of the saturated rocks deep below the site.

The design of the repository system must address preclosure concerns such as the effect of seismic activity. Accordingly, an extensive program to investigate seismicity affecting the site is planned. This program will

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evaluate the probability and magnitude of ground motion and potential surface rupture at the Yucca Mountain site.

The site characterization program must also address those processes and events that might occur in the future and disrupt the site characteristics important to waste isolation. For example, the possibilities for extreme climatic changes or faulting will be investigated to evaluate effects on percolation, local flux, and the altitude of the water table in relation to the repository horizon. The probability of occurrence and the potential effects of volcanism on the characteristics of the site will also be investigated. The following is a general list of the disruptive processes and events that present data suggest are sufficiently credible to warrant consideration:

1. Extreme climate change.
2. Stream erosion.
3. Faulting and seismicity.
4. Magmatic intrusion.
5. Extrusive magmatic activity.
6. Extensive irrigation.
7. Intentional ground-water withdrawal.
8. Exploratory drilling.
9. Resource mining.
10. Climate control.
11. Surface flooding and impoundments.
12. Regional changes in tectonic regime.
13. Folding, uplift, and subsidence.

This description of the general priorities that the top-level strategy leads to serves primarily as a broad introduction to the detailed discussions in Sections 8.1. through 8.4. Readers who wish to understand fully the planned investigations and the reasons for them must consult those sections, which provide complete strategies, derive investigation plans from the strategies, and explain the investigations in detail.

TITLE I DESIGN SUMMARY REPORT
REVISION 1
DRAFT H
VOLUME 5, APPENDIX

5.6 Yucca Mountain Administrative Procedure AP-5.19Q, Interface Control

YUCCA MOUNTAIN PROJECT OFFICE
DOCUMENT APPROVAL SHEET

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Y-AD-002
4/90

Title
ADMINISTRATIVE PROCEDURE: INTERFACE CONTROL

NO. AP-5.19Q
[X] Q
[ ] Non Q

APPROVAL

PROJECT MANAGER: Original signed by	Carl Gertz Signature	6/8/89 Date
DIRECTOR OF QUALITY ASSURANCE:	Edwin L. Wilmot Signature	6/7/89 Date
N/A (OTHER, AS REQUIRED)	N/A Signature	N/A Date

REVISION 0 EFFECTIVE DATE: 6/15/89

REVISIONS

	INITIAL AND DATE			
	REVISION 1	REVISION 2	REVISION 3	REVISION 4
for PROJECT MANAGER:	10/19/90			
DIRECTOR, QA:	DW for DG Horton 10/18/90			
N/A (OTHER, AS REQUIRED)	N/A			
EFFECTIVE DATE:	10/19/90			

Title
ADMINISTRATIVE PROCEDURE: INTERFACE CONTROL

1.0 PURPOSE AND SCOPE

1.1 PURPOSE

The purpose of this procedure is to provide the instructions for the management of Level C&D interfaces on the Yucca Mountain Project (Project) as required in the Configuration Management Plan, YMP/88-4.

1.2 SCOPE

This procedure includes identification, development, approval, control, and changes to Level C&D (See Attachment 1) interfaces.

2.0 APPLICABILITY

This procedure applies to all Project Participants and activities conducted during scientific investigations and testing in support of site characterization and other design and construction activities. Any Project employee can identify a need for an interface.

3.0 DEFINITIONS

NOTE: Terms in this procedure are used as defined in the Project Glossary. The following additional definitions are adopted for the purpose of this procedure.

3.1 DATA REQUESTOR

A Data Requestor is a person and/or organization requesting one or more Participants to provide interface data and/or support. All requests shall be processed through the requesting organization's Interface Control Working Group (ICWG) Representative. For clarity, each mention of Data Requestor or Requestor in this procedure means Data Requestor's ICWG Representative.

3.2 DATA SUPPLIER(s)

A Data Supplier(s) is one or more Participants providing data to the Data Requestor as requested and documented by the Interface Control Documentation. All data shall be supplied through the supplying organization's ICWG Representative. For clarity, each mention of Data Supplier or Supplier in this procedure means Data Supplier's ICWG Representative.

3.3 INFORMATIONAL/ORGANIZATIONAL INTERFACE

An informational interface, also referred to as an organizational interface, is a controlled process used to officially request, document, and transfer information between various Project organizations (Participants) that must share and/or transfer information. This information is usually technical in nature (e.g., scientific data) and is used for technical studies, design analysis, safety analysis, environmental impact, scientific investigation, and testing involving two or more Participants.

One type of informational interface is an information hold. An information hold defines the point at which one activity cannot proceed without appropriate input from another activity.

3.4 INTERFACE

An interface is the physical, functional, and software boundary between two or more systems, pieces of equipment, facilities, or computer programs, or within a system between two or more design Participants, or the transfer of information between two or more design Participants who must share data/information.

3.5 INTERFACE CONTROL DOCUMENT

An interface control document (ICD) is a document/drawing, i.e., Component Interface Document (CID), System Interface Drawing (SID), Interface Revision Notice (IRN), or Interface Memorandum of Understanding (IMOU), used to establish and control physical, functional, and software design requirements at selected interfaces, and to define, record, and control technical and/or informational requirements between interfacing Participants and organizations. An ICD shall not be used to procure, fabricate, assemble, install, or test parts or to otherwise perform any manufacturing function.

3.6 INTERFACE MEMORANDUM OF UNDERSTANDING

An IMOU is a controlled document used to establish, define, document, and control informational and organizational interface requirements.

3.7 INTERFACE REVISION NOTICE

An IRN is a controlled document used to define or describe new physical interface requirements or to change existing physical interface requirements. Until approved, the IRN is a Proposed IRN (PIRN). When approved by the Project, the PIRN becomes an IRN and is attached to the ICD until incorporated by revision to the ICD.

3.8 PHYSICAL INTERFACE

A physical interface is the place where the boundaries of two or more systems, subsystems, or components intersect. A physical interface is the place where there is a flow of material, energy, or information between two or more systems, subsystems, or components. The form, fit, function, and software of one depends on the form, fit, function, and software of the other. The interactions at this boundary must be controlled for the system to function, be effective, or be efficient.

3.9 PROCESSOR

The Processor, as designated by the Yucca Mountain Project Office (Project Office) as the responsible agent for all Project Level C&D interface development and coordination shall, as requested by the Project Office ICWG Chairperson, coordinate interface documentation to obtain appropriate concurrence of the interfacing Participants.

3.10 INTEGRATION

Integration is a function assigned by the Project Office to the T&MSS ICWG representative, for integration support, to provide technically coordinated input to the ICWG for its evaluation of interface control documentation.

4.0 RESPONSIBLE PARTIES

The following Project individuals and organizations are responsible for the activities identified in Section 5.0 of this procedure:

1. Data Requestor
2. Processor
3. Participant Technical Project Officer (TPO)
4. ICWG
5. ICWG Chairperson
6. Data Suppliers
7. Evaluators (Work Breakdown Structure (WBS) Coordinators, Data Supplier, Data Requestor)

5.0 PROCEDURE

NOTE: A flowchart of the following processes described in this procedure is attached as Figure 1.

RESPONSIBLE PARTY	STEPS	PROCEDURE
		IDENTIFICATION AND EVALUATION
Data Requestor	1.	Identify interface requirement.
Data Requestor and Processor	2.	Determine if interface is informational/organizational or physical.
Data Requestor	3.	Define necessary interface data through coordination with affected Participants and Integration.
	4.	For informational/organizational interface, complete the following:
		a. Fill out an IMOU (see Attachment 2).
		b. Obtain an interface control number from the Processor. Send the IMOU to the Processor.
	5.	For physical interfaces, complete the following (See Attachment 3):
		a. Document the engineering data on the appropriate interface document (SID and/or CID).
		b. Fill out a PIRN (See Attachment 4).
		c. Attach engineering data to the PIRN.
		d. Obtain a PIRN identifier number and ICD drawing number(s) from the Processor. Send the PIRN package to the Processor.

RESPONSIBLE PARTY	STEPS	PROCEDURE
Processor	6.	Process the IMOU and/or PIRN package as follows: a. Review for completeness, clarity and Project authority (e.g., Work Breakdown Structure). b. Assign a Software/Configuration Item number as required. c. Enter the applicable information into the Configuration Information System (CIS).
	7.	Send copies of the IMOU and/or PIRN to Evaluators.
Evaluators (WBS Coordinators, Data Supplier, Data Requestor)	8.	Perform the following activities: a. Evaluate the IMOU and/or PIRN from an overall integration viewpoint in terms of completeness, clarity, technical compatibility, quality affecting, and justification, and impact on Program level, Project Baseline, Change Control Board (CCB)-controlled documents and other IMOUs or PIRNs. b. If the IMOU and/or PIRN are acceptable, sign and return original signature document (front sheet only) to the Processor. Go to Step 9. c. If the IMOU and/or PIRN has unresolved issues, the Evaluator identifying the unresolved issue shall document the reason for the rejection and send to the other Evaluators, ICWG Chairperson, and Processor. Go to Step 31.

Title
ADMINISTRATIVE PROCEDURE: INTERFACE CONTROL

RESPONSIBLE PARTY	STEPS	PROCEDURE
		d. If the IMOU and/or PIRN cannot be signed due to impact on Program level, Project Baseline or CCB-controlled documents (controlled documents) the Evaluator identifying the impact shall document the reason for the impact and send to the other Evaluators, ICWG Chairperson, and Processor. Go to Step 37.
Processor	9.	For informational/organizational interfaces, go to Step 10. If interface is physical, go to Step 21.

INFORMATIONAL/ORGANIZATIONAL INTERFACE WITH NO UNRESOLVED ISSUES AND NO IMPACT ON CONTROLLED DOCUMENTS

	10.	Send the IMOU to distribution and to the Local Records Center (LRC).
Data Supplier	11.	Compile and send data to the Requestor. Send a copy of the transmittal letter only to Processor for IMOU closeout.
Processor	12.	Transcribe the letter number on the IMOU, update the CIS, transmit the IMOU to the Requestor for data acceptance signature.
Data Requestor	13.	Perform the following activities: a. If data is unacceptable, document reason for rejection, and send rejection to Data Supplier, ICWG Chairperson, and Processor. Return unsigned IMOU to Processor. Go to Step 39. b. If data is acceptable, go to Step 14.
	14.	Sign the IMOU for data acceptance. Return the signed IMOU to Processor.

RESPONSIBLE PARTY	STEPS	PROCEDURE
Processor	15.	Update the CIS; send the IMOU to distribution and to the LRC.
WBS Coordinators	16.	Upon notification of data acceptance (Refer to Steps 14 and 15) coordinate with ICWG Representatives as required, Field Operations, and the Technical Data Manager, as a minimum, to determine if other Project-controlled or Program-level documents are affected by the data. Inform the Processor and ICWG Chairperson in writing of the determination. If yes, go to Step 18. If no, go to Step 17.

INFORMATIONAL/ORGANIZATIONAL INTERFACES NOT AFFECTING OTHER DOCUMENTS

Processor	17.	Update the IMOU indicating no affect on other documents. Update the CIS indicating that the IMOU is closed; send the IMOU to distribution and to the LRC. Stop the process.

INFORMATIONAL/ORGANIZATIONAL INTERFACES AFFECTING OTHER DOCUMENTS

ICWG Chairperson	18.	Direct the Data Requestor to initiate a change (if necessary) or appropriate documentation as required, if other Project-controlled or Program-level documents are affected by the data.
Data Requestor	19.	Prepare and submit the change (if required) per Administrative Procedure (AP)-3.3Q, Change Control Process, and/or AP-3.7, Cost and Schedule Baseline Maintenance and Change Control. Prepare other documentation as directed by the ICWG Chairperson.
Processor	20.	Obtain change identification number and transcribe on the IMOU, and send the IMOU to distribution and the LRC. Stop the process.

Title
ADMINISTRATIVE PROCEDURE: INTERFACE CONTROL

RESPONSIBLE PARTY	STEPS	PROCEDURE

PHYSICAL INTERFACES WITH NO UNRESOLVED ISSUES AND NO IMPACT ON CONTROLLED DOCUMENTS

Processor	21.	Obtain concurrence signatures from affected Participants and Integration. Submit the PIRN to ICWG Chairperson for concurrence/approval signature.
ICWG Chairperson	22.	Sign the PIRN, and go to Step 23; or reject the PIRN, and go to Step 31.
	23.	Direct the Data Requestor to prepare a change.
Data Requestor	24.	Prepare and submit the change, with attached PIRN, in accordance with AP-3.3Q, Change Control Process.
Processor	25.	Perform the following activities: a. If change approved, go to Step 26. b. If change cancelled, go to Step 28. c. If decision is to rewrite, go to Step 29.

CHANGE CONTROL BOARD APPROVED

	26.	Obtain the IRN number.
	27.	Transcribe the number on the IRN, and send to distribution and to the LRC. Update the CIS. Stop the process.

CHANGE CONTROL BOARD DISAPPROVED

	28.	Implement the CCB disposition as follows: Transcribe the directive number on the PIRN, indicate cancelled on the PIRN, and send to distribution and to the LRC. Update the CIS. Stop the process.

Title
ADMINISTRATIVE PROCEDURE: INTERFACE CONTROL

RESPONSIBLE PARTY	STEPS	PROCEDURE
ICWG Chairperson	29.	Direct the Data Requestor to update the PIRN, and resubmit.
Data Requestor	30.	Update the PIRN as necessary, and resubmit for further processing; go to Step 6.

INTERFACES WITH UNRESOLVED ISSUES

RESPONSIBLE PARTY	STEPS	PROCEDURE
ICWG Chairperson	31.	Resolve the issue. If unsuccessful, go to Step 34. If successful, a. Notify Affected Participants of decision. b. Direct the Data Requestor and/or the Processor to revise the IMOU and/or the PIRN if required, and re-submit to the system for continued processing.
Data Requestor and or Processor	32.	Revise the IMOU and/or the PIRN, if required.
Processor	33.	Resubmit the IMOU and/or the PIRN to system for continued processing. Go to Step 9.
ICWG Chairperson	34.	Perform the following activities: a. Schedule issues presentation to the CCB through the CCB Secretary. b. Present issues and recommendations to the CCB for disposition.
Data Requestor and Processor	35.	Comply with the following, depending on the CCB decision: a. If the IMOU and/or the PIRN is approved as is or with changes, go to Step 32. b. If the IMOU and/or the PIRN is cancelled, go to Step 36.

Title
ADMINISTRATIVE PROCEDURE: INTERFACE CONTROL

RESPONSIBLE PARTY	STEPS	PROCEDURE
Processor	36.	Record CCB decision on the IMOU and/or the PIRN, close the IMOU and/or the PIRN, and send the closed IMOU and/or PIRN to distribution and to the LRC. Stop the process.

INTERFACES WITH IMPACT ON CONTROLLED DOCUMENTS

RESPONSIBLE PARTY	STEPS	PROCEDURE
Identifying Evaluator	37.	Prepare and submit the change per AP-3.3Q, Change Control Process, and/or AP-3.7, Cost and Schedule Baseline Maintenance and Change Control.
Processor/ Data Requestor	38.	Perform the following activities: a. If the proposed IMOU and/or PIRN is disapproved and cancelled, go to Step 36. b. If the change is approved and/or approved with changes, go to Step 32. c. If the change is disapproved because of no impact to controlled documents, go to Step 9 and continue process.

INFORMATIONAL/ORGANIZATIONAL INTERFACES WITH UNACCEPTABLE DATA

RESPONSIBLE PARTY	STEPS	PROCEDURE
ICWG Chairperson	39.	Resolve the issue. If successful, go to Step 40. If unsuccessful, go to Step 41.
Data Supplier	40.	Revise data if required, and send to Data Requestor. Go to Step 14.
ICWG Chairperson	41.	Perform the following activities: a. Schedule the issue presentation to the CCB through the CCB Secretary. b. Present the issue and recommendation to the CCB for disposition.

RESPONSIBLE PARTY	STEPS	PROCEDURE
Data Requestor and/or Data Supplier	42.	Implement the following depending on the CCB decision: a. If the data is determined to be acceptable, go to Step 14. b. If the data is determined to be unacceptable, go to Step 11.

6.0 REFERENCES

NOTE: Refer to the latest revision of the documents listed below unless otherwise stated.

6.1 REQUIREMENTS DOCUMENTS

Project Configuration Management Plan, YMP/88-4

Project Glossary, YMP/89-15

6.2 INTERFACE DOCUMENTS

AP-3.3Q, Change Control Process

AP-3.7, Cost and Schedule Baseline Maintenance and Change Control

7.0 FIGURES AND ATTACHMENTS

Figure 1, AP-5.19Q Flowchart

Attachment 1, Interface Control Levels

Attachment 2, Interface Memorandum of Understanding

Attachment 3, Minimum Standards for Physical Interface Control Documentation

Attachment 4, Interface Revision Notice

8.0 RECORDS

Records packages of documentation generated as a result of this procedure shall be assembled and submitted to the appropriate LRC in accordance with requirements specified in approved procedures. Quality Assurance records are those IMOUs and IRNs generated by this procedure that are noted as quality affecting.

Title

ADMINISTRATIVE PROCEDURE: INTERFACE CONTROL

IDENTIFICATION AND EVALUATION

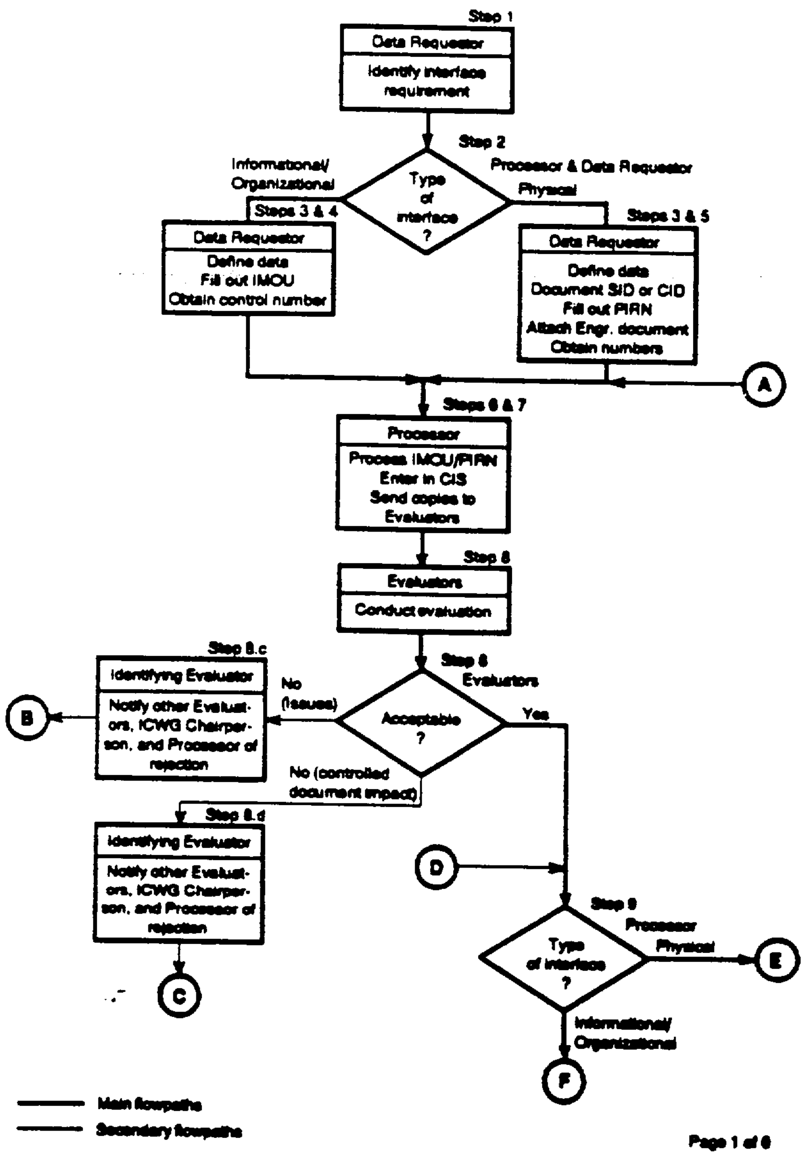

Figure 1 - AP-5.19Q Flowchart

INFORMATIONAL/ORGANIZATIONAL INTERFACES

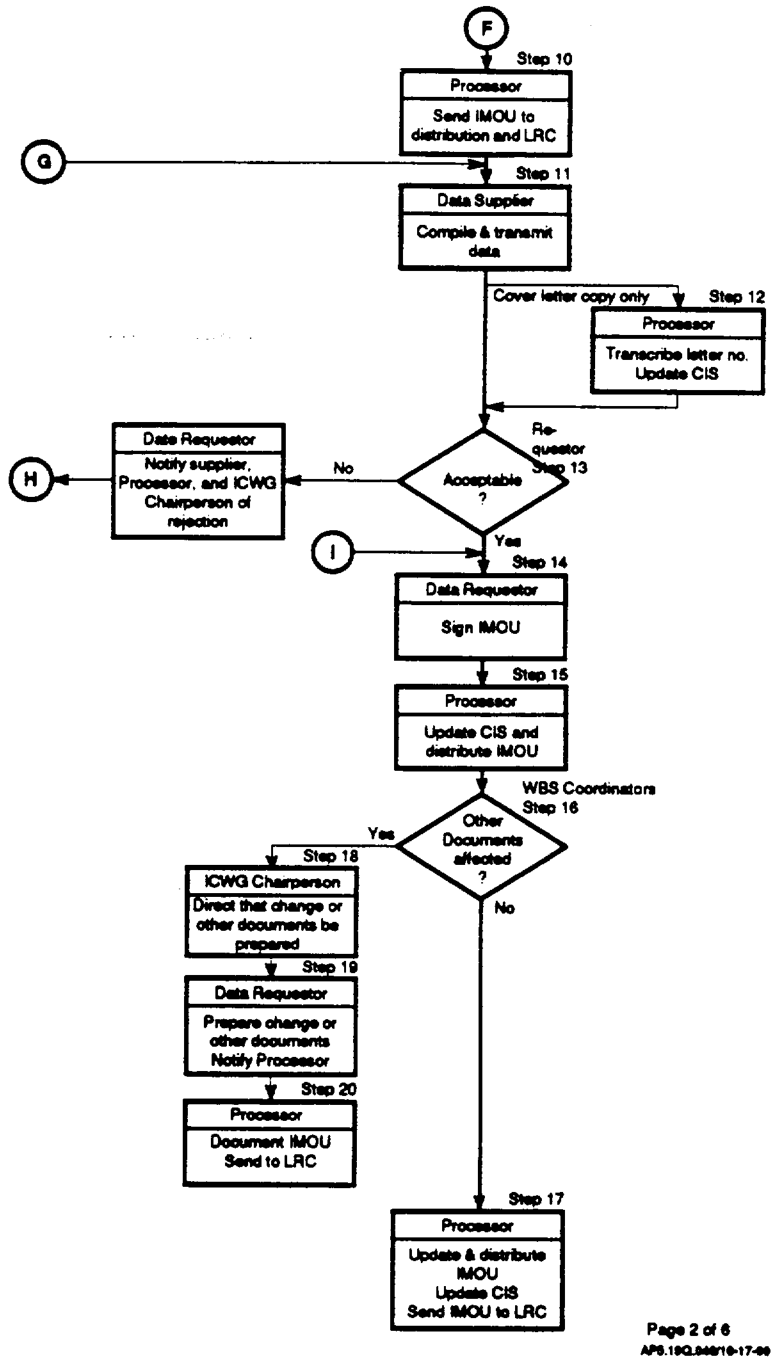

Figure 1 - AP-5.19Q Flowchart (continued)

Title

ADMINISTRATIVE PROCEDURE: INTERFACE CONTROL

PHYSICAL INTERFACES

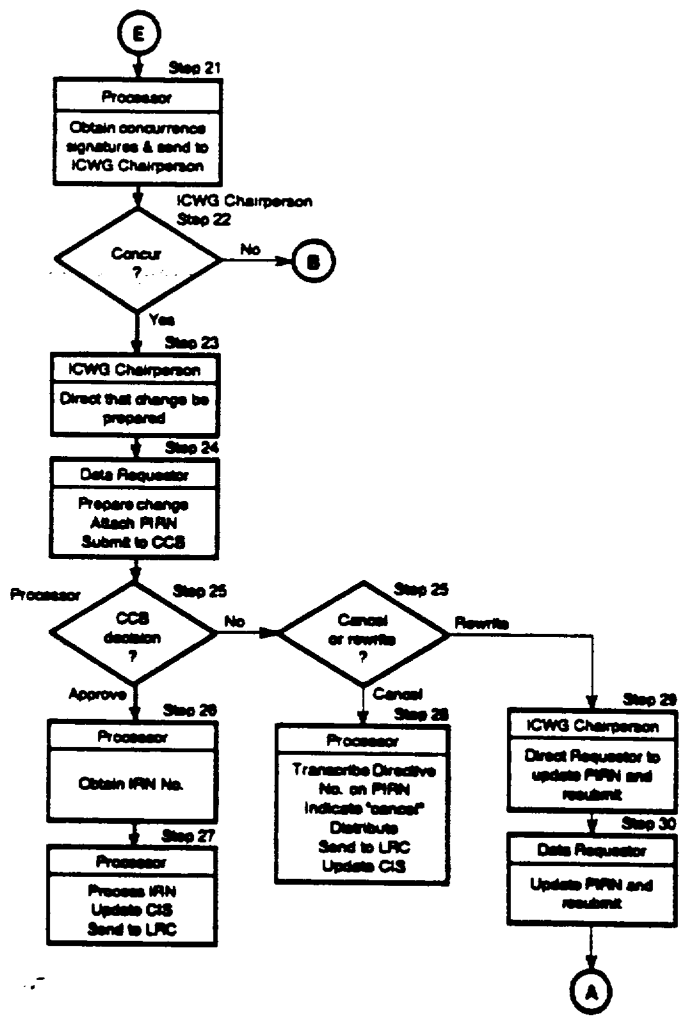

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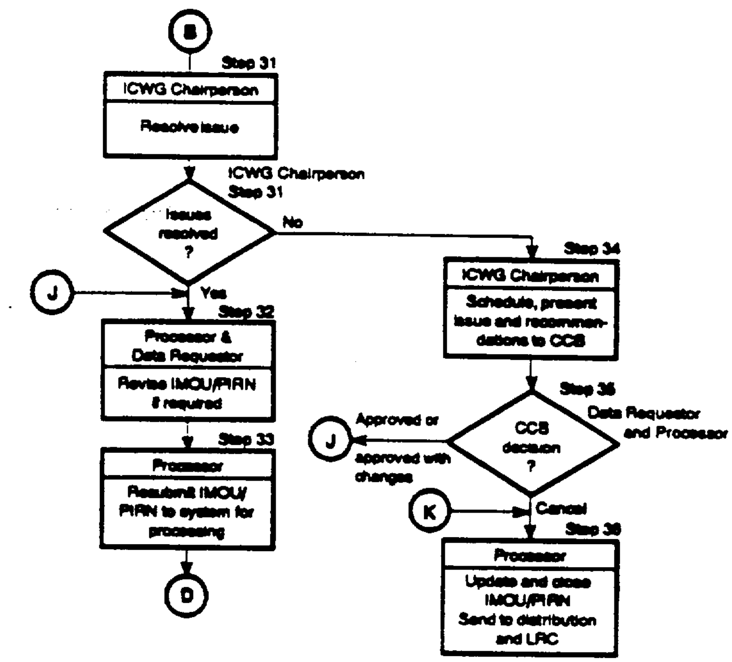
Figure 1 - AP-5.19Q Flowchart (continued)

Title
ADMINISTRATIVE PROCEDURE: INTERFACE CONTROL

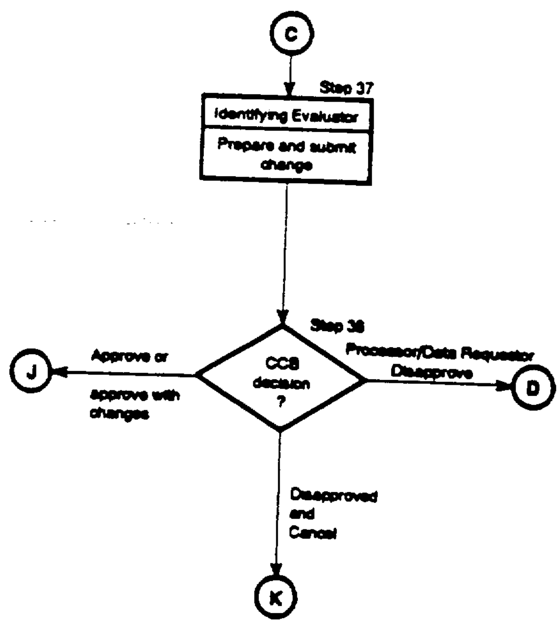
INTERFACES WITH UNRESOLVED ISSUES



Page 4 of 6

Figure 1 - AP-5.19Q Flowchart (continued)

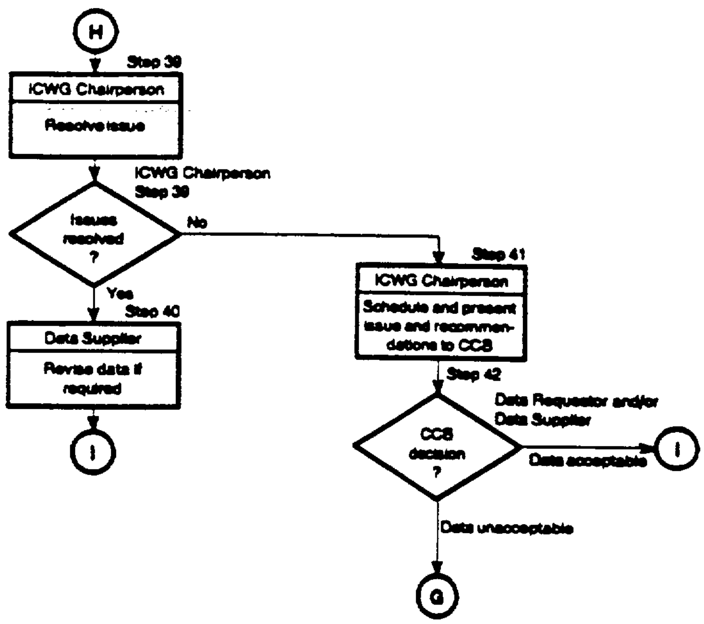
INTERFACES WITH IMPACT ON CONTROLLED DOCUMENTS



Page 5 of 6

Figure 1 - AP-5.19Q Flowchart (continued)

INFORMATIONAL/ORGANIZATIONAL INTERFACES WITH UNACCEPTABLE DATA



Page 6 of 6

Figure 1 - AP-5.19Q Flowchart (continued)

Interface control levels are specific hierarchical levels established for control of interfaces (see Table 1). The approval authority and description are listed in Table 2.

An interface is classified to the highest level of the classification that it affects. Thus, an interface between an ESF subsystem (Level D) and a Repository subsystem (Level D) is defined as a Level C interface. An interface between two Level D CI's that are both within the same Level C CI, is a Level D interface. Figure 1 depicts the organization of CIs and interface control levels.

Attachment 1 - Interface Control Levels

Table 1. Interface Control Level Descriptions

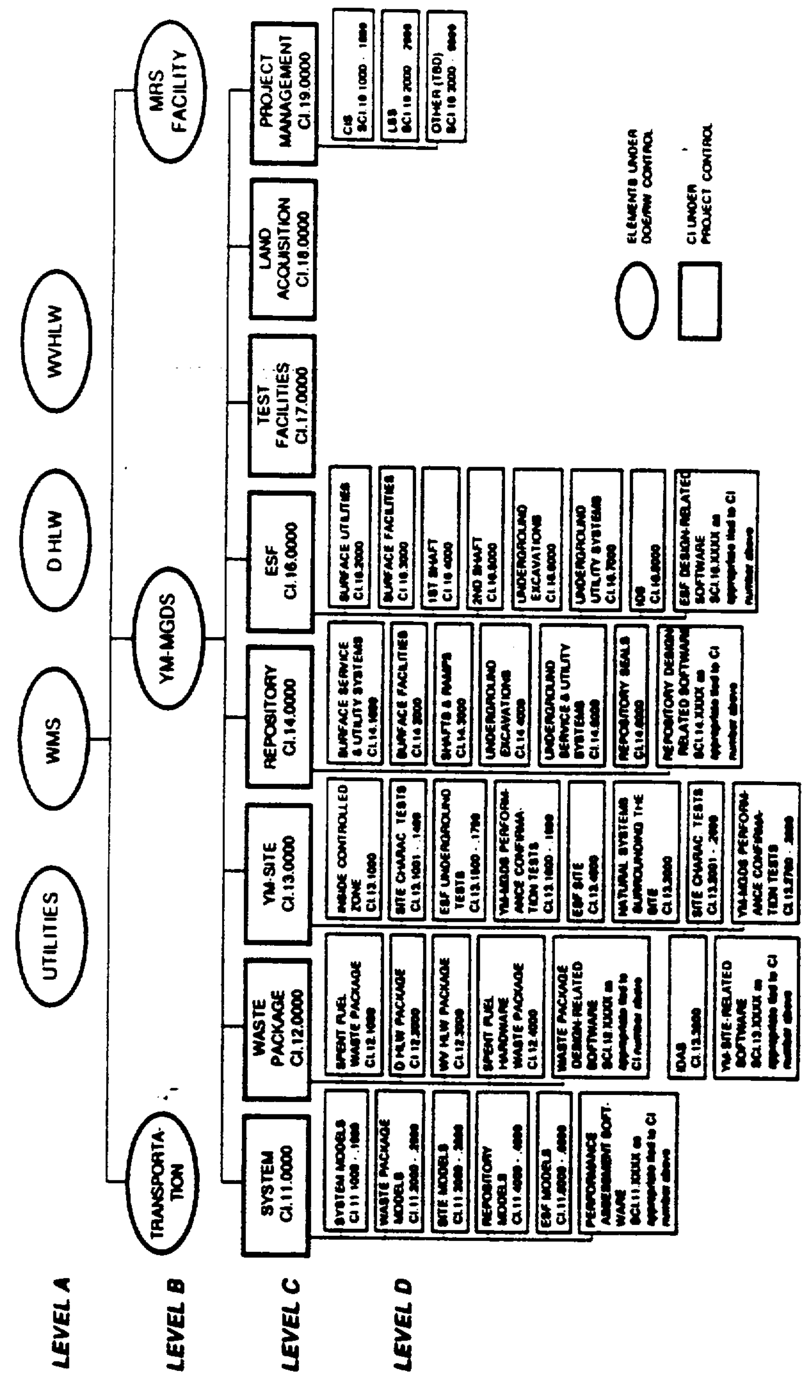
Level	Description
A	Interfaces between the Waste Management System (WMS) and other external systems (e.g., waste producers)
B	Interfaces between the WMS elements (Repository, Transportation, and Monitored Retrievable Storage).
C	Interfaces between the Project system (e.g., System, Repository, Waste Package, ESF, and Site CIs).
D	Interfaces between subsystems internal to a Project system.

Table 2. Interface Control Authorities

Authority	Description
DOE/RW	Level A and B interfaces.
Project Office	Level C interfaces and Level D and lower interfaces that involve more than one Project Participant.
Project Participant	Level D and lower level physical interfaces that are internal to one single Project Participant.

Attachment 1 - Interface Control Levels (continued)

Title
ADMINISTRATIVE PROCEDURE: INTERFACE CONTROL



Attachment 1 - Interface Control Levels (continued)

Title
ADMINISTRATIVE PROCEDURE: INTERFACE CONTROL

YUCCA MOUNTAIN PROJECT
INTERFACE MEMORANDUM OF UNDERSTANDING
N-AD-056
9/90

1 INTERFACE CONTROL NO.:	2 REVISION:	3 DRAFT:	4 CI NO.:	5 PAGE ___ OF ___

6 QUALITY RELATED ☐ YES ☐ NO	7 REQUESTED BY/ORGANIZATION:	8 PREPARED BY/ORGANIZATION:

9 SUBJECT:	10 WBS NO.:

11 DATA DESCRIPTION:

12 REASON:

13 NEED DATE:	14 DATA SUPPLIER ORGANIZATION:

15 SIGNATURE AND ORGANIZATION	DATE	SIGNATURE AND ORGANIZATION	DATE

CLOSEOUT

16 DATA TRANSMITTAL REF. NO.:	DATE	17 DATA ACCEPTED BY: *(Signature)*	DATE

18 OTHER DOCUMENTS AFFECTED ☐ YES ☐ NO	19 CR NO.:

Attachment 2 - Interface Memorandum of Understanding

Title

ADMINISTRATIVE PROCEDURE: INTERFACE CONTROL

YUCCA MOUNTAIN PROJECT
INTERFACE MEMORANDUM OF UNDERSTANDING
CONTINUATION PAGE

N-AD-056
9/90

1 INTERFACE CONTROL NO.:	2 REVISION:	3 DRAFT:	4 CI NO.:	5 PAGE ___ OF ___

Attachment 2 - Interface Memorandum of Understanding (continued)

**INSTRUCTIONS FOR PREPARATION OF
YUCCA MOUNTAIN PROJECT
INTERFACE MEMORANDUM OF UNDERSTANDING
N-AD-056**

1. The interface control number shall be requested by the Requestor and assigned and controlled by the Processor (T&MSS Configuration Management).
2. Revisions shall be numeric and sequential.
3. Draft shall be alphabetic and sequential starting with A.
4. Leave blank. To be filled in by the Processor after the form has been submitted.
5. Enter individual and total number of pages.
6. Check QA related designation either as YES or NO.
7. Enter the individual and organization requesting the IMOU.
8. Enter the individual and organization that prepared the form.
9. Enter the subject in brief format.
10. Enter the WBS number.
11. Describe clearly the requirement(s) and/or data being requested. Identify, if possible, the Project documents (e.g., Baseline and Planning) governing the interface.
12. Enter a brief statement as to why the IMOU is required and/or what Project milestone requirement is supporting.
13. Enter the date when the information/data must be available.
14. Enter name(s) of organization(s) supplying data.
15. To be signed by each affected TPO or his designee.
16. Leave blank. To be filled in by Processor upon receipt of data transmittal letter number.
17. Signature and date of requesting TPO or his designee upon receipt and acceptance of the data.
18. Leave blank. To be determined by Integration, and filled in by the Processor.
19. Leave blank. To be filled in by the Processor.

Attachment 2 - Interface Memorandum of Understanding (continued)

INTERFACE CONTROL DOCUMENTATION

Physical interface control documentation (CIDs/ICDs) shall be prepared when it is determined that the design of physical and functional features between items (subsystems, facilities, or components) could result in a mismatch, omission, interference, or duplication.

ICD delineates design features on both sides of the boundary to the extent required to control physical, functional, and operational compatibility between the affected items.

Interface requirements shall include all pertinent information needed by the designers of the interface, including general configuration and the interface dimensional data specifically applicable to the envelope, mounting and mating of the item (e.g., space dimensions, location and dimensions of supporting planes with respect to common datum, forces, weights, moments, and temperature with tolerances).

Interface requirements shall include all necessary design input interface data requirements, such as mechanical, electrical, electronic, hydraulic, pneumatic, optical, and computer data links and software that affect characteristics of cofunctioning items.

Any other characteristics that cannot be changed without affecting the cofunctioning item are also interface requirements.

Engineering drawings containing information controlled by ICDs shall be consistent with the interface boundaries and features in the ICDs. Engineering drawings shall provide traceability to the ICDs, and conversely, the ICD shall provide traceability to the engineering drawings.

INTERFACE DESIGNATION ON DESIGN PARTICIPANTS DOCUMENTATION

All design or engineering drawings, and any other documentation that describes the interface requirements defined by an ICD, shall be clearly annotated by the design Participant to specify that any proposed change to the drawing/documentation may affect an interface and require formal configuration control processing. The following statement shall be entered on the first sheet of the drawing/documentation:

> "This drawing/document contains information controlled by an ICD. Changes to information controlled by an ICD shall not be made prior to Project Office CCB authorization."

Attachment 3 - Minimum Standards for Physical Interface Control Documentation

In addition, the appropriate interface control number(s) shall be identified on the drawing/document in a manner to identify the source of the interface data requirement.

ICDs shall not be included as part of construction/fabrication packages.

To preclude ICDs from being considered as more than design requirements, the following statement shall be entered on the first sheet of the drawing/document:

> "This document shall not be used for manufacturing, procurement of hardware, inspection of manufactured items, or assembly, but shall govern pertinent design documentation. Revisions to this document or the properly identified pertinent design documentation can only be made with approval of the responsible interface authority."

CHANGES TO INTERFACE CONTROL DOCUMENTATION

Changes to ICDs controlled by the Project CCB shall be submitted to the ICWG prior to being submitted to the CCB. The ICWG shall evaluate and concur/approve the submitted change and transmit to the CCB or return it to the submitting Participant with an explanation why it was not approved.

FIELD CHANGES TO INTERFACE CONTROL DOCUMENTATION

Field changes processed under AP-3.3Q, Change Control Process that affect an interface must be presented before the ICWG the next work day after the field change is approved.

INTERFACE CONTROL DOCUMENTATION CROSS-REFERENCE INDEX

Each design activity/contractor shall be required to have and maintain an ICD cross-reference index that denotes which engineering drawings are affected by ICDs. This cross-reference will allow the designer to determine if and which drawings and/or ICDs may be affected by a proposed change.

Attachment 3 - Minimum Standards for Physical Interface
Control Documentation (continued)

Title
ADMINISTRATIVE PROCEDURE: INTERFACE CONTROL

INTERFACE REVISION NOTICE
YUCCA MOUNTAIN PROJECT

Y-AD-126
9/90

1 AFFECTED ICD NO.:	2 REV.	3 TRACK IDENT.	4 IRN	5 PAGE ___ OF ___
6 TITLE:	7 WBS NO.	8 INITIATED BY/ORG.:		9 PREPARED BY/ORG.:

10 QUALITY RELATED: ☐ YES ☐ NO

11 REASON FOR CHANGE:

12 EFFECTIVITY:

14 SIGNATURES AND ORGANIZATIONS

PARTICIPANT	ORG.	DATE
	INTEGR	
	ICWG	

13 DESCRIPTION OF CHANGE:

Attachment 4 - Interface Revision Notice

INTERFACE REVISION NOTICE
YUCCA MOUNTAIN PROJECT
CONTINUATION PAGE

Y-AD-128
9/90

1 AFFECTED ICD NO.:	2 REV.	3 TRACK IDENT.	4 IRN	5 PAGE ___ OF ___

Attachment 4 - Interface Revision Notice (continued)

INSTRUCTIONS FOR PREPARATION OF
INTERFACE REVISION NOTICE
YUCCA MOUNTAIN PROJECT
Y-AD-126

1. Enter the complete ICD number/descriptive number and revision symbol, if applicable, of the ICD affected by the IRN.
2. Fill in as required.
3. Tracking identifier will be issued by the Processor.
4. Leave blank. To be filled in by the Processor at the time IRN is approved.
5. Enter total number of pages.
6. Enter title of the ICD.
7. Enter WBS number.
8. Enter name and organization of the initiator.
9. Enter name and organization of the person preparing the IRN.
10. Check QA related designation either Yes or No.
11. Brief description of reason(s) or justification(s) for requesting change. Additional comments may be placed in Block 10 and so identified if additional space is required.
12. Identify recommended effectivity for the IRN.
13. Enter the exact proposed change to the affected ICD for both sides of the affected interface(s). When the IRN is used to release a revised ICD, enter all baselined IRN's incorporated. Use continuation pages as necessary.
14. Technical concurrence signature and date of each TPO or designee affected by the IRN, technical concurrence signature and date of the Integration Contractor TPO or designee and concurrence and/or approval signature of the ICWG Chairperson.

Attachment 4 - Interface Revision Notice (continued)

TITLE I DESIGN SUMMARY REPORT
REVISION 1
DRAFT H
VOLUME 5, APPENDIX

5.7 "Synopsis of Past Stability Analyses for the ESF Title I Design," SAND88-2294

NOTE: This document is valid for the methodology only as it pertains to the Reference Design Study.

FINAL DRAFT

SAND88-2294

December 1988

Rev. 0

A SYNOPSIS OF ANALYSES (1981-87) PERFORMED
TO ASSESS THE STABILITY OF UNDERGROUND EXCAVATIONS
AT YUCCA MOUNTAIN

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ABSTRACT

This paper synopsizes 14 analyses by 10 different investigators that were performed to assess the preclosure (up to 100 yr) stability of underground excavations for a potential nuclear waste repository located at Yucca Mountain, Nevada. The analyses were primarily based on thermomechanical models of the conceptual design of shafts and drifts. The material properties, codes, and design configurations used in the analyses varied over the seven years because of the acquisition of additional data and refinement in codes and design. However, all the analyses indicate that shafts and drifts can be constructed and will remain stable with minimum ground support through decommissioning of the repository. This information supports the feasibility of constructing a safe Exploratory Shaft Facility and the expectation that it will remain stable should repository construction and waste emplacement follow.

CONTENTS

QUALITY ASSURANCE LEVELS

	QA LEVEL
SECTIONS 1-4	II
Appendix A	
Synopsis 1: SAND83-7068	NQ
Synopsis 2: SAND83-7069	NQ
Synopsis 3: SAND84-7213	III
Synopsis 4: SAND81-0629	NQ
Synopsis 5: SAND83-0372	NQ
Synopsis 6: SAND84-2354	NQ
Synopsis 7: SAND82-2034	III
Synopsis 8: SAND84-2641	III
Synopsis 9: SAND83-7451	III
Synopsis 10: SAND83-0070	III
Synopsis 11: SAND84-7208	III
Synopsis 12: SAND86-7005	III
Synopsis 13: SAND86-7011	III
Synopsis 14: SAND86-1250	III

1.0 INTRODUCTION

The purpose of this report is to synopsize stability analyses of the repository shafts and drifts completed for the conceptual design of the Yucca Mountain Project (YMP). The principle regulatory requirement for performing the stability analyses stems from 10 CFR 60-133(e) (NRC, 1986) stating that "Openings in the underground facility shall be designed (1) so that operations can be carried out safely and the retrievability option maintained and (2) to reduce the potential for deleterious rock movement or fracturing of overlying or surrounding rock." 10 CFR 960.5-2-9(d) states that "the site shall be disqualified if the rock characteristics are such that the activities associated with repository construction, operation or closure are predicted to cause significant risk to the health and safety of personnel, taking into account mitigating measures that use reasonably available technology" (DOE, 1987).

The analyses synopsized here, although not specifically based on the current Exploratory Shaft Facility (ESF) design, provide a preliminary assessment of the stability of the ESF. An assessment can be made by comparing the similarities of the shafts and openings of the ESF design with the past analyses synopsized.

As depicted on Sandia National Laboratories (SNL) drawings R07048A/1 through 15 (ESF Repository Interface Control Drawings, dated March 1988), the ESF consists of two 12-ft-diameter concrete-lined shafts (ES-1 and ES-2) and drift(s) of repository size or smaller in the Upper Demonstration Breakout Room (UDBR), the Main Test Level (MTL), and the Calico Hills Drill Room (CHDR). ES-1 penetrates the Topopah Spring and terminates in the underlying Calico Hills Member (recent updates to the drawings show ES-1 terminating in the Topopah Spring). ES-2 terminates in the Topopah Spring Member. The UDBR and MTL are constructed in the TSw1 and TSw2 units of the Topopah Spring Member, respectively. The CHDR is constructed in the Calico Hills Formation. The synopses emphasize analyses results pertinent to the stability of shafts and drifts constructed in the Topopah Spring and Calico Hills.

Section 2.0 summarizes the results of the past thermomechanical and empirical analyses of shafts (Section 2.1) and underground drifts (Section 2.2). Details of the data, codes, models, design geometries, and results can be found in Appendix A, which synopsizes each analysis.* The material properties, codes, and design configurations used in these analyses span a 7-yr period during which additional data were acquired, codes were enhanced, and changes in design were made. Elastic and plastic models, continuum joint models, and empirical approaches were used to assess the stability of the excavations. In the analyses discussed, the "matrix" or "intact" rock strength refers to the laboratory test values of unconfined compressive strength; to obtain the "rock mass" strength, these values were reduced by 50%, to account for scale effects. The jointed rock models used the matrix or intact properties together with properties of the joints. Elastic models used the rock mass properties. Except as noted, the analyses did not model the contributions of ground support, and seismic loading was not modeled in any of the analyses.

Section 3.0 examines the design of the ESF and uses the results of past analyses presented in Section 2.0 to conclude that the shafts and drifts of the ESF should be stable over the operational life (up to 100 yr) of the repository.

---

*Data evolution over the period that the analyses were performed resulted in several data sets used in the analyses that may not match the current values in the Reference Information Base and Site Engineering Properties Data Base.

2.0 SUMMARIES OF COMPLETED ANALYSES

Results of the analyses performed for the conceptual design of the repository shafts (Section 2.1) and drifts (Section 2.2) are summarized below and are listed in chronological order. A detailed synopsis of each analysis can be found in Appendix A. Table 2-1 shows the primary characteristics modeled in each analysis.

2.1 Shafts

Hustrulid (1984a) (Synopsis 3) analyzed a concrete liner in a circular shaft in the Calico Hills and lower units using both elastic and plastic models. The Calico Hills Formation lies below the Topopah Spring Member and is approximately five times weaker than the Topopah Spring welded tuff (TSw2). A 10.8-MPa hydrostatic in situ stress was applied to the shaft in the Calico Hills Formation. When the model took into account rock mass properties, a failed zone of rock was likely to occur in the Calico Hills Formation because of the in situ stresses. The concrete liner thickness needed to prevent the failure of the rock mass annulus around the shaft was calculated using a safety factor of 1.5. It was determined that a 0.41-m-thick concrete liner was required if wet conditions prevailed, and no liner was required for dry conditions.

Models used by Hustrulid in this analysis were shown to be conservative based on a comparison he made between actual liner pressures as measured in a conventionally sunk concrete-lined shaft at Mt. Taylor (Grants, New Mexico) and predicted analytic values. He states that considerable differences existed between the theoretical analysis and actual field measurements because the theoretical analyses appeared to be exceptionally conservative.

Hustrulid (1984b) (Synopsis 2) used a boundary element code to model a shaft with a 12-ft finished diameter and a 1-ft concrete liner in the Calico Hills Formation. These analyses modeled two conditions: (1) a condition where the minimum horizontal principal stress of 5 MPa was combined with a maximum principal stress of 10 MPa and (2) a condition

Table 2-1

PRIMARY CHARACTERISTICS OF ANALYSES SYNOPSIZED

Synopsis* Number	Type of Opening		Geologic Formation		Loads Applied		Waste Emplacement		Model Assumed		
	Shaft	Drift	Calico Hills	Topopah Spring	In situ	Thermal	Horizontal	Vertical	Elastic	Plastic	Joint
1	X		X		X				X	X	
2	X		X		X				X		
3	X			X	X	X			X		
4		X	X	X	X	X		X			X
5		X	X	X	X	X		X			X
6		X		X	X				X		X
7		X	X	X	X					empirical	
8		X		X	X	X	X	X	X		
9		X		X	X		X	X	X		
10		X	X	X	X	X		X			X
11		X		X	X	X	X		X		
12		X		X	X	X	X	X	X		
13		X		X	X	X	X		X		
14		X		X	X	X	X		X		

* 1 W. Hustrulid, 1984a
2 W. Hustrulid, 1984b
3 C. St. John, 1987d
4 R. Johnson, 1981
5 J. Johnstone, R. Peters, and P. Gnirk, 1984
6 J. Hill, 1985
7 B. Langkopf and P. Gnirk, 1986
8 B. Ehgartner, 1986
9 C. St. John, 1987b
10 R. Thomas, 1987
11 C. St. John, 1987c
12 C. St. John, 1987a
13 C. St. John and S. Mitchell, 1987
14 B. Ehgartner, 1987

where both principal stresses were 10 MPa. When the model took into account rock mass properties, no failure was predicted to occur in the rock mass where equal components of in situ horizontal stress were assumed. With a ratio of 2 to 1 for the in situ horizontal stresses, failure extended 2 ft into the rock mass at 90° to the direction of maximum horizontal stress. It was concluded that major difficulties are not expected in sinking a shaft in the Calico Hills Formation, and if minor spalling of the walls occurs, rock bolts 5 to 6 ft in length would easily restrain deterioration. Although not stated in the conclusions of the report, improved conditions are expected in the Topopah Springs tuff (TSw2) since it has a higher compressive strength and lower in situ stresses.

St. John (1987d) (Synopsis 3) analyzed 6.5-m-external-diameter, concrete-lined, repository access shafts at two different locations at repository depth (Topopah Spring). Elastic analyses were performed for a shaft located (1) centrally in the repository within a 200-m-diameter shaft pillar and (2) 100 m from the edge of the repository. The analyses were time dependent and considered the thermally induced load up to 100 yr after waste emplacement. The thermal load was based on an areal power density (APD) of 57 kW/acre. The STRES3D code generated a three dimensional stress field of the repository by superimposing both the in situ and thermally induced stresses. The stress field then was imposed on the circular shaft using the SHAFT code to calculate stresses for both the 0.5-m-thick concrete shaft liner and the rock mass surrounding it. The alternative shaft locations at the center and edge of the repository showed slight differences, but in neither instance was the rock mass surrounding it predicted to be fractured because of the in situ and thermally induced loading. The liner hoop stresses were low in comparison to the compressive strength of typical concrete. The concrete shaft liner was predicted to have approximately 4.3 MPa of tensile stress induced along its axis at the repository horizon after waste emplacement. This stress could produce horizontal cracks in the liner. However, it was concluded that no evidence exists that such cracking would be detrimental to the performance (stability) of the liner. The analysis assumed placement of the shaft in an elastic continuum with no expansion joints in the liner along the shaft. The transfer of the induced tensile stress from the rock mass to the liner will likely be moderate because of the presence of naturally occurring and excavation-induced joints in the rock mass surrounding the shaft liner.

2.2 Underground Drifts

Johnson (1981) (Synopsis 4) varied the APD for an unventilated vertical emplacement scheme from 75 to 100 kW/acre to determine the effects on rectangular drifts in the Topopah Spring and Calico Hills. The ADINAT model and ADINA model, incorporating ubiquitous jointing, was used for analyses of times up to 100 yr after waste emplacement. Boundary compressive stresses at the crown and sidewall were 20 and 25 MPa 100 yr after emplacement of 75 kW/acre. An emplacement power density of 100 kW/acre resulted in nearly the same level of stress at both locations. For both cases the only intact failure that occurred was locally in the corners of the drifts, and in neither case did it extend more than 1 m into the rock mass.

Johnstone et al. (1984) (Synopsis 5) analyzed rectangular emplacement drifts in the Topopah Spring, Calico Hills, and lower geologic units to establish the maximum APD for each of the formations. The repository was assumed to be located in the formation analyzed. Non-linear thermal analyses were performed using ADINAT and SPECTROM-41. The APD of the repository was established as 57 kW/acre for the Topopah Spring tuff. For the Calico Hills Formation an APD of 54 kW/acre was determined as acceptable. The results of an analysis of an unventilated, vertical-emplacement drift using the ubiquitous-joint model in ADINA and SPECTROM-11 for times out to 100 yr were documented assuming average and limiting properties. The limiting properties were taken as either plus or minus two standard deviations from average values.

No matrix fracturing was predicted around the Topopah Spring drift over the waste emplacement period for either the average or limiting property case. The corresponding minimum safety factors were approximately 1.5 and 3.0 for the limiting and average cases, respectively. When average rock properties at 100 yr after waste emplacement were assumed, small regions of matrix fracturing occurred around the corners of the Calico Hills drift. For limiting properties, matrix failure extended approximately 1 m into the rock mass surrounding the drift. Limited amounts of vertical joint slip were predicted in the sidewalls of the drift both at and after waste emplacement. Analyses of G-tunnel drifts using the ubiquitous-joint model predicted a slightly larger slip region for the rock surrounding G-Tunnel than for the repository drifts, but no joint displacement was evident in the drifts of G-Tunnel. It was concluded that both the Topopah Spring and Calico Hills formations appear acceptable with regard to drift stability. Drift analyses were documented not only for the Topopah Spring and Calico Hills but also for the underlying Bullfrog and Tram Members. The report concludes that, although the rock strength and modulus varied by a factor of three over the four units, all units appear acceptable with regard to stability of the underground openings.

Hill (1985) (Synopsis 6) analyzed the structural stability of a conceptual design of the ESF main test level in the Topopah Spring Member. The results of this analysis were intended to aid drift instrumentation when the facility is actually constructed. The analysis comprised two independent parts--a three-dimensional model of the ESF and a two-dimensional parametric study of two drifts (rectangular and arched shaped) separated by a pillar. Two different pillar widths were analyzed--6 m and 2 m. The three-dimensional problem used a linear elastic material model, and the two-dimensional problem used an elastic and joint model in the ADINA code. Consistent parameters were used for both the two- and three-dimensional studies to allow comparison of results. The two-dimensional model considered both elastic and inelastic (joint) behavior and found the results to be similar. With an approximately 5-m drift and 6-m pillar, the elastic material model predicted a safety factor against intact rock failure of 4.5 near the drift boundary and the jointed material model predicted a safety factor of 4.0. Vertical stresses for the two material models were almost identical. The two-dimensional analysis of the narrow pillar predicted the lowest safety factor against intact rock failure as 3.0. The pillar width was only

2 m, yet little interaction of stresses resulting from the two drifts that created it was predicted to occur. A safety factor of 4.0 was found in the three-dimensional analysis of the 2-m pillar width. A safe ESF with no structural problems was concluded.

Langkopf and Gnirk (1986) (Synopsis 7) documented the results of tunnel indexing or rock mass classification methods applied to the Topopah Spring and Calico Hills. Both the South African Council for Scientific Industrial Research Classification System (CSIR) and Norwegian Geotechnical Institute Classification System (NGI) methods were applied. The result of the CSIR ratings for the Topopah Spring rock mass range from 48 to 84, indicating very good to fair rock. The CSIR results for Calico Hills range from 49 to 71, indicating good to fair rock. The result of the NGI ratings for the Topopah Spring range from a rock mass quality (Q) of 53.3 to 1.46, indicating very good to poor rock. The NGI results for Calico Hills ranged from 43.0 to 0.19, indicating very good to very poor rock. The NGI system further qualifies the required support as ranging from grouted rockbolts on a 1-m spacing with chain-link mesh and shotcrete to a no-support requirement for the above range in Q values. The classification systems are based on the results of many diversified case studies, but a specific case to which anticipated repository excavation conditions can be related is found in G-Tunnel. The NGI and CSIR classification systems both rank the welded Topopah Spring tuff and the Calico Hills formation as almost exactly the same with the Grouse Canyon tuff in G-tunnel. The G-Tunnel complex contains miles of drifts in a tuff unit known as Tunnel Bed 5 of the Grouse Canyon tuff. In this facility, spans of up to 9.3 m in width have been stable for up to 25 yr with minimal support (rock bolts and wire mesh).

Ehgartner (1986) (Synopsis 8) performed an elastic analysis of arched drifts by varing the thermal and thermal/mechanical properties of the Topopah Spring Member as a function of porosity in a thermomechanical model (HEFF code) of the horizontal and vertical emplacement drifts 100 yr after waste emplacement. An APD of 57 kW/acre was modeled. It was concluded that, for TSw2 with expected ranges in porosity of 9.8 to 18.0%, both vertical and horizontal drifts were stable and drift temperatures not excessive. A safety factor of less than 1.0 occurs at the crown of the horizontal emplacement drift, for porosities in excess of 45%. A safety factor of less than 1.0 occurs at the crown of the vertical emplacement drift for porosities greater than 21%.

St. John (1987b) (Synopsis 9) varied the shape of horizontal and vertical emplacement drifts over various in situ stress fields, ranging from uniaxial to hydrostatic, using rock mass properties from the Topopah Spring Member. The elastic analyses used the boundary element code HEFF and the elastic finite element code, BMINES. BMINES enabled rock bolts to be included in the analyses. A damage region was modeled around the drift to simulate the impact of blasting during excavation, and rock bolts were inserted in the crown region. Comparison of the analyses show that the rock bolts had an insignificant impact on reducing drift stresses and deformation, as compared to the analyses of an unsupported drift.

Thomas (1987) (Synopsis 10) performed two-dimensional analyses of rectangular, unventilated, vertical-emplacement drifts in both the Topopah Spring and Calico Hills for times up to 100 yr after waste emplacement, using an APD of 57 kW/acre. Both average and limiting properties were used in the ADINAT and JAC codes. Safety factor values against rock matrix failure for the Topopah Spring Formation varied from 4.5 at the crown to 6.0 at the drift sidewalls of the excavation using average properties. After 100 yr this value drops to 1.5 in the crown, the lowest safety factor for the drift boundary. For the limiting properties case, the safety factor for the crown drops from 3.0 at excavation time to 1.5 after 100 yr of thermal loading. The safety factor in the sidewall at 100 yr is 4.5 for the limiting case. For the Calico Hills Formation the minimum safety factors against rock matrix failure over the emplacement period are 1.5 for both average and limiting property values. No potential for intact rock failure was noted in the drifts for either the average or limiting properties case over the 100 yr analyzed for either the Topopah Spring or Calico Hills.

St. John (1987c) (Synopsis 11) documented analyses of an intersection of the emplacement drift with a panel access drift using an

APD of 57 kW/acre. The three-dimensional elastic calculations used STRES3D to generate the thermally induced stress field for the horizontal emplacement scheme and ADINA to elastically analyze the unventilated intersection located in the Topopah Spring Member. Drift shapes modeled were of the arched design. Stresses in the crown of the intersection reached approximately 23 MPa after 50 yr of waste emplacement. In this elastic analysis, tensile stresses approaching 9 MPa were predicted in the drift wall at the intersection. The tensile stresses dissipate 3 m into the drift wall; however, these tensile stresses predicted in the elastic model will likely be reduced in the field because of the presence of existing horizontal fractures. It was concluded that the conditions of the intersection immediately after excavation would be similar to those in the access drift, that there should be no unusual rock support problems, and that it is unlikely that the tunnel intersection will experience adverse conditions in either emplacement option.

St. John (1987a) (Synopsis 12) reported the results of two-dimensional finite and boundary element calculations for arched emplacement drifts that include thermal effects out to 100 yr after waste emplacement. The calculations are the most recent of the analyses performed on the emplacement drifts. The thermal analyses were performed using the finite element code DOT, and a second analysis used the boundary element code HEFF. The HEFF code resulted in temperatures of within ± 1°C of those predicted by DOT. Both codes used constant thermal and elastic properties. The model used an APD of 57 kW/acre. Both vertical and horizontal emplacement drifts were analyzed using continuously ventilated and unventilated drift conditions.

The stress results were obtained from the finite element code VISCOT, which used an elastic constitutive model, and average rock mass properties for the Topopah Spring Member. Drift shapes were of the arched design. The highest stresses were noted at the drift crown 100 yr after waste emplacement. The magnitudes of the principal stress in the drift crown ranged from 31 to 36 MPa for the horizontal emplacement drift, depending on the drift ventilation assumed. Higher stresses occurred for the unventilated drift condition. The vertical emplacement drift had crown stresses ranging from 13 to 54 MPa for the ventilated and unventilated conditions, respectively. The minimum safety factor against rock mass failure for the vertical emplacement drifts was 1.2. The minimum safety factor calculated for the horizontal emplacement drift was 1.6. These safety factors were minimal because they were based on stresses at a point on the drift boundary. Stress magnitudes in this elastic analysis decreased for locations removed from the drift. The safety factors increased in magnitude as distance from the drift crown increased. The mass of rock making up the crown area of the drift had an average safety factor much higher than the boundary values at the crown. The safety factor for the drift could be obtained by integrating or averaging the safety factor values over the crown region. The crown region was chosen because it had the lowest safety factor. For the crown region of the drifts, interpretation resulted in an average safety factor that was equal to or greater than 3.0. The report predicts that for both the horizontal and vertical emplacement drifts will be stable to 100 yr after waste emplacement.

St. John and Mitchell (1987) (Synopsis 13) documented results of the stability of the panel access drifts at various locations and standoff distances from the emplaced waste in the Topopah Spring Member. The elastic two-dimensional calculations used the HEFF code for analyses of the unventilated horizontal emplacement scheme to 50 yr after waste emplacement at 57 kW/acre. Arched-shaped drifts were analyzed at locations in the central part and outer edges of the repository. The hypothetical repository was configured of four panels. Interpanel locations were also considered. A near-hydrostatic in situ stress field was assumed. The lowest safety factor, 1.3, was found at the crown of the excavation. Although the results differed according to the locations of the drifts, no rock mass stability problems were identified at any of the potential locations.

Ehgartner 1987 (Synopsis 14) investigated specific parametric sensitivities and calculated the probability of failure of a horizontal emplacement drift using a probabilistic technique. Drift shapes were of the arched design. The input parameters to the HEFF code were varied both individually and jointly to determine the effect on the drift 50 yr after emplacement of waste at 57 kW/acre. The results indicated that changes in rock strength and modulus in the Topopah Spring Member had a greater effect on the safety factors of the drift rock than did the other parameters that were varied, but in no case was the safety factor for the rock mass less than 1.0 over the probable range of input variables. Drift temperatures were relatively insensitive to the thermal input variables. It was concluded that the horizontal emplacement drift would tolerate the expected range in the thermal and thermal/mechanical properties. The probability of encountering poor ground conditions that might need supplemental ground support for the horizontal emplacement drift is approximately 20%.

3.0 CONCLUSIONS

The analyses presented in Section 2.0 were performed for the conceptual design of repository shafts (concrete lined) and drifts in the Topophah Spring (TSw1 and TSw2 units) Member and Calico Hills Formation. Since the ESF is located in the same geologic formations with similar concrete-lined shafts and repository-size or smaller drifts, it is possible to make statements about the anticipated stability of the ESF based on these analyses. However, the conclusions regarding the stability of the ESF that follow are considered preliminary and design-specific; analyses that include seismic loading are required to verify the adequacy of the ESF design.

Shafts analyses by Hustrulid (1984a,b) and St. John (1987d) predict the preclosure (up to 100 yr) stability of concrete-lined shafts in the Topopah Spring Member and Calico Hills Formation. The exploratory shafts (ES-1 and ES-2) penetrate to similar depths, and, therefore, are expected to be stable.

Drift analysis by Ehgartner (1986) predicts the preclosure stability of waste emplacement drifts if such drifts were constructed in TSw1. Because this analysis assumed waste emplacement in TSw1, the thermal loads are in excess of those expected for the USBR drift, which is located above the waste emplacement level. Therefore, this room is expected to be stable.

Drift analyses by St. John (1987a,b,c), Johnstone et al. (1984), Ehgartner (1986 and 1987), Johnson (1981), Langkopf and Gnirk (1986), St. John and Mitchell (1987), Thomas (1987), and Hill (1985) predict that waste emplacement and panel access drifts constructed in TSw2, the repository's waste emplacement horizon, will be stable during the preclosure period. These analyses include thermal loads higher than those expected in the MTL of the ESF because of the closer proximity of the waste to the repository drifts; therefore, the MTL drifts of the ESF are expected to be stable.

Drift analyses by Johnstone et al. (1984), Langkopf and Gnirk (1986), and Thomas (1987) predict the preclosure stability of waste drifts constructed in the Calico Hills Formation. Two of the analyses assumed waste emplacement in the Calico Hills; therefore, the calculated loads are in excess of those actually expected for the CHDR drift, which is expected to be stable.

Based on interpretation of the above analyses, shafts and drifts in the Topopah Spring and Calico Hills units can be constructed and will remain stable through the decommissioning period of the repository. This includes the presently planned shafts and drifts of the ESF that may later become parts of the repository. Although these conclusions are preliminary, the ranges of properties used in the analyses are large and the conditions considered are, in many cases, more severe (in some cases much more severe), than those anticipated for the ESF drifts that become parts of the repository. Therefore, it is doubtful that analyses performed using ESF-specific geometries and properties will alter in these conclusions.

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APPENDIX A

SYNOPSES OF THERMO/MECHANICAL ANALYSES

This section comprises synopses of thermo/mechanical calculations that were performed for underground design analyses. Calculations synopsized here are those documented in SAND reports. The purpose of the section is to provide an overview of the calculations, indicating the codes and input data used and the results. In some cases, results were interpreted. Interpretations were either obtained directly from the reports or inferred from data and results in the analyses. The majority of analyses address excavations within unit TSw2 of the Topopah Spring Member and unit CHnv of the Calico Hills Formation. Results of analyses for excavations in geologic media are clearly identified. Specific values contained in the data sets listed in the following synopses of SAND reports reflect refinements or updates in data made over the 7-yr period during which the analyses were conducted. The most recent analyses, as reported in the 1987 SAND documents, used referenced repository data (SNL, 1987, Appendix O), which were used in developing the conceptual design of the repository. Earlier reports used data that were available at that time. The variability in data among some of the reports gives a perspective on the sensitivity of the results to data changes. Even though data varied considerably in some cases, the analyses predicted stable underground openings in all cases. The synopses numbers and titles, authors, and date of publication are list below.

Synopsis No.	Reference
1	"Lining Considerations for a Circular Vertical Shaft in Generic Tuff," W. Hustrulid, December 1984a.
2	"Preliminary Stability Analysis for the Exploratory Shaft," W. Hustrulid, December 1984b.
3	"Interaction of Nuclear Waste Panels with Shafts and Access Ramps for a Potential Repository at Yucca Mountain," C. St. John, September 1987d.

4 "Thermo-Mechanical Scoping Calculations for a High Level Nuclear Waste Repository in Tuff," R. Johnson, October 1981.

5 "Unit Evaluation at Yucca Mountain, Nevada Test Site: Summary Report and Recommendation," J. Johnstone, R. Peters, and P. Gnirk, June 1984.

6 "Structural Analysis of the NNWSI Exploratory Shaft," J. Hill, June 1985.

7 "Rock-Mass Classification of Candidate Repository Units at Yucca Mountain, Nye County, Nevada," B. Langkopf, P. Gnirk, February 1986.

8 "Effect of Porosity on Emplacement Drift Stability," B. Ehgartner, October 1986.

9 "Investigative Study of the Underground Excavations for a Nuclear Waste Repository in Tuff," C. St. John, July 1987b.

10 "Near Field Mechanical Calculations Using a Continuum Jointed Rock Model in the JAC Code," R. Thomas, May 1987.

11 "Thermomechanical Analysis of Underground Excavations in the Vicinity of a Nuclear Waste Isolation Panel," C. St. John, July 1987c.

12 "Reference Thermal and Thermal/Mechanical Analyses of Drifts for Vertical and Horizontal Emplacement of Nuclear Waste in a Repository in Tuff," C. St. John, May 1987a.

13 "Investigation of Excavation Stability in a Finite Repository," C. St. John and S. Mitchell, May 1987.

14 "Sensitivity Analyses of Underground Drift Temperature, Stresses, and Safety Factors to Variation in the Rock Mass Properties of Tuff for a Nuclear Waste Repository Located at Yucca Mountain, Nevada," B. Ehgartner, May 1987.

Synopsis 1: "Lining Considerations for a Circular Vertical Shaft in Generic Tuff," W. Hustrulid, December 1984a.

Introduction:

This analysis considered the stability of a shaft liner and the surrounding rock mass using both elastic and plastic approaches. A homogeneous, isotropic rock medium and concrete liner were assumed. As such, absolute dimensions were not important; rather, the effects of relative size were considered. Shaft stability was considered for three different geologic horizons--the Calico Hills, Bullfrog, and Tram.

Codes:

No computer codes were required for this analysis. The analytic equations were developed in the text along with the assumptions used for both the elastic and plastic conditions.

Data:

The data used are listed below.

LABORATORY VALUES OF ROCK STRENGTH

Formation	Matrix Cohesion (MPa)	Angle of Internal Friction(deg) Wet	Angle of Internal Friction(deg) Dry
Calico Hills	10	11	25
Bullfrog	12	25	35
Tram	12	25	35

Representative horizontal in situ stresses of each formation were applied to the shaft. The horizontal components of in situ stress were assumed equal at 10.8, 14.6, and 16.7 MPa, respectively, for the Calico Hills, Bullfrog, and Tram Formations. Thermally induced stresses resulting from waste emplacement were not considered.

Results:

The analysis of the rock mass surrounding the shaft established an "M" value or reduction factor for the laboratory strength for each formation. In most rock, the laboratory strength values as determined from intact rock are higher than the in situ rock mass strength; therefore, a reduction factor is applied. The laboratory strength divided by the strength reduction factor (M) equals the in situ rock mass strength. The amount of reduction necessary to realistically evaluate the in situ values is imprecise; it can be estimated only from past empirical approaches. The maximum reduction factor for no failure to occur was computed instead of applying a reduction factor to the laboratory values of the rock strength. The factors are listed below for each formation and different water condition.

MAXIMUM VALUES OF M WITHOUT SHAFT WALL FAILURE

Formation	M Factor	
	Wet	Dry
Calico Hills	1.12	1.45
Bullfrog	1.44	1.68
Tram	1.25	1.47

Because actual M values are likely to be higher than the above values, the presence of a failed zone (plastic) around the shaft is expected. In order to prevent the development of a failed annular region around the shaft, a liner may be necessary. The thickness of the shaft liner depends on the water condition of the rock and the strength reduction factor used. These values, assuming a safety factor of 1.5, are listed below.

REQUIRED SHAFT LINING THICKNESS (m)

Formation	Condition	Strength Reduction Factors				
		M=1	M=2	M=3	M=4	M=5
Calico Hills	wet	0	0.41	1.40	2.10	2.63
	dry	0	0	0.12	0.47	0.72
Bullfrog	wet	0	0	0.70	1.35	1.84
	dry	0	0	0	0.30	0.56
Tram	wet	0	0.30	1.52	2.48	3.24
	dry	0	0	0.32	0.77	1.10

Appendix O in the Site Charaterization Plan Conceptual Design Report (SCP-CDR) (SNL, 1987) uses an M factor of 2.0 for reducing the laboratory values of intact rock properties to rock mass values. The appendix also discusses the rationale used in deriving the reduction factor. Applying the reduction factor of 2.0 to the above results shows that the necessary liner thickness ranges from 0 to 0.4 m for the units that lie below the Topopah Spring Member. Further, it is anticipated that a failed region of rock will surround the shaft liner.

Synopsis 2: "Preliminary Stability Analysis for the Exploratory Shaft," W. Hustrulid, December 1984b.

Introduction:

A boundary element code was used to evaluate the stability of the rock mass around the exploratory shaft in the Calico Hills Formation. This work was undertaken because the shaft is to go below the repository horizon; consequently, the deeper, weaker Calico Hills was chosen for analysis rather than the Topopah Spring Member. The Calico Hills is approximately five times weaker than the Topopah Spring tuff unit (TSw2). It is estimated that a shaft liner, 1 ft thick, is sufficient for the exploratory shaft in the Calico Hills. A circular shaft within 14-ft-external diameter was analyzed.

Codes:

The computer code used for the analysis is not mentioned in the study, other than to say it was a boundary element code.

Data:

The data necessary for the boundary element analysis include knowledge of the rock mass strength and in situ stress state.

The stress states and unconfined compressive strengths assumed for the rock mass are given in the table below. The horizontal stress ratio is the ratio between the two horizontal stresses applied to the shaft. A ratio other than one represents a biaxial horizontal stress field with orthogonal stress components.

CASE STUDIES USING BOUNDARY ELEMENT SIMULATION

		Units in psi	
Case	Horizontal Stress Ratio	Minimum Horizontal Stress	Unconfined Compressive Strength
1a	1	725	4553
2b	1	725	2276
3c	1	725	1138
4a	2	725	4553
5b	2	725	2276
6c	2	725	1138

Case 'a' incorporates a reduction factor of 1 for the unconfined laboratory rock strength, 'b' a reduction factor of 2, and 'c' a reduction factor of 4. The friction angle of the rock mass was assumed constant at 28° for all cases.

Results:

Cases 1, 2, and 4 show no development of a failure region in the rock mass. Case 3 has a region of uniform annular failure that penetrates the rock mass for a distance of 1 ft. Case 5 has two failure regions develop at 90° to the direction of maximum horizontal stress. The failure extends 2 ft into the rock mass. Case 6 has a similarly oriented failure region, but it extends 4 ft into the rock mass and is peripherally more extensive, indicating the possible need for some rock reinforcement before the lining of the shaft. However, major difficulties are not expected for sinking a shaft in the Calico Hills Formation. Improved conditions are expected in the Topopah Spring tuff (Tsw2) since it has a higher compressive strength.

Synopsis 3: "Interaction of Nuclear Waste Panels with Shafts and Access Ramps for a Potential Repository at Yucca Mountain," C. St. John, September 1987d.

Introduction:

The effects of thermally induced loads on a repository shaft and ramp were considered; however, only the analysis pertaining to repository shafts is discussed here. Two shaft locations were analyzed; in the first, the vertical shaft was located at the repository center in a 200-m wide barrier pillar and in the second, 100 m beyond the edge of the repository. The shafts had an external diameter of 6.5 m. Analyses were performed for 0, 10, 50, and 100 yr after waste emplacement assuming an APD of 57 kW/acre. Two alternative in situ stress states were considered. One stress state used Poisson's ratio to determine the horizontal in situ stress; the other used a hydrostatic stress state at the repository level. In both cases the vertical stress was derived from the weight of the overlying strata. TSw2 properties were assumed for the thermomechanical model of the rock mass.

Codes:

Three computer codes were used for the analyses. The thermal portion of the work was performed by STRES3D, a three-dimensional semi-analytic code using the analytic solution for temperature, displacements, and stresses around constant or exponentially decaying, point heat sources. STRES3D is documented in a user's guide and manual (St. John and Christianson, 1980). Structural stability of the ramp was analyzed using HEFF, a two-dimensional boundary element code. This code is documented in a user's guide and manual (Brady, 1980). The structural code SHAFT used for shaft analyses enables the stability of both the liner and rock mass to be analyzed. The theoretical background for SHAFT is described by St. John and Van Dillen (1983). Also used was LINFD, a code for plane analysis of a lined circular hole.

Data:

The data are supplied below.

MECHANICAL PROPERTIES

Mechanical Properties	Value
For Tuff:	
Thermal Conductivity	1.85 W/M°C
Heat Capacity	2.17 $MJ/m^3 \cdot C$
Density	2093 Kg/m^3
Uniaxial Compressive Strength	75.3 MPa
Uniaxial Tensile Strength	-6.5 MPa
For Concrete:	
Modulus	27.6 GPa
Poisson's Ratio	0.15
Uniaxial Compressive Strength	34.5 MPa (5,000 psi)
Uniaxial Tensile Strength	-3 MPa

Results:

The heating of the repository host rock results in an induced horizontal stress of approximately 11 MPa at the repository level after 100 yr. A slight tensile stress of about 2 MPa is induced above the repository. The orientation of the induced tensile stress changes with location. The direction is vertical at the repository horizon and horizontal near the ground surface. The induced thermal stresses must be superimposed on the in situ stress state to form the total stress state to which a shaft or ramp is subject. The vertical in situ stress ranges from 0 at the surface to 6 MPa at repository level (300 m below surface). The corresponding horizontal stress ranges from 0 at the surface to 1.5 or 6.4 MPa depending on the case studied (6.4 MPa is the hydrostatic in situ stress case at the MTL). The potential for joint activation is determined by postprocessing the results from the elastic rock mass stress state at 0, 10, 50, and 100 yr after waste emplacement for both in situ stress states considered. Joint activation is limited to within 16 m of the ground surface for the hydrostatic in situ stress case. The in situ stress case, as determined by Poisson's ratio, shows a greater potential for joint activation after waste emplacement. For this case, the joints are activated in the upper half of the repository overburden at and after 50 yr.

The potential for rock failure and joint slip around the ramp was analyzed at various locations along the ramp. For the ramp the lowest safety factor for the intact rock is observed in the crown 100 yr after waste emplacement. This safety factor of 2.5 is based on a boundary stress of 31 MPa. Shafts were analyzed at two locations for 100 yr after waste emplacement. The shaft location at the center of the repository experiences roughly twice the induced thermal load as the outer shaft location. The maximum induced stress, both compressive and tensile, on the shaft at the center of the repository is approximately 4 MPa. Failure of the rock mass surrounding the shafts is unlikely for both stress states and locations examined.

Also, the state of stress in shaft liners was evaluated using a simple model accounting for interaction between the rock mass and the liner after thermal loading of the repository. A shaft with a 5.5-m external diameter and a 0.5-m concrete liner, in the horizontal cross section, shows no sign of failure. However, horizontal annular cracking occurs for the inner shaft location because of induced vertical tensile stress (4.3 MPa) that exceeds the tensile strength of the concrete (3 MPa). The induced tensile stress at the outer shaft location is less than the strength of the concrete. However, there is no evidence to suggest that such cracking would be detrimental to the performance of a liner.

Synopsis 4: "Thermo-Mechanical Scoping Calculations for a High Level Nuclear Waste Repository in Tuff," R. Johnson, October 1981.

Introduction:

The temperature, vertical stress, and horizontal stress contours were determined at 0, 1, 5, 10, 50, and 100 yr after emplacement of waste in a vertical emplacement drift. Vertical joint slip and dilation were also analyzed for the rock mass surrounding the drift. The 5-m wide by 5-m high drift was rectangular shaped with rounded corners. The drift had a 3-m standoff to the emplaced waste in a 6-m deep borehole. Drift spacing was 25 m. Both ground-water boiling and no-boil conditions were analyzed for two different APDs (75 and 100 kW/acre) for the emplaced waste. A reduced modulus of elasticity was used because it is more likely to result in an intact rock failure. However, the lower modulus results in a smaller region of joint motion in the sidewalls of the drift. The drift depth was 800 m, and the horizontal in situ stress was 65 percent of the vertical in situ stress as determined by the depth and density of the overburden.

Codes:

ADINAT (Bathe, 1978b) and ADINA (Bathe, 1978a) incorporating the ubiquitious-joint material model were used for the analyses.

Data:

The material properties used in this analysis are reproduced below.

MECHANICAL PROPERTIES FOR ROCK AND JOINT BEHAVIOR

Mechanical Properties	Value
Young's Modulus	2.0 GPa
Poisson's Ratio	0.25
Shear Modulus	8.0 GPa
Coefficient of Expansion (<100°C)	7.5E-6 /°C
for Temperature >100°C	10.3E-6 /°C
Friction Coefficient	0.93
Cohesion	8.5 MPa
Joint Friction Coefficient	0.70

MECHANICAL PROPERTIES FOR ROCK AND JOINT BEHAVIOR
(concluded)

Mechanical Properties	Value
Joint Cohesion	0.01 MPa
Joint Orientation	Vertical
Joint Angle Dispersion Coefficient	1.0E+6

Results:

Temperature of the drift for the 75-kW/acre loading peaks at 98°C approximately 50 yr after waste emplacement. The 100-kW/acre loading causes the temperature to peak at nearly the same time, but the value is higher--107°C. The latter temperature assumes an unventilated drift condition by approximating the radiative and convective properties of air with an equivalent thermal conductivity. Boundary compressive stresses at the crown and sidewall are 20 and 25 MPa, respectively, 100 yr after emplacement of 75 kW/acre of high-level waste. The higher loading of 100 kW/acre results in nearly the same stress levels for the drift, i.e, an increase of only 1 to 2 MPa in boundary stresses over the lower thermal loading of the drifts. For both cases the only intact rock failure occurs locally in the corners of the drifts, and in neither case does it extend more than 1 m into the rock mass. Joint activation extends 4 m into the sidewalls of the drift at 100 yr with a mixture of joint opening and slippage. Little difference is found between the boiling and no-boiling conditions for both loading densities.

Synopsis 5: "Unit Evaluation at Yucca Mountain, Nevada Test Site: Summary Report and Recommendation," J. Johnstone, R. Peters, and P. Gnirk, June 1984.

Introduction:

Thermal and mechanical analyses were conducted on units within the Topopah Spring, Calico Hills, Bullfrog, and Tram Members. To analyze the vertical emplacement drift, the row of canisters in a drift was approximated by a continuous heat source. An unventilated rectangular drift with round corners was assumed for these analyses. The drift standoff to the waste was 4.17 m. The borehole length was 8.0 m and drift spacing was 25 m. The drifts were 4.5 m wide by 6.5 m high. A jointed rock-mass model was used with an APD of 57 kW/acre for the Topopah Spring and 54 kW/acre for the Calico Hills. All geologic units were found acceptable with respect to opening stability. The drift in the Topopah Spring Member was found to be more stable than the drifts in the other units considered. This fact weighed in the selection of the Topopah Spring tuff for the repository horizon. Many of the results presented (specifically ubiquitous-joint analyses) are documented in "Unit Evaluation at Yucca Mountain, Nevada Test Site: Near Field Thermal and Mechanical Calculations Using the SANDIA-ADINA Code" (Johnson and Bauer, 1987).

Codes:

Thermal calculations were performed by two different codes, ADINAT and SPECTROM-41. The mechanical calculations containing ubiquitous vertical joints used both Sandia-ADINA and SPECTROM 11. All calculations were two-dimensional, planar, isotropic, and homogeneous. ADINAT is documented in Bathe (1978b); its companion code, ADINA, is documented in Bathe (1978a). The User's Manual for SPECTROM-41 is documented in Svalstad (1981), and its companion code, SPECTROM-11, is documented in Yamada (1981).

Data:

Data properties used in the above analyses were drawn from several different references. The average and limiting property values for Topopah Spring and Calico Hills are listed. The limiting property values were chosen to maximize rock damage on a room and pillar scale by using a reasonable bound for the range of data values.

Results:

Joint motion is limited at excavation time to the corners of the drift, but after 100 yr the slip region extends approximately 3 m into the sidewalls for the average property analysis. When the limiting properties are used, the same progression occurs but the joint slip region extends 4 to 5 m into the drift walls. The lowest safety factor against intact rock failure at any time is located in the roof of the excavation. With the use of average properties, the safety factor decreases from approximately 6.0 to 3.0 because of the induced thermal loading on the drift after 50 yr. If the limiting rock properties are used, the safety factor in the roof decreases from 4.5 to 1.5 over 50 yr. In both cases the drift is stable. The only sign of instability results in the limiting properties case 100 yr after waste emplacement. A slight failure of intact rock is noted at the rounded corners of the excavation. The rock failure, as evidenced by a safety factor of less than 1.0, extends only 0.2 m into the drift boundary. This localized instability is considered inconsequential to the overall stability of the drift. No failure is evidenced at any time when average properties are used.

Temperature contours of the unventilated drift were plotted by Johnson and Bauer (1987) for both limiting and average properties from which estimates of the drift floor temperatures were taken. The results are presented below for the vertical emplacement drift at optimized gross thermal loading (57 kW/acre).

AVERAGE AND LIMITING PROPERTIES

Property	Topopah Spring Average Value	Topopah Spring Limiting Value	Calico Hills Average Value	Calico Hills Limiting Value
Temperature Ranges (°C)				
saturated	<100	<100	<100	<100
transition	100-125	100-125	100-125	100-150
dry	>125	>125	>150	>180
Conductivity (W/m-°C)				
saturated	1.8	1.5	1.3	1.2
transition	1.7	1.45	1.1	1.0
dry 1.6	1.4		0.9	0.8
Heat Capacity (cal/cm^3-°C)				
saturated	0.52	0.53	0.65	0.67
transition	2.47	3.15	3.93	4.44
dry 0.42	0.40		0.32	0.29
Thermal Expansion (1/°C 10E-6)				
32-200°C/32-100°C	10.7	14.1	6.7	-0.4
200-350°C/100-150°C	31.8	53.6	-56.0	-115.0
350-400°C/150-300°C	15.5	23.1	-4.5	-9.3
Initial Temperature (°C)	26	29	30	34
Modulus of Elasticity (MPa)	26.7	18.2	8.1	6.3
Poisson's Ratio	0.14	0.16	0.16	0.14
Unconfined Compressive Strength (MPa)	91	63	29	22
Vertical In Situ Stress (MPa)	8.6	11.3	10.3	15.4
Ratio of Horizontal to Vertical In Situ Stress	0.96	0.96	0.87	0.87
Matrix Cohesion (MPa)	28.5	20.7	10.9	9.0
Angle of Friction (degrees)	26	23.4	15.9	12.3
Matrix Tensile Strength (MPa)	12.8	9.4	0.1	0.1
Joint Cohesion (MPa)	1	0	0.4	0
Coefficient of Sliding Friction	0.8	0.8	0.55	0.55
Joint Tensile Strength (MPa)	0.1	0.1	0	0

TEMPERATURE AT DRIFT FLOOR (°C)

Time (yr)	Average Properties	Limiting Properties
0	26	29
5	65	69
10	70	73
20	93	94
50	97	99
100	100	101

The results of the thermomechanical analysis for the Topopah Spring (vertical) emplacement drift compared well with those performed for the Grouse Canyon tuff in G-Tunnel. These calculations were compared at the time of excavation because G-Tunnel is not subject to thermal loading. G-Tunnel is a stable excavation, and the parallel that stable openings should be expected in Yucca Mountain (i.e., localized regions of joint slip have not caused problems in G-Tunnel operations) is drawn because of their similar properties and predicted response.

Synopsis 6: "Structural Analysis of the NNWSI Exploratory Shaft," J. Hill, June 1985.

Introduction:

This analysis was performed to predict rock stability conditions in the ESF (TSw2). The results of this analysis were intended to aid drift instrumentation when the facility is actually constructed. The analysis comprised two independent parts--a three-dimensional model of the ESF and a two-dimensional parametric study of two drifts separated by a pillar of two different widths. The three-dimensional problem used a linear elastic material model, and the two-dimensional problem incorporated jointing. The same codes and consistent parameters were used for both the two- and three-dimensional studies to allow comparison of results. The drifts were approximately 5 m by 5 m, square or arched shaped.

Codes:

The analysis executed the ADINA code on the Sandia CRAY-1 machine for both the two- and three-dimensional analysis. This code is referenced in "ADINA--A Finite Element Program for Automatic Dynamic Incremental Nonlinear Analysis," (Bathe, 1978a).

Data:

The material properties used in the analysis are listed below.

MATERIAL PROPERTIES

Mechanical Properties	Value
Young's Modulus	26.7 GPa
Poisson's Ratio	0.14
Grain Density	2.55 g/cm^3
Unconfined Compressive Strength	91.1 MPa
Matrix Internal Friction	0.488
Matrix Tensile Strength	-12.8 MPa
Joint Friction Coefficient	0.8
Joint Cohesion	1.0 MPa
Joint Tensile Strength	-0.1 MPa
Horizontal In Situ Stress (inplane)	1.87 MPa
Vertical In Situ Stress	9.47 MPa
Horizontal In Situ Stress (outplane)	2.62 MPa
Joint Angle	Vertical

Results:

The two-dimensional model considered both elastic and inelastic (joint) behavior and found the results to be similar. With an approximate 5-m drift and 6-m pillar, the elastic material model shows a safety factor against intact rock failure of 4.5 near the drift boundary. The jointed model had a safety factor of 4.0. Vertical stresses for the two material models are almost identical. The two-dimensional analysis on the narrow pillar shows the lowest safety factor against intact rock failure as 3.0. A similar safety factor of 4.0 is found in the three-dimensional analysis. On the basis of these analyses no structural problems are anticipated in the ESF.

Synopsis 7: "Rock-Mass Classification of Candidate Repository Units at Yucca Mountain, Nye County, Nevada," B. Langkopf and P. Gnirk, February 1986.

Introduction:

A set of analyses using two empirical methods for classifying rock mass was performed on core extracted from the nonlithophysal portion of the Topopah Spring Member. The purpose was to evaluate numerically the rock mass conditions of the emplacement horizon and compare the ratings to those established by case studies performed on many other mines and tunnels. The comparison led to general estimates of the rock quality. More specifically, the comparisons helped in the development of unsupported standup time for a certain opening width and requirements for ground support. A specific comparison to the case study of G-Tunnel was made because the rock characteristics in G-tunnel are similar to the rock characteristics expected at Yucca Mountain.

Codes:

No computer codes were required for the two empirical approaches. The two approaches used were the NGI Tunnel Quality Index (Barton et al., 1974) and the CSIR Geomechanics Classifications (Bieniawski, 1976) methods.

Data:

Two methods for classifying rock mass were used to predict the stability of underground openings. The NGI Tunnel Quality Index and CSIR Geomechanics Classification methods consider the unconfined compressive strength, rock quality designation (RQD), joint properties, ground water conditions, and in situ stress of the emplacement horizon. These parameters were quantified and related to tunnel or drift conditions for a large data base of case studies in all types of rock. One case study with very similar parameters to Unit TSw2 of the Topopah Spring Member was found at the G-Tunnel complex. Excavation dimensions, overburden loads, saturation, degree and nature of fracturing, and thermomechanical properties are similar. G-Tunnel is found in the same geologic medium (tuff). The history of G-Tunnel encompasses more than 20 yr and 3,500 m of drifting (most of which is in nonwelded tuff). The comparison between G-Tunnel drifts and the drifts at Yucca Mountain is specific while the rock-mass classification methods yield a conclusion based on a much broader scope.

The specific parameters called for in the NGI classification system are the RQD, number of joint sets, joint roughness number, joint alteration number, joint water reduction factor, and stress reduction factor. Values for these parameters depend on qualitative descriptions of the joint system and conditions to which they are exposed, as well as on quantitative descriptions of the strength, overburden stress, and the RQD of the rock. The RQD is determined by the amount of fractured core removed from a drill hole. The CSIR classification system uses the strength of the rock, RQD, condition of the joints (roughness, continuity), ground water conditions, and joint orientation to qualify the competency of the rock mass and to estimate standup times for unsupported excavation spans. The data requirements are similar for both classification systems and are listed below for the TSw2 horizon within the Topopah Spring Member and G-Tunnel's stronger unit, the Grouse Canyon tuff.

MECHANICAL PROPERTIES

Property	Topopah Spring Tuff	Grouse Canyon Tuff
Unconfined Compressive Strength	171 MPa	110 MPa
Overburden Stress	8.6 MPa	7.1 MPa
Rock Quality Designation (RQD)	57	44
Joint Sets	2-3 random	2-3 random
Joint Frequency	9.0 joints/m	3.75 joints/m
Joint Alteration	Unaltered wall surface staining only to low frict clay coat	Unaltered wall surface staining only to slight altered wall

MECHANICAL PROPERTIES
(concluded)

Property	Topopah Spring Tuff	Grouse Canyon Tuff
Joint Roughness	Discontinuous joints to smooth, undulating	Discontinuous joints to smooth, undulating
Joint Condition	Very rough surfaces, not continuous, no separation, hard joint wall rock to slightly rough surfaces, separation 1 mm	Very rough surfaces, not continuous, no separation, hard joint wall rock to slightly rough surfaces, separation 1 mm
Joint Orientation	Very favorable to very unfavorable	Very favorable to very unfavorable
Water	Dry excavation or minor inflow (<5 L/min)	Dry excavation or minor inflow (<5 L/min)

Results:

The results are given for TSw2. The CSIR rates the rock strength as high, based solely on knowledge of the unconfined compressive strength. Another important result of the classifications derives from the RQD values. Both the CSIR and NGI rate the rock as fair, based on RQD. When the other factors of the CSIR classification method are considered, the rock mass is rated from very good to fair, the average being good rock. The NGI classifies the rock from very good to poor rock with the average case being good rock. The related support requirements vary as well. The CSIR gives an average standup time of 466 days for an unsupported span of 6.1 m. The range in standup time for a span of that size is estimated at 3 to 930 days. The NGI classification system estimates the maximum unsupported roof span from 2.3 to 9.9 m, with the average being 6.0 m. The NGI system further qualifies the required support as ranging from grouted rockbolts on a 3-ft spacing with chain-link mesh and shotcrete to a no-support requirement.

The NGI and CSIR classification systems both indicate that the welded Topopah Spring tuff and the Grouse Canyon tuff are similar. This resemblance results from the similarities in not only the geologic media but also the in situ stress states. An underground facility (G-Tunnel complex), containing miles of drifts, exists in the Grouse Canyon tuff as well as the weaker, less jointed Tunnel Bed 5. The comparison is made with the stronger unit, but stable drift conditions are reported in both the strong and weak units. The drifts of G-Tunnel, which span up to 30 ft in some cases, are stable with minimal support. The observations at G-Tunnel aid in predicting stability of the repository drifts. The thermally induced stresses are not explicitly represented in the rock mass classification schemes, nor have they been accounted for in large-scale tests at G-Tunnel; numerical modeling is valuable in estimating these time-dependent excavation stresses.

Synopsis 8: "Effect of Porosity on Emplacement Drift Stability," Ehgartner, October 1986.

Introduction:

The purpose of this analysis was to estimate the effects of porosity change on the strength, stress, and temperature of the horizontal and vertical emplacement drifts 100 yr after waste emplacement. The emplacement drifts were modeled using the thermoelastic code HEFF and systematically varying the porosity-dependent properties. The modeling was performed at 100 yr after completion of waste emplacement because temperatures and stresses are highest at that time at the crown and floor locations (St. John, 1987a). The results from thermomechanical modeling of the drifts were examined for three specific drift boundary locations--the crown, midwall, and midfloor. The maximum and minimum principal stresses at the drift boundary occur in the crown and midwall, respectively. Consequently, the crown location was evaluated for potential compressive failure, and the midwall was evaluated for potential tensile failure. The temperature of the drift floor was of interest from an operations viewpoint. The problem geometries, material properties, thermal loadings, and assumptions used in the modeling of the emplacement drifts were the same as those defined in the reference drift calculations (St. John, 1987d) except where the noted effects of porosity were included. In the horizontal emplacement, the drifts were 5.99 m wide and 3.96 m high. The waste standoff distance was 35.8 m and borehole length was 207.87 m. In the vertical emplacement, the drifts were 4.88 m wide and 6.71 m high. The waste standoff distance was 3.048 m and borehole length was 7.62 m. Drift spacing was 426.72 and 34.14 m for horizontal and vertical emplacement, respectively. Porosity values discussed in this report reflected the functional or total porosity of the rock.

Codes:

HEFF, a two-dimensional boundary element code, was used to perform the analyses. This code is documented in a user's guide and manual (Brady, 1980).

Data:

Data used in this study varied the porosity over a range of 10 to 50%. Porosity affects several thermomechanical material properties, which determine the stress state surrounding an excavation after waste emplacement. Porosity has been correlated to unconfined compressive strength, angle of internal friction, cohesion, tensile strength, Poisson's ratio, elastic modulus, thermal conductivity, and heat capacity by means of best fit equations to laboratory data (Price, 1983; Price and Bauer, 1985). Of the strength parameters, the internal friction angle and cohesion are not required for determining the safety factor against rock mass failure because the results are examined only at the boundary of the drift. At the drift boundary the safety factor is assumed to be equal to the unconfined compressive strength of the rock mass divided by the stress. The relationships used in the following analyses are presented below:

$$\log q = 0.606 - 1.85 \log n$$

$$T = 0.12q$$

$$\log E = 1.932 - 3.023n$$

$$K = 2.82\exp(1-n)\ 0.607\exp(0.8n)\ 0.042\exp(0.2n)$$

$$Cp = 2.14 + 1.20n$$

$$\log u = -1.879 + 0.676 \log n$$

where

q = unconfined compressive strength (MPa);
n = effective porosity, expressed as a fraction;
T = tensile strength (MPa);
E = modulus of elasticity (GPa);
K = thermal conductivity (W/m-k);
Cp = heat capacity (J/cm^3-k); and
u = Poisson's ratio.

The values for unconfined compressive strength and modulus of elasticity were divided by a factor of two to obtain the rock mass propert s (SNL, 1987, Appendix O). The HEFF code inputs for modulus of elasticity, heat capacity, thermal conductivity, and Poisson's ratio for various porosity levels were obtained from application of the porosity equations above. The values used are shown in the following table.

CODE INPUT

Porosity (%)	Modulus (GPa)	Heat Capacity (J/cm^3-k)	Thermal Condition (w/m-k)	Poisson's Ratio
10	21.31	2.260	2.293	0.101
15	15.05	2.320	2.067	0.133
20	10.63	2.380	1.864	0.161
25	7.503	2.440	1.681	0.188
30	5.298	2.500	1.515	0.212
35	3.741	2.560	1.366	0.235
40	2.642	2.620	1.232	0.258
45	1.865	2.680	1.111	0.279
50	1.317	2.740	1.002	0.300

Porosity values were modeled to establish a trend. The calculated porosity-dependent properties are within the limits to which the porosity equations are applicable.

Results:

The results of the code runs are reported in tabular form. The following table presents the stresses and temperatures calculated by HEFF as well as the compressive strength calculated by using the porosity equation. The designators H and V refer to output for the horizontal and vertical emplacement drifts, respectively.

CODE OUTPUT

Porosity (%)	Crown Stress (MPa) H	Crown Stress (MPa) V	Wall Stress (MPa) H	Wall Stress (MPa) V	Floor Temp (°C) H	Floor Temp (°C) V	Compressive Strength (MPa)
10	36.90	58.80	-3.13	-1.20	57.17	109.1	143.0
15	29.42	47.30	0.015	0.684	57.37	114.8	67.5
20	23.52	38.15	2.62	2.24	57.46	120.9	39.67
25	18.93	30.97	4.74	3.50	57.36	127.4	26.25
30	15.35	25.31	6.46	4.53	57.09	134.3	18.74
35	12.59	20.90	7.84	5.34	56.62	141.6	14.09
40	10.47	17.49	8.92	5.98	55.97	149.3	11.0
45	8.83	14.83	9.79	6.48	55.09	157.5	8.85
50	7.59	12.78	10.48	6.88	54.00	166.2	7.28

In both horizontal and vertical cases, the strength and stress decrease as porosity increases. However, the strength decreases at a faster rate than the crown stress does and results in lowered safety factors for increased porosities. The safety factor for the vertical emplacement drift drops below 1.0 for porosities greater than 21%. The safety factor represents that of the rock mass. Porosities greater than 45% result in a safety factor of less than 1.0 at the crown for the horizontal emplacement drift. Conditions at midwall improve as porosity increases. The wall stresses become less tensile until a state of compression is achieved at the wall for porosities above 15%. In no case does the tensile stress exceed the tensile strength of the rock. However, the compressive wall stresses at porosities greater than 43% exceed the compressive strength of the wall rock for the horizontal emplacement drift.

Little change is noted in the horizontal drift temperature; however, the floor of the vertical emplacement drift experiences large temperature increases as the porosity increases. The temperature increases an average of 1.4°C for each percent increase of porosity for the vertical emplacement drift.

The porosity value is 13.9% for the Tsw2 unit with a standard deviation of 4.1% (SNL, 1987, Appendix O). This expected value range in porosities does not result in drift instability or excessive drift temperature.

The low lithophysal layers within TSw1 have an expected porosity of 14%, which implies stable drifts. The high lithophysal layers within TSw1 have an expected porosity of 35%. For these layers, the horizontal emplacement drift would be stable; however, the crown stresses of the vertical emplacement drift would exceed the rock mass strength. Safety factors of slightly less than 1.0 imply the possibility of localized failure of the crown rock, not of the drift itself. It was concluded that emplacement drifts can satisfactorily withstand the thermal loading of a repository constructed in a rock mass of higher-than-expected porosities.

Synopsis 9: "Investigative Study of the Underground Excavations for a Nuclear Waste Repository in Tuff," C. St. John, July 1987b.

Introduction:

In this parametric study, three drift shapes (arched, rectangular, and a shape that resembles the current emplacement drift design) were analyzed for both horizontal and vertical waste emplacements using boundary and finite element methods. The study included the effects of in situ stress and rockbolting. Because the analyses were performed at excavation time only, the effect of the thermally induced stresses was not considered. In the first analysis, the effect of ground support was assessed by creating a blast-induced fractured region around the excavation and installing fully grouted rock bolts. The second analysis provided an understanding of the extent to which excavation dimensions and shapes influence the deformation and stress around the emplacement drifts immediately after excavation. All analyses were linear elastic, and joint motion was estimated by post-processing the results of the elastic analyses.

Codes:

Two computer codes were used for the analyses of the drifts--HEFF (Brady, 1980) and BMINES. BMINES is a computer program for analytic modeling of rock/structure interaction (Agbabian Associates, 1981).

Data:

The properties used in the second analysis of alternative drift shapes are consistent with those of Appendix O of the SCP-CDR (SNL, 1987). The first analysis, which considered the effects of rock bolting, used data other than those listed in Appendix O of the SCP-CDR. Therefore, the properties used in the first analyses are listed below.

MATERIAL PROPERTIES

Properties	Value
In Situ Stress Gradient	0.023 MPa/m
Modulus of Elasticity	26.7 GPa
Modulus of Damaged Zone	5.54 GPa
Poisson's Ratio	0.14
Uniaxial Compressive Strength	91.1 MPa
Internal Friction Angle	26°
Tensile Strength	12.8 MPa

Results:

The span or width of the horizontal emplacement drift was varied (18, 20, and 23 ft) for each shape considered. The crown or roof stresses for all three of the drift shapes increase (or become more compressive) as the spans decrease for each in situ stress state considered. The crown or roof stresses increase for all drift shapes and spans as the ratio of horizontal to vertical in situ stress increases. In all the cases considered, the maximum compressive stresses do not exceed 12 MPa in the drift roof; however, a tensile stress of approximately 6 MPa in the roof is predicted for each drift shape where the horizontal in situ stress is 0 MPa.

The height of the vertical emplacement drift was varied (15, 18, and 22 ft) for each drift shape considered. Generally, as the height of the drift increases, the stresses in the crown become more compressive. As in the horizontal emplacement drifts, the stresses in the crown of the vertical emplacement drift are more tensile with the lower ratios of horizontal to vertical in situ stress. For all the cases analyzed, the maximum crown stresses are approximately 15 MPa, while the minimum stress levels in the crown are near 6 MPa tensile for most drift shapes and heights.

The second part of the study concludes by stating that, of the three shapes investigated, the one currently being used for the design results in the most moderate stresses, displacements, and number of regions in which the matrix or joint strengths are exceeded. The analyses of different drift dimensions show that the response of the rock mass is relatively insensitive to the drift height and more sensitive to excavation span. Of the alternative in situ stress states, the one with the lowest horizontal stress provides the least favorable response.

The first part of the study found the axial stress developed in the roof bolts to be approximately 50% of the bolt strength when the damaged region around the excavation resulting from blasting was considered. The bolting has an insignificant impact on the drift closure.

Synopsis 10: "Near Field Mechanical Calculations Using a Continuum Jointed Rock Model in the JAC Code," R. Thomas, May 1987.

Introduction:

This analysis aided in the selection of the TSw2 unit within the Topopah Spring Member as the emplacement horizon. Two-dimensional analyses of vertical emplacement drifts in both the Calico Hills and Topopah Spring were performed at times up to 100 yr after waste emplacement using an APD of 57 kW/acre. The drift was rectangular with rounded corners. The drift size was 5 m wide by 7 m high. The waste standoff was 4.17 m and drift spacing was 25 m. Because the TSw2 is the selected disposal horizon, discussion will focus on results obtained from its analyses; however, it should be noted that the Calico Hills emplacement drift was stable up to 100 yr after waste emplacement.

Codes:

The thermal portion of the problem was [illegible] using ADINA (Bathe, 1978a), and the mechanical portion of the [illegible]sis used JAC. JAC is "A Two-Dimensional Finite Element Computer Program for the Nonlinear Quasistatic Response of Solids with the Conjugate Gradient Method" (Biffle, 1984). The code incorporated a compliant joint model for a single set of joints in the tuff. The jointed rock model is described in "A Material Constitutive Model for Jointed Rock Mass Behavior" (Thomas, 1980).

Data:

Thermal input data for the analysis were the same as those used in the unit evaluation study (Johnstone et al., 1984). The analyses parallel each other but differ in the mechanical code and joint model used. The thermal and mechanical properties used in the analyses are listed below. Both average and limiting values are listed. The limiting property values were chosen to maximize rock damage on a room and pillar scale by using a reasonable bound for the range of data values.

AVERAGE AND LIMITING PROPERTIES FOR THE TOPOPAH SPRING

Property	Average Value	Limiting Value
Temperature Ranges (°C)		
saturated	<100	<100
transition	100-125	100-125
dry	>125	>125
Conductivity (W/m-°C)		
saturated 1.8		1.5
transition	1.7	1.45
dry	1.6	1.40
Heat Capacity (cal/cm3-°C)		
saturated	0.52	0.53
transition	2.47	3.15
dry	0.42	0.40
Thermal Expansion (1/°C 10E-6)		
32-200°C	10.7	14.1
200-350°C	31.8	53.6
350-400°C	15.5	23.1
Initial Temperature (°C)	26	29
Modulus of Elasticity (GPa)	26.7	18.2
Poisson's Ratio	0.14	0.16
Vertical In Situ Stress (MPa)	8.6	11.3
Horizontal/Vertical In Situ Stress	0.96	0.96
Rock Cohesion (MPa)	28.5	20.7
Internal Friction (degrees)	26.0	23.4
Joint Orientation	Vertical	Vertical
Joint Spacing (m)	0.5	0.5
Joint Cohesion (MPa)	1.0	0.0
Joint Friction Angle (degrees)	38.7	38.7

Results:

Safety factor plots, made to determine regions of intact rock failure and joint slip about the drift, show that the time-dependent thermal loading tends to decrease the safety factor values for intact rock and joints. For the average property case, the safety factors of intact rock vary from 4.5 at the crown to 6.0 at the sidewalls at excavation time. After 100 yr this value drops to 1.5 in the crown, the lowest safety factor for the drift boundary. Similarly, for the limiting properties case the safety factor at the crown drops from 3.0 at excavation time to 1.5 after 100 yr of thermal loading. The safety factor in the sidewall at 100 yr is 4.5 for the limiting properties case. Joint slip, although isolated to the sidewalls of the drift, becomes more extensive with time. Joint activation after excavation is localized to the immediate corners of the drift; however, after 100 yr the joint activation area extends 3 m into the drift sidewalls for the average property case. The limiting property conditions results in an initial 2.5-m region of joint activation at the time of excavation and extends 5.5 m into the drift pillar or sidewalls 100 yr after waste emplacement. No potential for intact rock failure is noted in either the average or limiting properties case over the 100 yr analyzed.

Synopsis 11: "Thermomechanical Analysis of Underground Excavations in the Vicinity of a Nuclear Waste Isolation Panel," C. St. John, July 1987c.

Introduction:

This analysis considered the stability of the main access drifts, the emplacement drifts, and the intersection of the two drifts. Both spent fuel and defense high-level waste emplaced at 57 kW/acre were considered in the analysis of the drifts. Both horizontal and vertical emplacement drifts were analyzed at emplacement time, 10, 25, and 50 yr later. The geometry of the horizontal emplacement scheme using alcoves was considered as well. For the alcove, the size was 27 ft wide and 14.5 ft high and waste standoff was 25 m. The nominal drift size was 15 ft wide and 14.5 ft high. For the vertical emplacement, drifts were 15 ft wide and 25 ft high. The main repository drifts were modeled as single units and as interactive teams with the neighboring mains. The intersection of the waste emplacement drift and the main access drift was modeled in both two and three dimensions using superposition. Horizontal and vertical loads were applied separately to the intersection geometry to determine their individual effects. With this information, the influence of any stress field can be determined for the intersection by superimposing the composite effects of the applied stresses. Applied thermal stress fields for 0, 10, 25, and 50 yr after waste emplacement were determined from thermomechanical analyses of a horizontal emplacement repository.

Codes:

All analyses were linearly elastic. The two-dimensional analyses of the drifts and intersections used HEFF (Brady, 1980). The three-dimensional analyses of the intersection used a 1981 updated version of ADINA (Bathe, 1978a). Stress fields for the horizontal emplacement panels were determined by STRES3D (St. John and Christianson, 1980) for use in the superpositioning of stresses on the intersection.

Data:

The material and joint properties used in the analysis are listed below.

THERMOMECHANICAL PROPERTIES

Properties	Value	
Thermal Conductivity	1.8	W/m°C
Heat Capacity	0.06923	W-yr/m^3°C
Density	2253	kg/m^3
Poisson's Ratio	0.14	
Elastic Modulus	26.7	GPa
Coefficient of Thermal Expansion	10.7E-6	/°C
Vertical In Situ Stress	7.5	MPa
Horizontal In Situ Stress	7.2	MPa
Uniaxial Strength	91.2	MPa
Matrix Cohesion	28.5	MPa
Friction Angle	26°	
Joint Cohesion	1.0	MPa
Joint Friction Angle	39°	
Joint Orientation	Vertical	

Results:

Thermally induced stresses increase both the vertical and horizontal in situ stresses to 16.4 MPa 50 yr after waste emplacement. The horizontal and vertical stresses are both 12.8 MPa after 25 yr as a result of horizontal waste emplacement. These stress levels correspond to a region of joint slip and localized rock breakage at the sidewalls of the excavation but have a safety factor of approximately 1.5 for the crown of the main access drift. Although the analyses were completed for both spent fuel and commercial high-level waste, there is little difference between the resulting stresses on the drift. Little if any difference is noted between the model of the single drift and the model including its neighboring drift. The modeling of the intersection between the drifts resulted in stress concentrations similar to the modeling of the single respository main drift. The three-dimensional geometry results in an approximately 10% increase in stress over the two-dimensional model. Safety factors for the rock surrounding both the horizontal and vertical emplacement drifts are similar. Both cases show the safety factor near the roof to be between 1.5 and 2.0 after 25 yr of waste emplacement. Joint activation occurs in the drift sidewalls of both types of emplacement drifts. The joint activation region generally extends less than 2 m into the drift walls. Safety factor plots for the horizontal emplacement alcove show equal or slightly increased stability for the rock mass surrounding it. This stability probably results from the elliptical shape of the alcove being oriented favorably to the principal stress.

Synopsis 12: "Reference Thermal and Thermal/Mechanical Analyses of Drifts for Vertical and Horizontal Emplacement of Nuclear Waste in a Repository in Tuff," C. St. John, May 1987a.

Introduction:

This analysis reflects the current properties and geometries of the emplacement drift. Both horizontal and vertical emplacement drifts were modeled under ventilated and unventilated conditions at 0, 10, 35, and 100 yr after waste emplacement at 57 kW/acre. The horizontal emplacement drifts were 5.99 m wide and 3.96 m high and waste standoff was 35.8 m. For vertical emplacement the drifts were 4.88 m wide and 6.71 m high and waste standoff was 3.048 m. Drift spacing was 426.72 m and 34.14 m for horizontal and vertical emplacements, respectively. Two different codes were used with the same thermal and mechanical model parameters to increase confidence in the results.

Codes:

HEFF (Brady, 1980), a boundary element code, was used to compare results with the finite element code VISCOT (ONWI, 1983b). A two-dimensional elastic plane strain model with homogeneous, isotropic material properties was used. The thermal companion code used was DOT. DOT is "A Nonlinear Heat Transfer Code for Analysis of Two-Dimensional Planar and Axisymmetric Representations of Structures (ONWI, 1983a)."

Data:

Material properties used are referenced in Appendix O of the SCP-CDR (SNL, 1987). Material properties (rock mass) used in the analysis were particular to unit TSw2 and are listed below.

THERMOMECHANICAL PROPERTIES

Property	Value
Thermal Conductivity (K)	2.18 W/mC
Heat Capacity (c_p)	$2.07 * 10^6$ J/m^3K

THERMOMECHANICAL PROPERTIES
(concluded)

Property	Value	
Thermal Diffusivity * (κ)	33.235	m^2/yr
Density (ρ)	2340.0	kg/m^3
Poisson's Ratio (ν)	0.2	
Elastic Modulus (E)	15.1	GPa
Coefficient of Thermal Expansion (α)	$10.7 * 10^{-6}$	K^{-1}
Uniaxial Strength (σ_c)	75.4	MPa
Matrix Tensile Strength (σ_T)	-9.0	MPa
Intact Friction Angle (ϕ)	29.2°	
Cohesion (C_j)	1.0	MPa
Friction Angle (ϕ_j)	38.6°	

$$*\text{Thermal Diffusivity} = \frac{\text{Thermal Conductivity}}{\text{Heat Capacity}}$$

Results:

Average temperatures in the unventilated drifts 100 yr after waste emplacement rise from the in situ value of 23° to 109°C for the vertical emplacement drifts and from 23° to 58°C for the horizontal emplacement drifts. In the horizontal emplacement drift, the increased temperature in the rock mass raises the induced horizontal stress from the in situ value of 3.82 to 14.5 or 13.0 MPa (unventilated and ventilated drifts, respectively) but slightly decreases the in situ vertical stress of 6.95 MPa 100 yr after waste emplacement. These levels of induced stress on the horizontal emplacement drift result in a crown stress of 36.15 MPa and 30.88 MPa at 100 yr for the unventilated and ventilated conditions, respectively. Corresponding midwall stresses are -5.17 MPa and -8.81 MPa (tensile) for the unventilated and ventilated conditions.

The effects of ventilation are more pronounced on the vertical emplacement drift. Crown stresses are 54.28 MPa and 11.60 MPa for the unventilated and ventilated conditions. Here, induced horizontal stress from the increased temperature of the rock mass was 18.0 and 6.0 Mpa for unventilated and ventilated drift, respectively. Midwall stresses for these two conditions are -3.84 MPa (tensile) and 5.78 MPa respectively.

No intact rock failure is observed in the drifts for either of the boundary conditions. Safety factor values in the crown of the vertical emplacement drift range from a low of 1.2 for the unventilated drift to 3.9 for the ventilated condition 100 yr after waste emplacement. The initial safety factor value at excavation time is 7.2 in the crown. The horizontal emplacement drift has a safety factor of 10.4 in the crown at emplacement time. This value decreases to 1.6 and 1.8 for the unventilated and ventilated conditions, respectively. Joint slip regions appear in the sidewalls of the drifts at excavation time but are limited in extent. The slip region for the vertical joints progresses into the rock mass 2 m from the sidewalls 100 yr after waste emplacement for both drift types. Consideration of both the safety factor values for the intact rock and the potential for joint slip results in the conclusion that the drifts will be stable for the mining and emplacement conditions analyzed.

Synopsis 13: "Investigation of Excavation Stability in a Finite Repository," C. St. John and S. Mitchell, May 1987.

Introduction:

This analysis studied the effects of a finite-size repository. Prior repository-scale analyses usually placed reflection boundaries between repository panels. The effect was to model a repository infinite in size or areal extent. In this study, discrete linear heat sources were placed at realistic locations to model a four-panel-wide repository with waste emplaced at 57 kW/acre. The edge effects of the repository on drift stability were analyzed for the first time.

Codes:

The computer code HEFF (Brady, 1980) was used in the analysis.

Data:

Data used in the study for unit TSw2 are referenced in Appendix O of the SCP-CDR (SNL, 1987) and are listed below. The analysis used two different in situ stress states. The recommended stress state derived from the Poisson's ratio and one that reflects a nearly hydrostatic stress state given by St. John (1987c) were used for this analysis. A horseshoe-shaped drift was located at five possible positions for purposes of the analysis. The drifts were assumed to be located within a central shaft pillar, within a small pillar between adjacent panels, or at the repository perimeter. The drift size was 5.5 m wide and 4.4 m high, and waste standoff distances varied at 25, 50, and 100 m. Drift spacing was 428.2 m. The data for this analysis are listed below.

DATA FOR THERMAL AND THERMAL/MECHANICAL ANALYSES OF EMPLACEMENT DRIFTS

Property	Value
Specific Gravity	2.34 g/cc
Young's Modulus	15.1 GPa
Poisson's Ratio	0.2
Thermal Conductivity	
(25 to 100°C temp range)	2.07 W/m * K
Thermal Capacitance	2.25 J/cm^3 K
Thermal Expansion ($*10^6$)	

DATA FOR THERMAL AND THERMAL/MECHANICAL
ANALYSES OF EMPLACEMENT DRIFTS
(concluded)

Property	Value
(25 to 200°C temp range)	10.7 /°C
Horiz./Vert. In Situ Stress	0.55
Ground Surface Temperature	16.0 °C
Temperature Gradient	0.0239°C/m
Unconfined Compressive Strength of Rock	75.4 MPa
Tensile Strength	-9.0 MPa
Angle of Internal Friction	29.2°
Joint Cohesion	1.0 MPa
Joint Coefficient of Friction	0.8 (38.7°)
Joint Angle (frequently assumed value)	90° (vertical)

Results:

Differences in stress states and safety factors for the rock mass occur after waste emplacement because of the two alternative in situ ~ess states used in the analysis, but the differences are minor. .e lowest safety factors occur after waste emplacement when the induced thermal stresses act on the drift openings. The drift located between the outer panels, analyzed at 50 yr, has the lowest safety factor. Fifty years after emplacement was the latest time analyzed; trends indicate that later times, if analyzed, may show lower safety factors. The lowest safety factor, 1.3, is found at the crown of the excavation. Localized joint slip conditions exist for all the drifts analyzed. The extent of joint slippage is inconsequential to the drift stability. Vertical joint slip occurs in the drift sidewalls. Joint slip is a postprocessed option and therefore represents only the potential for joint slip. Horizontal joint slip was also considered. This potential joint slip occurs in the roof and floor of the excavation. Several three-dimensional joint orientations were considered. The largest region of joint slip is associated with the vertical joints oriented parallel to the drift axis. The basic conclusion of the study was that, although some differences occur in drift stability because of either drift location or the effect of the finite size of the repository, all drifts are found stable for both a finite- and infinite-size repository for up to 50 yr.

Synopsis 14: "Sensitivity Analyses of Underground Drift Temperature, Stresses, and Safety Factors to Variation in the Rock Mass Properties of Tuff for a Nuclear Waste Repository Located at Yucca Mountain, Nevada," B. Ehgartner, May 1987.

Introduction:

This analysis determined the sensitivity of horizontal emplacement drift temperatures, stresses, and safety factors to changes in the elastic rock mass properties of TSw2. The drift size was 5.49 m wide and 3.96 m high with an arched shape. The two-dimensional model represented waste emplaced at 57 kW/acre. Two boundary locations, the crown and sidewall of the drift, were examined at 50 yr for stress changes resulting from property changes. In some instances, it was inappropriate to examine the sensitivity of stress levels, such as for the postprocessing parameters. In these cases, the changes in safety factors were examined. The sensitivity of temperature to the purely thermal properties was also investigated.

Codes:

The computer program HEFF (Brady, 1980) was used for the analyses. HEFF is a boundary element code for linear elastic analysis using decaying heat sources.

Data:

Data used for the analysis are referenced in Appendix O of the SCP-CDR (SNL, 1987). Also required for the analysis were the standard deviations for the rock mass properties. The standard deviations were obtained through statistical analysis of data from the Topopah Spring Member. The parameters that were varied and their corresponding standard deviations are listed below.

PARAMETER DATA

Parameter Varied	Average Value	Standard Deviation
Density of Rock (g/cm^3)	2.34	0.07
Compressive Strength (MPa)	75.4	44.0
Elastic Modulus (GPa)	15.1	5.1
Poisson's Ratio	0.2	0.04

PARAMETER DATA
(concluded)

Parameter Varied	Average Value	Standard Deviation
Tensile Strength (MPa)	9	1.3
Thermal Conductivity (W/m-°C)	2.07	0.46
Rock Friction Angle (degrees)	29.2	3.2
Thermal Capacitance ($J/cm^3 °C$)	2.25	0.11
Geothermal Gradient (°C/m)	0.0239	0.0093
Joint Cohesion (MPa)	1.0	0.38
Joint Friction Angle (degrees)	38.7	4.25
Thermal Expansion (per °C)	10.7E-6	1.6E-6

Results:

The sensitivity of a model response (temperature, stress, or safety factor) is defined as the average change in model response divided by change in parameter. The model response was recorded at the drift crown, midwall, and midfloor. A positive sensitivity would indicate that, as the numerical value of the parameter increases, the model response increases as well. A negative slope would indicate that, as the parameter increases, the model response decreases. The varied parameters, the sensitivities, and the locations of the recorded model response are tabulated below.

PARAMETERS AND RESULTS

Parameter Varied	Sensitivity	Response, Location
Rock Density (g/cm^3)	-5.28	Stress (MPa), midwall
Rock Density (g/cm^3)	1.50	Stress (MPa), crown
Compressive Strength (MPa)	0.018	Rock S.F., crown
Elastic Modulus (GPa)	-1.05	Stress (MPa), midwall
Elastic Modulus (GPa)	1.66	Stress (MPa), crown
Poisson's Ratio	-2.15	Stress (MPa), midwall
Poisson's Ratio	31.5	Stress (MPa), crown
Tensile Strength (MPa)	0.36	Rock S.F., midwall
Thermal Conductivity (W/m-°C)	2.39	Temperature (°C), midwall
Thermal Conductivity (W/m-°C)	3.15	Stress (MPa), midwall
Thermal Conductivity (W/m-°C)	-2.82	Stress (MPa), crown
Rock Friction Angle (degrees)	-.025	Rock S.F., crown
Thermal Capacitance (J/cm^3-°C)	-2.20	Temperature (°C), midfloor
Thermal Capacitance (J/cm^3-°C)	-4.04	Stress (MPa), midwall
Thermal Capacitance (J/cm^3-°C)	3.69	Stress (MPa), crown
Geothermal Gradient (°C/m)	301	Temperature (°C), midfloor
Joint Cohesion (MPa)	0.368	Joint S.F., midwall

PARAMETER AND RESULTS
(concluded)

Parameter Varied	Sensitivity	Response, Location
Joint Friction Angle (degrees)	1.65	Joint S.F., crown
Thermal Expansion (10E-6 1/C)	-1.49	Stress (MPa), midwall
Thermal Expansion (10E-6 1/C)	2.34	Stress (MPa), crown
Hor./Ver. In Situ Stress Ratio	-5.64	Stress (MPa), midwall
Hor./Ver. In Situ Stress Ratio	18.06	Stress (MPa), crown

The conclusion is that drift temperatures are relatively insensitive to the thermal properties. The horizontal emplacement drift can tolerate the expected range in thermal and thermal/mechanical properties. The probability of encountering poor ground conditions that may require supplemental ground support for the horizontal emplacement drift is approximately 20%.

APPENDIX B

YUCCA MOUNTAIN PROJECT REFERENCE INFORMATION BASE AND SITE ENGINEERING PROPERTIES DATA BASE

Information from the Reference Information Base Used in this Report

This report contains no information from the Reference Information Base.

Candidate Information for the Reference Information Base

This report contains no candidate information for the Reference Information Base.

Candidate Information for the Site Engineering Properties Data Base

This report contains no candidate information for the Site and Engineering Properties Data Base.

Appendix B.2

3-D Thermomechanical Far-Field Analyses of the ESF Title I Design