315
5-28-81
JW

①

LH. 2674

ONWI-63

MASTER R. 4622

RETRIEVAL OPTIONS STUDY

Technical Report

March, 1980

Kaiser Engineers, Inc.
300 Lakeside Drive
P. O. Box 23210
Oakland, CA 94623

ONWI
Office of Nuclear Waste Isolation
Battelle

REPRODUCTION OF THIS DOCUMENT IS UNLIMITED

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A10
Microfiche copy: A01

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

RETRIEVAL OPTIONS STUDY

Technical Report

March, 1980

Kaiser Engineers, Inc.
300 Lakeside Drive
P. O. Box 23210
Oakland, CA 94623

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report was prepared by Kaiser Engineers, Inc. under Subcontract E512-02800 with Battelle Project Management Division Office of Nuclear Waste Isolation under Contract No. DE-AC06-76RLO1830-ONWI with the U.S. Department of Energy. This subcontract was administered by the Battelle Office of Nuclear Waste Isolation.

fy

ABSTRACT

This Retrieval Options Study is part of the systems analysis activities of the Office of Nuclear Waste Isolation to develop the scientific and technological bases for radioactive waste repositories in various geologic media. The study considers two waste forms, high level waste and spent fuel, and defines various classes of waste retrieval and recovery. A methodology and data base are developed which allows the relative evaluation of retrieval and recovery costs and the following technical criteria: safety; technical feasibility; ease of retrieval; probable intact retrieval time; safeguards; monitoring; criticality; and licensability. A total of 505 repository options are defined and the cost and technical criteria evaluated utilizing a combination of facts and engineering judgments. The repositories evaluated are selected combinations of the following parameters:

Geologic Media:	Salt; granite; basalt; shale
Retrieval Time after Emplacement:	5 and 25 years
Emplacement Design:	Nominal hole; large hole, carbon steel canister; corrosion resis- tant canister; backfill in hole; nominal sleeves; thick wall sleeves
Emplacement Configuration:	Single vertical; multiple vertical; single horizontal; multiple horizontal; vaults
Thermal Considerations:	Normal design; reduced density; once-through ventilation; re- circulated ventilation
Room Backfill:	None; run-of-mine; early; 5 year delay; 25 year delay; de- commissioned
Rate of Retrieval:	Same as emplacement; variably slower depending on repository/ canister condition

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
1.0 INTRODUCTION	1
2.0 SUMMARY	3
2.1 Definition of Retrieval and Recovery Classes	3
2.2 Retrieval and Recovery Options	3
2.3 Evaluation Criteria	5
2.4 Impact of Design Considerations on Retrieval/Recovery	8
2.4.1 Thermal Considerations	
2.4.1.1 Storage Arrangements for HLW	8
2.4.1.2 Storage Arrangements for Spent Fuel	8
2.4.1.3 Storage of Multiple Waste Canisters in Long, Horizontal Holes in Salt Formation	9
2.4.2 Geology and Mining Considerations	11
2.4.2.1 Media Temperatures	11
2.4.2.2 Ground Support	12
2.4.2.3 Ventilation	13
2.4.3 Waste Handling	13
2.4.3.1 Retrieval	13
2.4.3.2 Recovery	14
2.5 Evaluation of Options	15
2.5.1 "Base Case" Costs	15
2.5.2 "Base Case" Technical Criteria Evaluation	18
2.5.2.1 Safety	18
2.5.2.2 Technical Feasibility	18
2.5.2.3 Ease of Retrieval	21
2.5.2.4 Probable Intact Retrieval Time	21
2.5.2.5 Safeguards	21
2.5.2.6 Monitoring	21
2.5.2.7 Criticality	22
2.5.3 "Broad Options" Cost and Technical Evaluations	22
2.5.3.1 Safety	22
2.5.3.2 Technical Feasibility	23
2.5.3.3 Ease of Retrieval	24
2.5.3.4 Probable Intact Retrieval Time	24
2.5.3.5 Safeguards	25
2.5.3.6 Monitoring	26
2.5.3.7 Criticality	26

Table of Contents (con't)

<u>Section</u>	<u>Page</u>
2.5.4 General Trends and Conclusions	26
2.5.4.1 Extended Retrieval Time	26
2.5.4.2 Recovery	27
2.5.4.3 Retrieval vs Recovery	27
2.5.4.4 Backfilling of Rooms and Vaults	27
2.5.4.5 Corrosion Life of Canister	28
2.5.4.6 Criticality	28
2.5.4.7 Locally Overheated Repository Schemes	29
References	30
3.0 METHODOLOGY	31
3.1 Guidelines and Constraints	31
3.2 Assumptions	32
3.2.1 Packaging	32
3.2.2 Geology and Mining	32
3.2.3 Thermal Analysis	41
3.2.4 Waste Handling Equipment	43
3.2.5 Cost Estimating	45
3.3 Terminology	45
3.3.1 Retrieval and Recovery	46
3.3.2 Parameters	50
3.3.3 Options	51
3.3.4 Criteria	51
3.3.4.1 Cost	51
3.3.4.2 Safety	52
3.3.4.3 Technical Feasibility	52
3.3.4.4 Ease of Retrieval	52
3.3.4.5 Probably Intact Retrieval Time	52
3.3.4.6 Safeguards	52
3.3.4.7 Monitoring	53
3.3.4.8 Criticality	53
3.3.4.9 Licensability	53
3.4 Options Analysis	53
References	55
4.0 THERMAL ANALYSIS	56
4.1 Background	56
4.2 Purpose of the Thermal Analyses	57
4.3 Scope of Thermal Analyses	57
4.4 Summary of Results	57

<u>Section</u>	<u>Page</u>
4.4.1 Storage Arrangements for 10-Year-Old High-Level Waste	57
4.4.2 Storage Arrangements for 10-Year-Old Spent Fuel Assemblies	59
4.4.3 Storage of Multiple Waste Canisters in Long, Horizontal Holes in Salt Formation	59
4.5 Basis of Repository Design	59
4.5.1 Repository Configuration and Operations	61
4.5.1.1 Mine Plan	61
4.5.1.2 Nuclear Waste Receipts	61
4.5.1.3 Vertical Storage Arrangements	61
4.5.1.4 Horizontal Storage Arrangements	62
4.5.1.5 Ventilation of Storage Rooms	62
4.5.2 Nuclear Waste Package Description and Decay Heat	62
4.5.3 Thermal Properties of Rock Types	63
4.5.4 Storage Room Cross Sections	63
4.5.5 Design Criteria	63
4.5.5.1 Areal Thermal Loadings	63
4.5.5.2 Extraction Ratio Limitations	64
4.5.5.3 Limitations on Thickness of Web Between Storage Holes	65
4.5.5.4 Guidance Rock Temperature	65
4.5.5.5 Maximum Allowable Waste Temperatures	66
4.6 Method of Calculation	66
4.6.1 Determination of Storage Arrangements	66
4.6.1.1 Vertical Storage of Waste Canisters	66
4.6.1.2 Storage of Multiple Waste Canisters in Long Horizontal Holes	69
4.6.2 Calculation of Extraction Ratio	70
4.6.3 Calculations of Storage Rock Temperatures	70
4.6.3.1 Applications of Conductive Model	70
4.6.3.1.1 Variations of Thermo-dynamic Properties with Temperature	71
4.6.3.1.2 Uncoupling of Waste and Storage Rock Temperatures	71
4.6.3.1.3 Influence of the Thermal Resistance of the Storage Room	72
4.6.3.2 Representation of Waste Decay Heat in Calculation of Storage Rock Temperatures	72

Table of Contents (con't)

<u>Section</u>	<u>Page</u>
4.6.3.3 Selection of Rock Temperatures to be Calculated	76
4.6.4 Selection of Optimum Storage Arrangements for Areal Thermal Loadings	76
4.6.5 Selection of Storage Arrangements for Reduced Areal Thermal Loadings	77
4.7 Discussion of Results	77
4.7.1 Storage of 10-Year-Old High-Level Waste	78
4.7.1.1 Selection of Storage Arrangements for Design Areal Thermal Loadings	78
4.7.1.2 Storage Arrangements for Reduced Areal Thermal Loadings	78
4.7.1.3 Peak Average Storage Room Temperatures for Selected Storage Arrangements	78
4.7.2 Storage of 10-Year-Old Spent Fuel Assemblies	82
4.7.2.1 Selection of Storage Arrangements for Design Areal Thermal Loadings	82
4.7.2.2 Storage Arrangements for Reduced Areal Thermal Loadings	84
4.7.2.3 Peak Average Storage Room Temperatures for Selected Storage Arrangements	84
4.7.3 Storage of Multiple Canisters in Long Horizontal Holes in Salt Formation	87
4.7.3.1 Multiple Canister Storage of 10-Year-Old High-Level Waste in Salt	87
4.7.3.2 Multiple Canister Storage of 10-Year-Old Spent Fuel Assemblies in Salt	87
4.7.3.3 Comparison of Storing Multiple Canisters in Long, Horizontal Storage Holes with Single Canister Vertical Storage Arrangements	88
References	90
5.0 GEOLOGY AND MINING	92
5.1 Geology	92
5.1.1 Geological Assumptions	93
5.1.2 Rock Descriptions	93
5.1.2.1 Rock Salt	93
5.1.2.2 Granite	93
5.1.2.3 Basalt	94
5.1.2.4 Shale	94
5.1.3 Media Temperatures	95

Table of Contents (con't)

<u>Section</u>	<u>Page</u>
5.2 Mining	96
5.2.1 Ground Support	96
5.2.2 Ventilation	97
5.2.3 Excavation and Replacement of Backfill	98
References	99
6.0 WASTE HANDLING EQUIPMENT	100
6.1 Retrieval and Recovery	100
6.2 Work Effort	100
6.2.1 Retrieval	101
6.2.1.1 Retrieval: Class A-1	101
6.2.1.2 Retrieval: Class A-2	101
6.2.1.3 Retrieval: Class B-1	102
6.2.1.4 Retrieval: Class B-2	102
6.2.1.5 Retrieval: Class C-1	102
6.2.1.6 Retrieval: Class C-2	103
6.2.1.7 Retrieval: Class D-1	103
6.2.1.8 Retrieval: Class D-2	103
6.2.1.9 Retrieval: Class E-1	104
6.2.1.10 Retrieval: Class E-2	104
6.2.1.11 Retrieval: Class F-1	104
6.2.1.12 Retrieval: Class F-2	105
6.2.2 Recovery	105
6.2.2.1 Recovery: Class A	106
6.2.2.2 Recovery: Class B	106
6.2.2.3 Recovery: Class C	106
References	107
7.0 EVALUATION OF RETRIEVAL OPTIONS	108
7.1 Cost Estimates for Base-Case Options	108
7.1.1 Capital Costs	108
7.1.1.1 Mine Development for Retrieval	114
7.1.1.2 Shafts	114
7.1.1.3 Shaft Stations	114
7.1.1.4 Surface Structures	115
7.1.1.5 Mine Equipment	115
7.1.2 Operating Costs	115
7.1.2.1 Mining	115
7.1.2.2 Canister Retrieval	119
7.1.2.3 Other Costs	119
7.1.2.4 Total Costs	119

Table of Contents (con't)

<u>Section</u>	<u>Page</u>
7.2 Cost of Broad Options	119
7.2.1 Cost of Repository	119
7.2.2 Retrieval and Recovery Costs	123
7.3 Technical Evaluation of "Base Case" and "Broad Options"	123
7.3.1 Safety	123
7.3.2 Technical Feasibility	124
7.3.3 Ease of Retrieval	125
7.3.4 Probable Intact Retrieval Time	126
7.3.5 Safeguards	127
7.3.6 Monitoring	128
7.3.7 Criticality	129
7.3.8 Licensability	129
7.4 Analysis Matrix	130
7.5 Evaluation of Options	132
7.5.1 "Base Case" Technical Criteria Evaluation	132
7.5.1.1 Safety	132
7.5.1.2 Technical Feasibility	132
7.5.1.3 Ease of Retrieval	132
7.5.1.4 Probable Intact Retrieval Time	133
7.5.1.5 Safeguards	133
7.5.1.6 Monitoring	133
7.5.1.7 Criticality	134
7.5.2 "Broad Options" Technical Evaluation	134
7.5.2.1 Safety	134
7.5.2.2 Technical Feasibility	135
7.5.2.3 Ease of Retrieval	137
7.5.2.4 Probable Intact Retrieval Time	137
7.5.2.5 Safeguards	139
7.5.2.6 Monitoring	139
7.5.2.7 Criticality	140
7.5.3 General Trends and Conclusions	140
7.5.3.1 Extended Retrieval Time	140
7.5.3.2 Recovery	140
7.5.3.3 Retrieval vs Recovery	142
7.5.3.4 Backfilling of Rooms and Vaults	142
7.5.3.5 Corrosion Life of Canister	143
7.5.3.6 Criticality Considerations	144
7.5.3.7 Canister Physical Protection - Engineered Barriers	145
7.5.3.8 Shielded Canisters	146

Table of Contents (con't)

<u>Section</u>	<u>Page</u>
7.5.3.9 Filled Canisters	146
7.5.3.10 Locally Overheated Repository Schemes	147
7.5.3.11 Horizontal Storage of Multiple Canisters per Hole in Salt	147
References	187
8.0 APPENDIX - CALCULATED ROCK VARIATIONS FOR SELECTED STORAGE ARRANGEMENTS	189
A.1 Storage of 10-Year-Old High-Level Waste	189
A.2 Storage of 10-Year-Old Spent Fuel Assemblies	189
A.3 Multiple Canister Storage of 10-Year-Old High-Level Waste in Salt	190
A.4 Multiple Canister Storage of 10-Year-Old Spent Fuel Assemblies in Salt	190
References	225

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
3.1	Spent Fuel Canister Design	33
3.2	High-Level Waste Canister Design	34
3.3	Master Mine Plan	37
3.4	Typical Room and Pillar Configuration	39
3.5	Decay Heat Characteristics of Spent Fuel Assemblies and HLW	44
4.1	Graphical Definition of Terms in Equations Used to Establish Storage Arrangements	68
4.2	Comparison of Line-Source Model and Finite-Difference Model HEATING5	75
4.3	Calculated Peak Temperatures at Selected Extraction Ratios for the Storage of High-Level Waste at Design Areal Thermal Loadings	79
4.4	Calculated Peak Temperatures at Selected Extraction Ratios for the Storage of High-Level Waste at Reduced Storage Densities	80
4.5	Calculated Peak Average Room Temperatures at Selected Extraction Ratios for the Storage of High-Level Waste	81
4.6	Calculated Peak Temperatures at Selected Extraction Ratios for the Storage of Fuel Assemblies at Design Areal Thermal Loadings	83
4.7	Calculated Peak Temperatures at Selected Extraction Ratios for the Storage of Fuel Assemblies at Reduced Areal Thermal Loadings	85
4.8	Calculated Peak Average Room Temperatures at Selected Extraction Ratios for the Storage of Fuel Assemblies	86

LIST OF TABLES

<u>Table</u>		<u>Page</u>
2.1	Retrieval and Recovery Classes	4
2.2	Retrieval/Recovery Parameters	6
2.3	Selected Storage Arrangements for 10-Year-Old High-Level Waste and Resulting Temperatures	9
2.4	Selected Storage Arrangement for 10-Year-Old Spent Fuel Assemblies and Resulting Temperatures	10
2.5	Retrieval Class A-1 Costs for Selected Storage Arrangements of High-Level Waste	16
2.6	Retrieval Class A-1 Costs for Selected Storage Arrangements of Spent Fuel	17
2.7	Rating Summary of Analysis Matrix: Options 1-81	19
3.1	Comparative Rock Statistics, Generic Rocks	35
4.1	Selected Storage Arrangements for 10-Year-Old High-Level Waste	58
4.2	Selected Storage Arrangements for 10-Year-Old Spent Fuel Assemblies	60
4.3	Assumed Constant Properties of Candidate Storage Media	63
4.4	Design Areal Thermal Loadings (kW/Acre)	64
4.5	Maximum Allowable Extraction Ratios for Candidate Rock Types	65
4.6	Guidance Temperatures for Candidate Rock Types	66
4.7	Temperature Rise °F of PWR (Rod Region) Stored When 1-Year-Old	73
4.8	Temperature Rise °F of Salt Surrounding PWR (Rod Region) Stored When 1-Year-Old	74
4.9	Comparison of Horizontal and Vertical Storage of High-Level Waste in Salt at 150 kW/Acre	88
4.10	Comparison of Horizontal and Vertical Storage of Spent Fuel Assemblies in Salt at 60 kW/Acre	89
7.1	Options for Class A-1 Retrieval	109
7.2	Options for Class A-2 Retrieval	111
7.3	Estimated Total Capital Costs of Options for 25-Year Class A-1 Retrieval	112

List of Tables (con't)

<u>Table</u>		<u>Page</u>
7.4	Estimated Total Capital Costs of Options for 25-Year Class A-2 Retrieval	113
7.5	Estimated Annual Operating Costs for Class A-1 Retrieval	116-117
7.6	Estimated Annual Operating Costs for Class A-2 Retrieval	118
7.7	Comparison of Costs for Class A-1 Retrieval	120-121
7.8	Comparison of Costs for Class A-2 Retrieval	122
M-1	Sheets 1-7: Listing of Broad Options for Spent Fuel	149-161
M-2	Sheets 1-2: Analysis Matrix for Base-Case Options	163-165
M-3	Sheets 1-9: Analysis Matrix for Broad Options Listing Spent Fuel	167-183
M-4	Listing of Broad Options for Spent Fuel - Sketches of Schemes	185

1.0 INTRODUCTION

Battelle Memorial Institute's Office of Nuclear Waste Isolation (ONWI) is directing projects to develop the scientific and technological bases and investigate the engineering feasibility of constructing repositories for radioactive waste in various geological media. The study described in this report was performed as a part of ONWI's overall program of radioactive waste management.

In order to understand the purpose of this report, the reader must understand why wastes may be retrieved and what the process entails. Wastes might be retrieved for a variety of reasons including safety, economics, and sampling. Safety reasons might lead to removal of part or all of the wastes. For instance, an influx of water might lead to abandonment of some sites. Similarly, if the formation was not responding as predicted, one might remove part of the waste to reduce the areal thermal loading. If certain canisters were found defective (or suspect), they might be removed. Economic reasons may be driven by the anticipated resource value of the uranium, plutonium, and certain other isotopes. However, current policy is that these are wastes and that we will not plan on retrieval for economic reasons. Sampling should involve only a few canisters and would be for monitoring or validation. Retrieval (or recovery) is a contingency operation; it is hoped that it would not be necessary to retrieve. Still, it may be desirable to provide the capability to retrieve. To minimize the difficulty and cost of retrieving the waste at some future date, it is desirable to investigate the concept of waste retrieval and identify desirable features to be included in the design of the repository.

The purpose of the study is to develop a data base from which a systems analysis of retrieval options can be evolved at a later

date. This is accomplished by systematically investigating various methods of retrieving radioactive waste from a mined geologic repository. After developing definitions of various degrees of retrieval and recovery, the following parameters which define a retrieval option are investigated:

- o Emplacement in various media
- o Sleeved and non-sleeved holes
- o Vertical and horizontal emplacement
- o Alternate canister designs
- o Thermal loadings
- o Spent fuel and high level waste
- o Engineered barriers
- o Alternate backfill materials
- o Early and late backfilling of the rooms and holes
- o Package life/integrity
- o Timing of retrieval

The information developed during the investigation is quantified to allow comparisons between the various parameters and options. The evaluation criteria are cost, safety, technical feasibility, ease of retrieval, probable intact retrieval time, safeguards, monitoring, criticality, and licensability.

2.0 SUMMARY

The classifications of retrieval and recovery that are utilized in this study, the repository options that are considered, and the evaluation criteria that were used are described below. This section also discusses thermal, geological and waste handling impacts on retrieval and recovery, provides an evaluation of the options, and identifies trends and conclusions.

2.1 Definition of Retrieval and Recovery Classes

The word "retrieval" has been used to refer to retrieval of a sound canister containing radioactive waste, or of a canister that is leaking or has ruptured and thus is releasing radioactive materials. In this study, a distinction is made between these two canister conditions.

In general, retrieval refers to removal of a sound canister from a repository while recovery refers to removal of a canister that is no longer sound and is leaking radioactivity. Since various degrees of operational effort may be required, a broad range of conditions is defined. Table 2.1 summarizes the various classes of retrieval and recovery used in this study.

2.2 Retrieval and Recovery Options

To reduce the retrieval and recovery options to a manageable number, the options investigated are divided into two categories. The first category consists of 81 "base cases" and includes Classes A-1 and A-2 (see Table 2.1) retrieval of spent fuel and high level waste, 5 and 25 years after emplacement. Horizontal and vertical emplacement in salt, granite, basalt, and shale is considered at various thermal loadings. The specific combinations of parameters were chosen because they result in logical repositories and specific cost data already existed for some of these "base cases." These 81 "base case" options are described in Section 7.0

TABLE 2.1

RETRIEVAL AND RECOVERY CLASSES

Classes of Retrieval or Recovery	Retrieval										Recovery				
	Class										Class				
	A		B		C		D		E		F		A	B	C
	1	2	1	2	1	2	1	2	1	2	1	2			
<u>Applicable Conditions</u>															
Rooms open	X		X		X		X		X		X		X		
Rooms backfilled and reopened		X		X		X		X		X		X		X	X
Canister free	X	X													
Canister structurally weak			X	X			X	X							
Canister lodged by backfill					X	X	X	X							
Sound canister lodged by detritus* and/or close-in									X	X					
Weak canister lodged by detritus and/or close-in											X	X			
Canister breached													X	X	X
Mine decommissioned															X

*Broken rock

(see Tables 7.1 and 7.2). The second category consists of 424 "broad options."

The parameters considered for both categories are the same and are shown in Table 2.2. An option is defined by a unique set of these parameters.

2.3 Evaluation Criteria

The evaluation criteria consist of both cost and technical criteria. For the 81 "base cases," considerable effort was expended to develop capital cost and operating cost estimates. The capital and operating cost estimates developed are only those additional costs required for retrieval. The cost estimates for the 424 "broad options" are based upon engineering judgment.

The technical evaluation criteria consisted of eight criteria. Each of the evaluation criteria with the exception of licensability, is assigned a rating scale from ten to zero, with a rating of ten being the most desirable and a rating of zero being the least. Licensability, the one exception, is considered to be related to technical feasibility; thus, it is not rated separately but is included as a part of technical feasibility. The eight criteria are:

- o Safety - This is a measure of the protection of the operators and public from radiological exposure and occupational hazards. A rating of six or less is considered not sufficiently safe.
- o Technical feasibility - This is a measure of the ability to design, construct and operate a facility satisfactorily. Ratings vary from ten for a system based upon proven practices, to five where technical aspects are resolved but major problems are encountered, to zero for a system that is theoretically infeasible.

TABLE 2.2

RETRIEVAL/RECOVERY PARAMETERS

Geologic Media:	Salt; granite; basalt; shale
Waste Form:	Spent Fuel; High-Level Waste
Retrieval Time after Emplacement:	5 and 25 years
Emplacement Design:	Nominal hole; large hole, carbon steel canister; corrosion resistant canister; backfill in hole; nominal sleeves; thick wall sleeves
Emplacement Configuration:	Single vertical; multiple vertical; single horizontal; multiple horizontal; vaults
Thermal Considerations:	Normal design; reduced density, once-through ventilation; recirculated ventilation
Room Backfill:	None; run-of-mine; early; 5 year delay; 25 year delay; decommissioned
Rate of Retrieval:	Same as emplacement; variably slower depending on repository/canister condition

- o Ease of retrieval - This is a measure of the amount of work required to accomplish retrieval. Ratings vary from ten, where the canister is in a vault needing only to be picked up, to zero which would be nonretrievable.
- o Probable intact retrieval time - This is a measure of the estimated time in years after emplacement of a canister that the probability of intact retrieval goes from 0.999, or approximately 1.0, to a value significantly less than 1.0. Ratings vary from 10, which indicates a time scale of approximately 100 years, to 0.5, which indicates a time of approximately 5 years.
- o Safeguards - Safeguards refer to the effort required to protect the nuclear materials from sabotage and theft. Ratings vary from ten for a system that is so foolproof no guards are required, to six which requires many people for a long period of time, to zero which requires large amounts of surface equipment and very large numbers of people for a substantial length of time.
- o Monitoring - This refers to the ability to determine the status of radioactivity confinement and thermal and geologic conditions of the repository. Ratings vary from ten for a repository that is easily accessible for monitoring to zero for a repository which is inaccessible for monitoring.
- o Criticality - Criticality is a measure of the ability to prevent the occurrence of criticality in the repository. This varies from a rating of ten for a repository where criticality is not credible to a rating of zero where the system is predictably critical.
- o Licensability - As noted previously, licensability is related to, and thus included in, the evaluation of technical feasibility.

2.4 Impact of Design Considerations on Retrieval/Recovery

2.4.1 Thermal Considerations

The purpose of the thermal analysis performed in the study was to establish "base case" storage arrangements that satisfy the thermal criteria given for each waste and rock type and to determine the thermal conditions of the waste and the storage rooms in each storage arrangement. Storage arrangements were primarily restricted to single waste canisters stored vertically and horizontally in holes located either in the floor or sidewalls of a storage room. However, the storage of multiple canisters in horizontal storage holes in salt was considered in order to quantify the economic advantage of this multiple canister arrangement.

2.4.1.1 Storage Arrangements for HLW

Table 2.3 summarizes the storage arrangements established for high-level waste canisters stored individually in vertical storage holes and the resulting peak media temperatures and room temperatures 5 years and 25 years after emplacement. Although these cases apply to vertical storage, the room temperatures may be considered the same for individually-stored canisters in horizontal storage holes. The arrangements for the higher areal thermal loadings were established on the basis of: design thermal loadings previously used in preparing the GEIS¹; mine extraction ratio; allowable canister spacings; and, for the salt medium, a guidance rock temperature limit. The reduced areal thermal loadings were obtained by removing every other canister in a row and alternatively, by removing every other storage room.

2.4.1.2 Storage Arrangements for Spent Fuel

Table 2.4 summarizes the storage arrangements established for spent fuel canisters, containing 1 PWR fuel assembly or 2 BWR fuel assemblies, stored individually in vertical storage holes with the room temperature also applying for individually stored canisters in horizontal storage

TABLE 2.3

SELECTED STORAGE ARRANGEMENTS FOR 10-YEAR-OLD HIGH-LEVEL WASTE AND RESULTING TEMPERATURES

<u>Option*</u>	<u>Rock Type</u>	<u>Thermal</u>	<u>Rows</u>	<u>Canister</u>	<u>Room</u>	<u>Pillar</u>	<u>Peak</u>	<u>Room Temperature °F</u>	
		<u>Loading</u>	<u>Per</u>	<u>Spacing</u>	<u>Width</u>	<u>Width</u>	<u>Medium</u>	<u>5 Yr</u>	<u>25 Yr</u>
		<u>(kW/Acre)</u>	<u>Room</u>	<u>(ft)</u>	<u>(ft)</u>	<u>(ft)</u>	<u>Temperature (°F)</u>		
32/40	Salt	150	1	6.0	17.5	77.0	457	223	283
36/44		75	1	12.0	17.5	77.0	306	152	182
33/41	Granite	190	1	13.5	17.5	15.0	488	227	302
37/45		95	1	27.0	17.5	15.0	352	153	197
34/42	Basalt	190	1	13.5	17.5	15.0	720	257	419
38/46		95	1	27.0	17.5	15.0	527	182	254
35/43	Shale	130	1	8.0	20.0	62.0	661	221	340
39/47		65	1	16.0	20.0	62.0	477	152	212

*Vertical/horizontal storage option numbers are defined in Section 7.0.

TABLE 2.4

SELECTED STORAGE ARRANGEMENT FOR 10-YEAR-OLD SPENT FUEL ASSEMBLIES AND RESULTING TEMPERATURES

<u>Option*</u>	<u>Rock Type</u>	<u>Thermal Loading (kW/Acre)</u>	<u>Rows Per Room**</u>	<u>Canister Spacing (ft)</u>	<u>Room Width (ft)</u>	<u>Pillar Width (ft)</u>	<u>Peak Medium Temperature (°F)</u>	<u>Room Temperature °F</u>	
								<u>5 Yr</u>	<u>25 Yr</u>
1/11	Salt	60	2	4.0	17.5	141.5	283	157	191
6/16		30	2	8.0	17.5	141.5	190	125	142
3/13	Granite	190	2	6.0	17.5	16.0	422	227	294
8/18		95	2	12.0	17.5	16.0	261	155	188
4/14	Basalt	190	2	6.0	17.5	16.0	636	268	418
9/19		95	2	12.0	17.5	16.0	376	175	250
5/15	Shale	100	2	4.0	24.0	73.0	568	221	345
10/20		50	2	8.0	24.0	73.0	340	153	220

*Vertical/horizontal storage option numbers are defined in Section 7.0

**Rows separated by 5.5 ft.

holes. These arrangements were established on the same basis described for high level waste storage arrangements. The areal thermal loading for shale had to be reduced from the design level of 130 kW/acre to 100 kW/acre in order not to exceed the maximum allowable extraction ratio of 25% at the minimum canister spacing of 4.0 ft.

2.4.1.3 Storage of Multiple Waste Canisters in Long, Horizontal Holes in Salt Formation

The storage of multiple canisters of both HLW and spent fuel assemblies in long, horizontal holes in salt was found to require less mining and result in lower storage room temperatures than the storage of single canisters. In the case of storing multiple canisters of HLW, less than half the room salt must be mined than for single canisters and the average room temperature, between 5 and 25 years of storage, was calculated to be 100°F lower than that for single canisters. In the case of storing multiple canisters of spent fuel assemblies, approximately one-third the room salt must be mined as for single canisters and the average room temperature, between 5 and 25 years of storage, was calculated to be more than 35°F lower than that for single canisters. The disadvantage of long horizontal storage is that retrieval or recovery from long horizontal holes can be extremely difficult.

2.4.2 Geology and Mining Considerations

2.4.2.1 Media Temperatures

Potential effects of increased temperatures in the various media have not been evaluated; however, the temperatures at which thermal effects may change the media properties are discussed for each rock type. These temperatures were used as a guide in determining the storage configuration. If the media temperatures are calculated to be under the guidance temperatures, no changes to the media properties are anticipated. If the guidance temperatures are exceeded, properties of the media will probably change but the impact of the change has not been investigated for inclusion in this report.

For rock salt, a guidance temperature of 482°F has been used; this is consistent with the criteria for the NWTSR2² conceptual design. The basis for this temperature stems from the experimental work performed for Project Salt Vault.

As shown in laboratory work³, feldspars, which are found in both granite and basalt, have the potential of converting to kaolinite under the action of hot water. Thus, a guidance temperature of 392°F has been used for these rocks.

A guidance temperature of 212°F was selected for shale. This temperature, the boiling point of water, was selected to prevent dehydration of the shale with consequent decrepitation and spalling.

2.4.2.2 Ground Support

It is anticipated that storage rooms in salt would be excavated by conventional boring-type continuous miners to a rectangular cross section; storage rooms in shale would be developed by a tunneling machine to a circular cross section. The circular opening would provide the best design stability for the most generically weak rock considered. Storage rooms in granite and basalt would be excavated using drilling and blasting techniques to a rectangular cross section.

It is assumed that all storage rooms are capable of being reentered. For rooms left standing open five years in salt, granite, or basalt, no support additional to that needed during the emplacement period is considered. However, for rooms left standing open five years in shale, it is believed that steel support arches will be needed because of the laminated structure of shale and its tendency to spall.

Additional support will be needed for rooms left standing open 25 years in salt or shale. Rooms in salt will require steel bolts imbedded in the roof; rooms in shale will require steel support arches. No additional supports are considered for rooms in granite or basalt left standing open for 25 years.

It is anticipated that rooms from which backfill has been removed may require more support than rooms that have never been backfilled because open rooms will be maintained periodically and stress relief will be effected. Rooms that have been backfilled will have their closure and stress relief restricted and may be in a high state of stress when reexcavated.

2.4.2.3 Ventilation

Ventilation requirements for cooldown to acceptable working temperatures (125°F for rooms left open and 83°F for retrieval operations in rooms from which backfill has been removed) were manually calculated using intake air to the rooms at a temperature of 71°F. Ventilation requirements have a significant effect upon the cost of retrieval because additional ventilation equipment, and in some cases additional ventilation shafts, are required.

2.4.3 Waste Handling

Each established retrieval/recovery classification identifies a specific storage state. Removing the waste canister from each storage state will require a specific work effort that will include mine maintenance, mine reopening, canister removal from the hole, canister transfer from the mine to the surface hot cell, and rebackfilling of the storage room where applicable. The amount of work effort will then be factored into the cost of each of the "base case" options evaluated in Section 7.0. It will also be included in the relative cost rankings for the "broad options" cases.

2.4.3.1 Retrieval

Retrieval Classes A-1 and A-2 will be accomplished using the same equipment as used for emplacement since retrieval for these cases is essentially a reversal of the emplacement operation. Consequently, the retrieval rate is assumed to be the same as the emplacement rate.

As the canister, emplacement hole, and repository deteriorate and retrieval proceeds from Class B to Class F, progressively more equipment will be required to free the canister, protect the canister, lift it from the hole and transport it from the repository. The amount of work required to retrieve a canister will steadily increase and the rate of retrieval will decrease.

If analysis shows that a significant fraction of the canisters are likely to be ruptured during removal, it may be necessary to plan for a recovery operation rather than a retrieval operation.

2.4.3.2 Recovery

The execution of reliable recovery of the canisters in Classes A, B and C will require a thorough analysis and evaluation of the prevailing storage conditions and an engineered plan for the operation. In all classes, specialized machinery, with suitable protective devices, will be needed. Trained operators, directing the machinery by remote control, may be required. The canisters may be found in a condition of change so radical as to dictate that the surrounding rock and the canister be removed from the mine and taken to the surface facility for processing. A major facility change may be necessary to accomplish this task. Canisters may be warped, bent, or sheared by rock movement, and in some cases, fuel rods may be fractured, permitting fuel pellets to invade the rock. This poses a major cleanup task and will affect facilities and facilities operation. The work effort required in any of the recovery classifications will be large and any attempt, at this time, to postulate a production rate would not be practical. The cost ratings for the "broad options" in Section 7.0 pertaining to recovery included engineering judgements of the work effort required.

2.5 Evaluation of Options

2.5.1 "Base Case" Costs

The costs for the 81 "base cases," which only include Retrieval Classes A-1 and A-2, are placed on a comparable basis by estimating the retrieval cost per canister. Retrieval cost per canister is obtained by adding the capital cost required to make retrieval possible to the annual operating cost to accomplish retrieval. The annual operating cost depends upon the number of rooms that must be retrieved per year which in turn depends upon the canister pitch in the rooms (the number of canisters stored per room). It is also determined by such variables as the repository media, the years after emplacement and amount of cooling required to return the repository to allowable temperatures. This cost is then divided by the number of canisters retrieved per year which, for Retrieval Classes A-1 and A-2, is set equal to the emplacement rate. Retrieval costs for selected storage arrangements of HLW and spent fuel are shown in Tables 2.5 and 2.6, respectively.

In general, the retrieval cost per canister is approximately the same for a salt, granite or basalt repository but increases significantly for a shale repository. This is primarily because the shale repository requires significantly more roof support.

The cost of retrieving HLW is higher than the cost of retrieving spent fuel because the HLW canisters release more heat initially than do the canisters containing spent fuel. Thus, the separation distance is larger and more rooms must be retrieved annually. In addition, as can be seen from Figure 3.6, the decay heat from HLW starts higher than that from spent fuel; however, since the long-lived TRU is removed, the decay heat from HLW falls below that of spent fuel after approximately 100 years. This permits a higher temperature to exist in rooms containing HLW when retrieval takes place than for rooms containing spent fuel. Consequently, additional shafts and ventilation equipment are required to cool the HLW waste containing rooms when retrieval takes place. A

TABLE 2.5

RETRIEVAL CLASS A-1 COSTS FOR
SELECTED STORAGE ARRANGEMENTS OF HIGH LEVEL WASTE

<u>Option*</u>	<u>Media</u>	<u>Thermal Loading kW/A</u>	<u>Retrieval Cost \$'s/Canister</u>	
			<u>Vertical</u>	<u>Horizontal</u>
32/40	Salt	150	2,760	2,730
36/44	Salt	75	3,360	3,130
33/41	Granite	190	3,650	3,590
37/45	Granite	95	5,150	5,090
34/42	Basalt	190	3,390	3,300
38/46	Basalt	95	4,920	4,860
35/43	Shale	130	7,770	6,330**
39/47	Shale	65	12,930	10,480**

*Vertical/horizontal storage option numbers are defined in Section 7.0.

**Lower than vertical storage because room diameter is smaller and thus less ventilation air is required.

TABLE 2.6

RETRIEVAL CLASS A-1 COSTS FOR
SELECTED STORAGE ARRANGEMENTS OF SPENT FUEL

<u>Option*</u>	<u>Media</u>	<u>Thermal Loading kW/A</u>	<u>Retrieval Cost \$'s/Canister</u>	
			<u>Vertical</u>	<u>Horizontal</u>
1/11	Salt	60	820	810
6/16	Salt	30	870	870
3/13	Granite	190	840	840
8/18	Granite	95	890	890
4/14	Basalt	190	830	830
9/19	Basalt	95	880	880
5/15	Shale	100	2,240	2,010**
10/20	Shale	50	3,570	3,350**

*Vertical/horizontal storage option numbers are defined in Section 7.0.

**Lower than vertical storage because room diameter is smaller and thus less ventilation air is required.

summary of the cost ratings for the 81 "base cases" is shown in Table 2.7. The cost ratings are based upon the cost estimates made for this study.

2.5.2 "Base Case" Technical Criteria Evaluation

A summary of the technical criteria evaluation for the 81 "base cases" is shown in Table 2.7. The ratings shown are a combination of facts and engineering judgments. Some trends identified and conclusions reached are noted below.

2.5.2.1 Safety

- o Shale repositories, and retrieval therein, are judged to involve distinctly greater mining hazards than the other rock types. Mining experience shows that shale tends to be relatively unpredictable and subject to roof falls and caving.
- o Recovery is considered to be significantly more hazardous than retrieval, due to the presence of radioactive materials that have leaked from the canisters.

2.5.2.2 Technical Feasibility

- o The highest ratings are reserved for some of the vault and cooled types (Options 82-505) because these types may minimize some of the uncertainties as to rock behavior under extended heating.
- o Shale repositories are rated lower because of the relatively greater uncertainties as to rock behavior.

TABLE 2.7
RATING SUMMARY OF ANALYSIS MATRIX: OPTIONS 1-81

(ALL SPENT FUEL AND HIGH-LEVEL WASTE EXCEPT AS NOTED)

TECHNICAL CRITERIA	REPOSITORY	RETRIEVAL A	RETRIEVAL C, D, E & F	RECOVERY A	RECOVERY B	RECOVERY C
COST	10 Salt per Option # 1; other salt options probably more costly; other options, in granite, basalt or shale probably significantly more costly	Range 10 to 0.5. See Table 7.1 through 7.4	For each option, cost per canister is somewhat more than for Retrieval A	Costs per canister significantly higher than retrieval	Costs are much higher than for retrieval	Very high costs
SAFETY	10 Salt, Granite & Basalt 8 Shale	10 Salt, Granite & Basalt 8 Shale	10 Salt, Granite & Basalt 8 Shale	9 Salt, Granite & Basalt 8 Shale	9 Salt, Granite & Basalt 7 Shale	9 Salt, Granite & Basalt 7 Shale
TECHNICAL FEASIBILITY	7 Salt, Granite & Basalt 5 Shale	9 Salt with backfill 9 Granite & Basalt (all) 8 Salt w/o backfill 8 Shale	8 Salt with backfill (C-D) 7 Salt with backfill (E-F) Salt without backfill (C-D-E-F) Granite-Basalt (all)	7 Salt, Granite & Basalt, Shale	8 Granite & Basalt 7 Salt, Shale	8 Granite & Basalt 7 Salt, Shale
EASE OF RETRIEVAL	Not Applicable	8 Granite-Basalt (all) Salt with backfill Shale with backfill 7 Salt w/o backfill 6 Shale w/o backfill	6 Salt with backfill (C-D) 5 Salt & Shale w/o backfill (C-D) 4 Salt w/o backfill (E-F) Granite & Basalt (all) (E-F)	Not Applicable	Not Applicable	Not Applicable
PROBABLE INTACT RETRIEVAL TIME	Not Applicable	* (See Note 1 below) 2.5 Options 21-81; includes all rock types and both with & without backfill. 0.5 Option 1-20; includes all rock types, all w/o backfill	5 Granite, Basalt & Shale (all) 4 Salt with backfill 3 Salt w/o backfill, where designed 25-yr retrieval 1 Salt w/o backfill, where designed 5-yr retrieval	Same as Retrieval C-D-E-F	10-All	10-All
SAFEGUARDS	9 Salt, Granite & Basalt 8 Shale	9 Salt, Granite & Basalt 8 Shale	9 Salt, Granite & Basalt 8 Shale	8 Salt, Granite & Basalt 7 Shale	6 Salt, Granite & Basalt 5 Shale	6 Salt, Granite & Basalt 5 Shale
MONITORING	4 Rooms open 25 yrs 3 Rooms open 5 yrs 2 Rooms backfilled early	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
CRITICALITY	10 All	10 All	10 All	10 All	10 All high-level waste 6 All spent fuel	10 All HLW 6 S.F. in Granite, Basalt & Shale 5 S.F. in Salt
COMMENTS	All repositories are rock-heat-sink	Retrieval B is similar, with some more cost and effort	Retrieval C-D N/A Granite & Basalt; E-F N/A Shale			

*NOTE 1: Time span is as designed and provided, including provision of backfill or roof bolting, etc. Costs are affected by these provisions.

2.5.2.3 Ease of Retrieval

- o The granite and basalt rock repositories rate high because of the general stability of these formations.

2.5.2.4 Probable Intact Retrieval Time

- o For Retrieval A, Options 1-20 are designed for 5-year retrieval, and Options 21-82 are designed for 25-year retrieval; hence, the ratings of 0.5 and 2.5, respectively, are automatic.
- o Recovery B and C are inherently attainable for a long time after emplacement - with high effort and cost.

2.5.2.5 Safeguards

- o Salt, granite and basalt repositories are all rated as high in this category.
- o The shale repository is rated low, because it is envisioned that more people and more extensive activity will be required to successfully open and maintain a shale repository.

2.5.2.6 Monitoring

- o Monitoring is a repository characteristic, not directly a part of retrieval or recovery. The time of backfilling of the rooms is the primary variable affecting the ability to monitor a repository. For a backfilled room, any individual canister or other localized monitors must have the information wired or otherwise conducted to accessible spaces, degrading reliability. Thus, the longer the room remains open the higher the rating.

2.5.2.7 Criticality

- o Retrieval and Recovery A are rated 10, being designed to avoid any credible criticality situation.
- o For Recovery B and Recovery C, HLW is rated 10 since it is essentially free of criticality possibilities, while spent fuel is rated 6-5 because of the possibility of criticality.

2.5.3 "Broad Options" Cost and Technical Evaluations

For the "broad options," the complexity of the matrix information precludes simple summary-table presentations. The tabulation below provides supplementary and explanatory information for major rating points and indicates some patterns and trends for these options.

2.5.3.1 Safety

- o All rock-heat-sink and isolated-cooled repositories, and retrieval therein, are rated 10.
- o Repositories and retrieval in shale are rated one point less safe, for the reasons cited for the "base case" options.
- o Once-through air-cooled systems are rated one point less safe because of the (small) potential for releasing radioactive materials into the environment via the ventilating air.
- o All recovery classes are rated less safe than the retrieval systems, because of the necessity for handling radioactive materials released by canister leakage or breakage.

2.5.3.2 Technical Feasibility

- o For the repository, and in general for Retrieval A, the following factors in combination contribute to high ratings:
 - Cooling, which by significantly reducing rock temperatures enhances the applicability of state-of-the-art mining and tunneling experience; also, for salt this lessens plastic flow;
 - Stable rock formation, especially granite and basalt;
 - Heavy sleeves, or structurally strong vaults. This is especially applicable to salt.
- o For Repository and Retrieval A, intermediate ratings of approximately 6 through 8 apply to options which have fewer of the high-rating attributes listed above.
- o For Retrieval A, ratings of 5 and below apply, for example, to multiple length vertical rock-heat-sink repositories in granite and basalt. For this type of repository, the equipment systems required to emplace several canisters in a deep hole, and the drilling and equipment to prepare the hole, all to operate within the confines of a reasonable-height room, is envisioned as being very complex.
- o For Repository and Retrieval A, repositories in shale are down-rated an average of one point, for the reasons cited for the "base cases."
- o For retrieval, some of the vault systems are rated relatively high, because (1) there is no excavation required for freeing the canisters, or (2) such excavation is quite predictable and amenable to assured design of equipment systems.

2.5.3.3 Ease of Retrieval

- o Vault systems receive the highest ratings, because there is (1) no excavation required for freeing the canisters, or (2) such excavation is predictable and relatively easy.
- o For Retrieval A, single-depth vertical or horizontal storage in salt and shale, with heavy sleeves enhance ease of retrieval; typical ratings are 8. Comparable emplacement in granite and basalt is typically rated 8 without need for sleeves.
- o Retrieval A for horizontal emplacement of multiple canisters (Options 140-156 for salt) is considered relatively easy with typical rating 8, based on the concept that the holes will be open at both ends to permit easy access.

2.5.3.4 Probable Intact Retrieval Time

- o The term "intact retrieval" applies strictly only to retrieval. However, the matrix tabulations also show, under the heading "Recovery Time Span", ratings on a comparable scale for Recovery, where the meaning is the time span during which recovery can clean out essentially all of the radioactive material from the rock. Recovery B and C are both rated at 10; the actual time may be very long and costs will be very high.
- o For retrieval and generally for Recovery A, the following factors in combination contribute to high ratings:
 - Cooling, which by significantly reducing rock temperatures lessens or minimizes rock plastic flow and/or spalling, cracking, or other degradation.

- Stable rock formation, especially granite and basalt;
 - Heavy sleeves, or structurally strong vaults, are especially applicable to salt.
 - Corrosion resistant or overpacked canisters.
 - Backfilling of rooms, especially for salt and shale, to prevent major distortion of the formations due to plastic flow.
- o For Retrieval A in salt, low ratings are shown for options which rely only on large burial holes to prevent close-in damage to canisters, or which leave rooms open and un-cooled and subject to early roof collapse.
 - o For Retrieval A in shale, comparable repository types are generally rated higher than for salt, with cooling given credit for extending time spans where applicable.
 - o For Retrieval A in granite and basalt, comparable repository types are generally rated higher than for either salt or shale. For these rock types, close-in is considered to be non-existent, and basic stability of holes, rooms and vaults is assumed to be high.

2.5.3.5 Safeguards

- o The ratings are essentially the same as described for Options 1-81 above, except that options utilizing cooling systems are down-rated. The so-called Convertible Air-Cooled Repository or once-through systems will require substantial equipment installation and personnel above-ground over a long time; these will require significant safeguards. The Convertible Isolated-Cooled (i.e., refrigerated) Repository systems will

require less, but significant, equipment and personnel above-ground, and is thus given intermediate ratings.

2.5.3.6 Monitoring

- o This category is a repository characteristic only. The highest rating of 9 is shown for cooled, horizontal long holes, with multiple canisters, with the holes lined and sealed. This combination can be monitored as a unit, and the rooms are cool and accessible for servicing of the monitoring sensors and signal systems.

2.5.3.7 Criticality

- o The ratings are essentially as described above for Options 1-81. Recovery, especially Recovery C, has ratings as low as 3. The low ratings reflect situations where complete mining of rock mixed with radioactive materials may be required, and where great care would have to be taken to avoid "clumping" of the fissionable material into critical masses.

2.5.4 General Trends and Conclusions

2.5.4.1 Extended Retrieval Time

The time span over which canisters can, with reasonable assurance, be retrieved intact is extended when: (1) the repository is in a more stable rock type; (2) active cooling is provided for the rooms or vaults; (3) mechanical protection (i.e., heavy sleeves or the equivalent) is provided for the canisters; (4) corrosion protection is provided for the canisters; and, (5) the heat-loading density is reduced.

2.5.4.2 Recovery

All classes of recovery appear to be very costly undertakings, particularly Recovery B and C for salt. Recovery must include the capability of recovering breached canisters, together with contaminated media and fill from the emplacement site, and handling and repackaging these in a suitable way for re-emplacement in another repository or for transport to reprocessing facilities. For some emplacement configurations, especially the long horizontal holes, Recovery B and C may not be at all technically feasible because of the excessively large extraction ratios that will be encountered during recovery.

2.5.4.3 Retrieval vs Recovery

Some of the canister protection provisions have characteristics that enhance retrievability while aggravating Recovery B and Recovery C tasks. The heavy sleeves and overpacks and the sleeve-racks for emplacement can deteriorate and their remains may make it extremely difficult to recover broken canisters.

2.5.4.4 Backfilling of Rooms and Vaults

In general, for the plastic rock (salt) and probably for the less stable of the other rock types (i.e., shale), backfilling of the rooms prior to gross distortion of the formation caused by close-in should ease the task of removing drifts or opening new drifts for the purpose of recovery. However, Recovery B or C for these rock types, after a lengthy storage period, is likely to be such a large undertaking that the backfilling factor may be negligible.

Backfilling of rooms and vaults also provides economy in materials handling during repository excavation by reducing the amount of excavated rock that must be hoisted to the surface. Further, disposing of excavated material (especially salt) may have an adverse impact on the environment. These are significant but not large factors.

The importation of "foreign" material, such as sand or clay, for room backfill may permit easier remining of the rooms or vaults because of their characteristics, including softness. However, this would force surface disposal of all excavation and make necessary rather large and costly supply and transportation tasks. For vault schemes in salt, the use of clay or sand for canister bedding and cover may well be worthwhile as a corrosion-protection measure and to ensure practical backfill removal for retrieval/recovery. Otherwise, the use of large amounts of "foreign" backfill appears to be uneconomical.

2.5.4.5 Corrosion Life of Canister

It appears that canister corrosion life in excess of 50 years⁴ can be attained with low-cost, carbon-steel-type canister material augmented for some rock types (especially salt) by backfilling canister emplacement holes or sites with inert clay, sand, or buffer materials.

Pinholing corrosion of spent fuel canisters is unlikely to release anything except gases and it is likely that, due to the incremental nature of corrosion, such gas release will be metered to provide a useful tell-tale rather than a serious safety hazard. In the case of vitrified high-level waste, pinholing will release extremely low levels of radioactivity.

2.5.4.6 Criticality

A preliminary analysis ^{5,6} indicates that as long as the emplacement sites are free of liquid water and the canisters are reasonably intact, spent fuel canister arrays will not become critical.

Chlorine in salt acts as a natural absorber (poison) for neutrons. Thus, even if water is present in a salt repository, in the form of brine, spent fuel canisters will not become critical.^{7,8}

A single spent PWR fuel assembly, if mangled and mashed into a compact mass, may present some risk of becoming critical depending upon the leaching that has taken place, the composition of the mass, and surrounding materials. The presence of water will make criticality more likely. Thus, Recovery B and Recovery C operations must include design, operational, and monitoring steps to preclude clumping of the fuel rods.

2.5.4.7 Locally Overheated Repository Schemes

Some repository schemes may be within acceptable far-field thermal effects, but excessive local rock temperatures may induce early excessive plastic flow (as for salt), or rock dehydration (as for shale), or other adverse behavior of the local rock. If recoverability were judged unimportant, such schemes may have a practical use.

REFERENCES

1. Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations. Volumes 1 and 2.
2. "Conceptual Design Report for a National Waste Terminal Storage Repository in a Bedded Salt Formation for Spent Unreprocessed Fuel," Kaiser Engineers Report No. 78-57-RI, Vols I and II, December 1978.
3. K.B. Krauskopf, Introduction to Geochemistry, McGraw-Hill, New York, 1967, p. 114.
4. "Management of Commercially Generated Radioactive Waste," Draft EIS, DOE/EIS-00046D, Vol. 1 of 2.
5. "Conceptual Design Description for a National Waste Terminal Storage Repository in a Bedded Salt Formation for Spent Unreprocessed Fuel," KE Report No. 78-58-R, December 1978, pp. 7-72.
6. "Report of Nuclear Engineering Analytical Support for the NWTSR2 Design," KE Report No. 77018 NWTN 3358, December 1978, p. 39.
7. "Draft Environmental Impact Statement Waste Isolation Pilot Plant," U.S. Department of Energy, DOE/EIS-0026-D, Vol. 1 of 2, April 1979, pp. 9-144.
8. E. J. Allen, "Criticality Analysis of Aggregation of Actinides from Commercial Nuclear Waste in Geological Storage," ORNL/TM-6458, August 1978.

3.0 METHODOLOGY

This section describes: the guidelines and constraints that controlled the performance of this study; the assumptions the study is based upon; the terminology used in the study, including definitions of various retrieval and recovery classifications; and the approach and procedures used in analyzing the many repository options.

3.1 Guidelines and Constraints

The purpose of this study is to systematically investigate various options for retrieving both high level waste and spent fuel from various repositories. The repository media considered are salt, granite, basalt and shale. It is necessary to have the basic design of a repository available to evaluate the retrieval options. For this purpose the National Waste Terminal Storage Repository No. 2 (NWTSR2)¹ designed for a bedded salt formation was selected as the basic repository configuration. However, since this study is intended to make a broad overview of retrieval and not be limited to one repository design, the various repository parameters (i.e., waste deposit hole spacing, heat loading per acre, storage mode, timing of retrieval, package life/integrity, ventilation, etc.) were considered as variables.

The retrieval options from the various repositories are evaluated using criteria such as cost, safety, technical feasibility, ease of retrieval, probable intact retrieval time, safeguards, monitorability, criticality and licensability.

The evaluation consisted of assigning a numerical rating value for the evaluation criteria. However, it did not rank the relative importance of one evaluation criteria with another evaluation criteria.

3.2 Assumptions

Assumptions utilized in the performance of the retrieval options study are listed below.

3.2.1 Packaging

The spent fuel will be contained in the canister shown in Figure 3.1. The same size canister will contain 1 PWR or 2 BWR fuel assemblies and a filler material, in this particular study, a sand filler. The nominal length of the fuel rod region is 12.5 feet.

The HLW will be contained in the canister shown in Figure 3.2. The nominal length of the contained waste is 8 feet.

3.2.2 Geology and Mining

The repository media considered are salt, granite, basalt, and shale. The significant properties of these materials are included in Table 3.1. The geologic stratification in the storage area is assumed to be continuous and infinite. No major faults are present and water inflow is minimal. The minerology of the rocks is generally uniform with the salt and shale formations laying horizontal. The mine workings are located at a depth of 2,000 feet. Drilling and blasting are not permitted during retrieval.

Two independent ventilation systems will be used: one for the confinement function and one for the mining function. The reference repository design selected for this study is shown in Figures 3.3 and 3.4. This design was developed for a bedded salt repository. The canister placement in each storage room, the storage room cross section, and the width of the pillar between storage rooms are adjusted in order to satisfy requirements of each waste and rock type. Open storage rooms will be ventilated only to allow personnel to enter during storage, and for inspection, maintenance, and retrieval operations. Ventilation air will be introduced at

FIGURE 3.1
SPENT FUEL CANISTER DESIGN

NOTES:

CAPACITY: 1 PWR OR 2 BWR

MATERIAL: CARBON STEEL

WEIGHT: 3,500 LB W/ 1-PWR AND SAND FILLER

HIGH LEVEL WASTE CANISTER DESIGN

FIGURE 3.2

TABLE 3.1
COMPARATIVE ROCK STATISTICS, GENERIC ROCKS

<u>Property</u>	<u>Salt</u> ²	<u>Granite</u> ³	<u>Shale</u> ⁴	<u>Basalt</u> ⁵
Unit Weight (lb/ft ³)	133	165	160*	180
Moisture Content (%)	0.08	-	2	-
Porosity (%)	0.5	0.4	4	0.6
Youngs Modulus (psi)	1.6x10 ⁶	2.5x10 ⁶	6x10 ⁵ Hor. 3x10 ⁵ Vert.	1.8x10 ⁶
Poisson's Ratio	0.35	0.18	0.15	0.26
Compressive Strength (psi)	3,200	19,000	4,000	18,000
Tensile Strength (psi)	50	0	0	0
Coefficient of Thermal Expansion	22x10 ⁻⁶	4.5x10 ⁻⁶	4.5x10 ⁻⁶	3x10 ⁻⁶
Heat Capacity (Btu/lb- °F)				
at 32°F	0.20	0.21	0.19	0.17
at 212°F	0.21	0.22	0.20	0.19
at 392°F	0.22	0.23	0.21	0.22
Thermal Conductivity (Btu/hr-ft°F)				
at 32°F	3.53	1.65	0.97	0.65
at 122°F	2.90	1.56	0.93	0.69
at 212°F	2.43	1.48	0.89	0.73
at 302°F	2.08	1.41	0.88	0.76
at 392°F	1.80	1.35	0.87	0.79
at 572°F	1.44	1.24	0.86	0.85
at 752°F	1.20	1.15	0.85	0.90
Backfill, Unit Weight (lb/ft ³)	100	103	99	122

* Unit weights of shales range from 160 to 176 lb/ft³ with an average of 170 lb/ft³. The value used in heat transfer studies is 176 lb/ft³.

the entrance of each storage room at a temperature of 71°F. The maximum allowable ambient temperature for retrieval will be 125°F. In rooms hotter than 83°F, spot cooling will be available to bring the local working environment to 83°F.

Backfill will be run-of-mine and occupy 90 percent of the original opening. Any increase in backfill percentages will require hydraulic techniques. However, the use of water necessary for this process will likely make the techniques prohibitive. Backfill, unless treated, will not be appreciably hardened or strengthened by the heat.

Rooms in salt will be rectangular, corresponding to openings made by continuous mining machines. Rooms in granite and basalt would also be rectangular but excavated by drilling and blasting techniques. Rooms in shale will be circular and made by a tunneling machine with a built-up floor.

The design basis Geologic Column for the media are given in the GEIS Study ², ³, ⁴, ⁵.

3.2.3 Thermal Analysis

The assumptions necessary to achieve the thermal analysis study objectives are itemized below.

- o Constant thermal properties of the media will be assumed for all thermal analyses.
- o The maximum allowable temperature of the HLW will be 1,100°F.
- o The maximum allowable temperature of the fuel rod cladding will be 715°F.

- o In the vertical storage mode, canisters will be situated in two parallel rows of holes in the floor of the storage room, with one canister per hole.
- o In the horizontal storage mode, packages will be in single rows of holes in each sidewall or in two parallel rows of holes in one sidewall. There will be one package per hole.
- o Spent fuel assemblies will be stored so that a maximum allowable decay heat density given in the GEIS⁶ for the 2,000-acre mine area is not exceeded.
- o The nominal discharge age of spent-fuel assemblies at emplacement will be 10 years.
- o The thermal conditions established for a vertical storage arrangement will apply to the associated horizontal storage arrangement.
- o All thermal calculations for repositories containing spent-fuel assemblies will be based on PWR spent-fuel characteristics.
- o The total receipts of spent-fuel canisters at a repository with a decay heat density of 60 kW/acre are 242,437 with the canisters containing approximately 60% BWR and 40% PWR fuel assemblies. This corresponds to the receipts for NWTSR2¹.
- o The HLW will be stored so that the maximum allowable decay heat density given in the GEIS for the 2,000-acre mine area is not exceeded.
- o The nominal age of HLW at implantation will be 10 years.

- o The decay-heat characteristics of the spent-fuel assemblies and HLW are those shown on Figure 3.5⁷. The initial source strengths for HLW and spent fuel are 2.1 kW and 0.55 kW, respectively.
- o The total receipts of HLW canisters are 53,741, the same as for the NWTSR1⁸.

3.2.4 Waste Handling Equipment

The following are assumptions for waste-handling machine/system design practices.

For Retrieval Classes A-1 and A-2, retrieval will be performed by the same machinery used for package emplacement. Retrieval for Classes B through F will require some added equipment. The recovery process will require a variety of machines. Each machine or machine system will be used to perform one of four functions: reopening the backfilled mine; locating the package and freeing it in the hole; transferring the package to the surface facility; and recovering broken packages and contaminated media.

- o All thermal and shielding requirements for waste-handling equipment will be based on the receipt of three-year-old spent fuel or HLW so that allowable radiation levels and equipment temperatures will not be exceeded if three-year-old waste is occasionally received.
- o Protective systems for operator safety will be basic to design specifications for all waste-handling systems.
- o Occupational radiation exposure limit will be established as 500 mR/year maximum.

FIGURE 3.5
DECAY HEAT CHARACTERISTICS OF
SPENT FUEL ASSEMBLIES AND HLW

- o Equipment prime movers will be electric drive motors or diesel engines. Air, electric, and hydraulic powered elements, individually or in combination, will be used for machine function actuating devices.
- o Spent fuel will be emplaced in rooms separate from those containing high-level waste. Low-level waste is not considered in this study.

3.2.5 Cost Estimating

Preparation of the estimated retrieval costs are based upon the following assumptions:

- o The cost estimates are based upon January 1978 costs.
- o Capital costs for this study are defined as costs required for retrieval, over and above capital costs for emplacement and initial backfill. (If the shafts, hoists, buildings, machinery, and special equipment for emplacement are suitable for retrieval, then capital costs are zero.)
- o Cost estimating will be based on retrieval/recovery from one single room.
- o The estimate is a KE "Type 1 Estimate." This type of estimate, used for economic feasibility studies, is based upon assumed flow sheets, sketches and equipment lists. While a Type 1 estimate is not sufficiently accurate for budgetary purposes, it is useful for preliminary comparison of alternate concepts.

3.3 Terminology

The terminology used in this report is defined below.

3.3.1 Retrieval and Recovery

The word "retrieval" has been used to refer to retrieval of a sound canister of radioactive material or of a canister that has ruptured releasing radioactive material. For the purposes of this study, a distinction is made between "retrieve" and "recover."

In general, retrieval refers to the period of time when the canister storing the waste is still intact; recovery refers to the period when the canisters have failed. Since various degrees of operational effort may be required, governed by the condition of the waste package and the mine, a broad range of conditions is defined. The cost of the equipment, systems, and the work effort for the various categories of retrieval and recovery can then be estimated to compare the various categories.

RETRIEVAL:

In this condition, intact packages will be retrieved from open rooms with equipment and facilities similar to those used for emplacement. These will be augmented, if necessary, by modified or specially-designed transporting and excavating machinery. The rate of retrieval will be equal to the emplacement rate for Class A retrieval with varying degrees of delay encountered for Classes B through F.

To meet the definition of retrieval, packages must be younger than their "assured corrosion-resistant life." This lifespan will vary with each rock type, the waste package, and the nuclear waste material within each package. Normally, the rooms will not have been backfilled (Cases A-1, B-1, etc.); however, it is possible that the rooms will have been backfilled (Cases A-2, B-2, etc.) to reduce room closure in the case of a salt media or roof cave-in for a shale media.

Retrieval: Class A-1

The mine room and the deposit hole are open; the canister, unbreached and structurally sound, is free in the hole.

Retrieval: Class A-2

The mine room can be reopened by routine means, having been protectively backfilled after emplacement; the canister is free in the hole and is unbreached and structurally sound.

Retrieval: Class B-1

The mine room and the deposit hole are open; the canister, free in the hole, is unbreached but structurally weak.

Retrieval: Class B-2

The mine room can be reopened by routine means, having been protectively backfilled after emplacement; the canister, free in the hole, is unbreached but structurally weak.

Retrieval: Class C-1

The mine room is open; the canister, tight in the deposit hole because of engineered backfill, is unbreached and structurally sound.

Retrieval: Class C-2

The mine room can be reopened by routine means, having been protectively backfilled after emplacement; the canister, tight in the deposit hole because of engineered backfill, is unbreached and structurally sound.

Retrieval: Class D-1

The mine room is open; the canister, tight in the deposit hole because of engineered backfill, is unbreached but structurally weak.

Retrieval: Class D-2

The mine room can be reopened by routine means, having been protectively backfilled after emplacement; the canister, tight in the deposit hole because of engineered backfill, is unbreached but structurally weak.

Retrieval: Class E-1

The mine room is open. The canister is tight in the deposit hole because of natural close-in or accidental close-in of the deposit hole due to collapse or spalling; it is unbreached and structurally sound. The rock or detritus (broken rock) embracing or deforming the canister is large, hard, or monolithic, or a combination of these.

Retrieval: Class E-2

The mine room can be reopened by routine means, having been protectively backfilled after emplacement; all other conditions are same as for E-1.

Retrieval: Class F-1

The mine room is open. The canister is tight in the deposit hole because of natural close-in or accidental close-in from deposit hole collapse or spalling; it is unbreached but structurally weak. The rock or detritus embracing or deforming the canister is large, hard, or monolithic, or a combination of these.

Retrieval: Class F-2

The mine room can be reopened by routine means, having been protectively backfilled after emplacement; all other conditions are same as for F-1.

RECOVERY:

In this condition, the canisters have failed either because they are older than their assured corrosion-resistant life or have been ruptured by some abnormal condition. The amount of work required to recover and repackage the waste and contaminated media could be very large compared to the work to accomplish retrieval.

Recovery: Class A

In this condition, the mine room will be open, packages will have failed, and the deposit hole and/or the mine room will be contaminated. A Class A recovery state will generally occur later than a retrieval state. The production rate for recovery will be lower than that for retrieval. Highly specialized machinery with suitable protective devices will be required; major facilities modification may be necessary.

Any package-waste removal from open rooms that requires, for any reason, major provisions or procedures additional to those for retrieval will also be considered a Class A Recovery.

Recovery: Class B

In this condition, the mine room will have been closed by backfill or cave-in, but the access galleries and entry shafts will still be open and functional. Packages will be considered suspect or failed. Provisions and systems for recovery will be larger than those found in a Class A Recovery. Handling systems

for mined rock must carry greater capacities and provisions for adding shafts and galleries may be necessary. Repackaging facilities may be very large.

Recovery: Class C

In this condition, the mine will have been decommissioned and all rooms, galleries, and shafts will be backfilled or otherwise closed. All packages will be suspect as failed. Provisions and systems will be comparable to those used in a Class B Recovery but augmented, if necessary, with capabilities for reopening or replacing shafts and galleries. If there is significant spread of contamination, the effort required to recover and repackage waste and contaminated media could be much larger than that for Recovery Class B.

The classes of retrieval and recovery defined above are utilized in the evaluation of various retrieval options described in Section 7.0. An additional distinction utilized in the evaluation of retrieval options is that Classes A-1, A-2, and B-1 are considered easy retrieval cases. Classes B-2, C-1, C-2, D-1, and D-2 involve moderately difficult retrieval. Classes E-1, E-2, F-1, and F-2 involve difficult retrieval.

3.3.2 Parameters

A parameter is an arbitrary constant which characterizes a member of a system. In the Retrieval Options Study, the following parameters can be selectively assembled to form a repository and nuclear waste storage "option":

Rock type

Nuclear waste package

Waste storage arrangement

Time period of storage before retrieval/recovery

Condition of the mine at the time of retrieval/recovery

Sleeved holes
Large holes
Emplacement in other materials
Early or late backfilling

3.3.3 Option

In this study, "option" indicates the selection of a geologic-mined repository consisting of a given rock type in which specific nuclear waste packages are stored in an isolated, predetermined arrangement for a known period of time. Once the selection is made, an analysis of the retrieval/recovery process is developed by means of criteria established for the purpose.

3.3.4 Criteria

Criteria are standards established for the purpose of evaluating retrieval/recovery processes for each option. Criteria established for this study include:

Cost
Safety
Technical feasibility
Ease of retrieval
Probable intact retrieval time
Safeguards
Monitoring
Criticality
Licensability

3.3.4.1 Cost

The cost of each retrieval option consists of operating costs and any capital costs necessary to accomplish retrieval and recovery. All costs are calculated in January 1978 dollars.

3.3.4.2 Safety

Safety criteria is a measure of the protection of the human population from radiological and occupational hazards. The criteria includes potential radiological exposure to the public and to workers as well as occupational hazards to workers.

3.3.4.3 Technical Feasibility

Technical feasibility is a measure of the ability to design, construct and place in operation in a reasonable time, systems that can provide predictable and reliable performance.

3.3.4.4 Ease of Retrieval

Ease of retrieval is a measure of the amount of work required to accomplish retrieval. It is reflected in the cost of retrieval.

3.3.4.5 Probable Intact Retrieval Time

Probable intact retrieval time is a measure of the estimated time in years after emplacement of a canister that the probability of intact retrieval goes from 0.999 or approximately 1.0 to a value significantly less than 1.0.

3.3.4.6 Safeguards

Safeguards refer to the protection of nuclear materials from sabotage and theft. Sabotage is defined as the dispersion of radioactivity into the environment, while theft refers to the use of stolen material for building an illicit nuclear explosive or contaminating device. In retrieval operations, theft is of less concern than sabotage because the nuclear material is in a form that cannot be easily handled.

3.3.4.7 Monitoring

Monitoring refers to instrumentation that can detect release of radioactive materials, repository instability and displacement, excessive temperatures in the mine and excessive water intrusion.

3.3.4.8 Criticality

Criticality can occur if sufficient fissile material is present such that a chain reaction can be sustained. This study considers that the initial waste package emplacement arrangement will maintain separation distances between the waste packages so as to preclude the possibility of a criticality condition. However, canister failure or repository media movement may clump the fissile material. If this occurs the waste may become critical.

3.3.4.9 Licensability

Licensability is a measure of the capability of a nuclear facility design and operation to meet federal, state, and local requirements with respect to: (a) nuclear safety requirements, (b) quality requirements, (c) siting requirements, and (d) environmental concerns.

3.4 Options Analysis

The repository options identified in this study are divided into two categories. The first category consists of 81 "base cases," which are combinations of parameters selected because they result in logical repositories. The second category consists of 424 "broad options."

The 81 "base cases" were all based upon Retrieval Classes A-1 and A-2. Cost estimates, prepared for each of these cases, include both the capital cost to accomplish the retrieval and the operating cost per year for retrieval. For these two retrieval classes, it was assumed that the retrieval rate is the same as the emplacement rate. Based upon the above information, the retrieval cost per canister was calculated. These costs are included in Tables 7.7 and 7.8.

In addition to the cost estimates, technical evaluation criteria were identified. These evaluation criteria are cost, safety, technical feasibility, ease of retrieval, probable intact retrieval time, safeguards, monitoring, criticality and licensability. Each of these criteria are assigned a rating scale varying from zero to ten with ten being the best rating, and zero the worst. Engineering judgement is then applied to each of these evaluation criteria.

The second category of repositories that was evaluated consists of 424 "broad options." These are developed as shown in Drawing M-1, Sheets 1 through 7 (see Section 7.0). These options are analyzed by applying engineering judgement to the same evaluation criteria noted above. In addition, since it was impractical to prepare cost estimates for all 424 broad options, engineering judgement was used to assign a cost rating. For the cost evaluation, the cost for the NWTSR2 Special Study #3⁹ was taken as being equal to a rating of 10. The cost rating scale is then inversely proportional to the cost. Thus, if one option costs twice as much as the NWTSR2 Special Study #3 cost, it is given a cost rating of 5.

In neither the 81 "base case" options nor the 424 "broad options" are the evaluation criteria rated with each other. Instead the options analysis described above provides a data base that can be used by others to rate the evaluation criteria with each other.

REFERENCES

1. "Conceptual Design Report for a National Waste Terminal Storage Repository in a Bedded Salt Formation for Spent Unreprocessed Fuel, "Kaiser Engineers Report No. 78-57-RE", Vols I and II, December 1978.
2. Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations. Volume 4 - Baseline Rock Properties in Salt.
3. Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations. Volume 5 - Baseline Rock Properties in Granite.
4. Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations. Volume 6 - Baseline Rock Properties in Shale.
5. Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations. Volume 7 - Baseline Rock Properties in Basalt.
6. Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations. Volume 19 - Thermal Analysis. OWI Report Y/OWI/TM-36/19, 1978.
7. G. H. Llewellyn, "Prediction of Temperature Increases in a Salt Repository Expected from the Storage of Spent Fuel or High-Level Waste," Report No. ORNL/ENG/TM-7. Oak Ridge, TN; Oak Ridge National Laboratory, 1978.
8. "National Waste Terminal Storage Repository No. 1 Conceptual Design Descriptions," Stearns-Roger Engineering Company, January 1979.
9. "Special Study No. 3: Waste Retrieval from Backfilled Regions for a National Waste Terminal Storage Repository in a Bedded Salt Formation for Spent Unreprocessed Fuel," Kaiser Engineers Report No. 78-56-R, September 1978.

4.0 THERMAL ANALYSIS

Thermal analyses used to establish "base case" storage arrangements for each candidate rock type are documented in Section 4.0. The basis of the repository design, including design criteria, and the method of calculation used are both described. Selected vertical and horizontal storage arrangements are identified for the storage of high-level waste and spent fuel canisters. Thermal conditions calculated for each of the selected storage arrangements, over a 28-year retrieval or recovery period, are summarized with references to detailed temperature variations presented in the Appendix of this report. The 28-year period was selected instead of the 25 years for retrieval to allow for possible extension due to decommissioning activities.

4.1 Background

A selected number of storage arrangements, referred to as "base cases," were considered in detail for each of four rock types: salt, granite, basalt, and shale. Based on a survey of existing documents, it was decided to perform thermal analyses to establish storage arrangements for the "base cases" and to determine the attending thermal conditions at different times of retrieval.

Storage arrangements and attending thermal conditions for the four rock types had been established in preparation of the Generic Environmental Impact Statement (GEIS) for Radioactive Waste in Geologic Formations.¹ However, the thermal conditions determined in preparation of the GEIS did not cover the entire 25-year storage period addressed in the Retrieval Options Study. In addition, the storage arrangements for salt differed from the storage arrangements established in subsequent and more detailed conceptual repository designs.^{2,3}

4.2 Purpose of the Thermal Analyses

The purpose of the thermal analysis was to establish "base case" storage arrangements that satisfy the thermal criteria given for each waste and rock type and to determine the thermal conditions of the waste and the storage rooms in each storage arrangement.

4.3 Scope of the Thermal Analyses

The storage of 10-year-old, high-level waste or 10-year-old, spent fuel assemblies in salt, granite, basalt, and shale was considered. Storage arrangements were primarily restricted to single waste canisters stored vertically and horizontally in holes located either in the floor or sidewalls of a storage room. However, the storage of multiple canisters in horizontal storage holes in salt were considered in order to quantify the apparent economic advantage of this multiple canister arrangement.

4.4 Summary of Results

4.4.1 Storage Arrangements for 10-Year-Old, High-Level Waste

Table 4.1 summarizes the storage arrangements established for high-level waste canisters stored individually in vertical storage holes. However, the room temperatures may be considered the same for individually stored canisters in horizontal storage holes. The arrangements for the higher areal thermal loadings were established on the basis of: design thermal loadings, previously used in preparing the GEIS; mine extraction ratio; allowable canister spacings; and, for the salt medium, a guidance rock temperature limit. The reduced areal thermal loadings were obtained by removing every other canister in a row and, alternating, by removing every other storage room.

Table 4.1

SELECTED STORAGE ARRANGEMENTS FOR 10-YEAR-OLD HIGH-LEVEL WASTE

Option*	Rock Type	Thermal Loading (kW/Acre)	Rows Per Room	Canister Spacing (ft)	Room Width (ft)	Pillar Width (ft)	Peak Medium Temperature(°F)	Room Temperature (°F)	
								5 Yrs	25 Yrs
32/40	Salt	150	1	6.0	17.5	77.0	457	223	283
36/44		75	1	12.0	17.5	77.0	306	152	182
NA**		75	1	6.0	17.5	171.5	426	192	208
33/41	Granite	190	1	13.5	17.5	15.0	488	227	302
37/45		95	1	27.0	17.5	15.0	352	153	197
NA**		95	1	13.5	17.5	47.5	383	163	222
34/42	Basalt	190	1	13.5	17.5	15.0	720	257	419
38/46		95	1	27.0	17.5	15.0	527	182	254
NA**		95	1	13.5	17.5	47.5	578	180	286
35/43	Shale	130	1	8.0	20.0	62.0	661	221	340
39/47		65	1	16.0	20.0	62.0	477	152	212
NA**		65	1	8.0	20.0	144.0	648	208	246

*Vertical/horizontal storage option numbers

**Not applicable

4.4.2 Storage Arrangements for 10-Year-Old Spent Fuel Assemblies

Table 4.2 summarizes the storage arrangements established for spent fuel canisters, containing one PWR fuel assembly or 2 BWR fuel assemblies, stored individually in vertical storage holes with the room temperature also applying for individually stored canisters in horizontal storage holes. These arrangements were established on the same basis described for high-level waste storage arrangements in Section 4.4.1. However, two arrangements were required for design areal thermal loading in salt: one for retrieval, where the minimum canister spacing of 4.0 ft can be used; and one for recovery from backfilled storage rooms and holes, where a larger canister spacing is required. In addition, the areal thermal loading for shale had to be reduced from the design level of 130 kW/acre to 100 kW/acre in order not to exceed the maximum allowable extraction ratio of 25% at the minimum canister spacing of 4.0 ft.

4.4.3 Storage of Multiple Waste Canisters in Long, Horizontal Holes in Salt Formation

The storage of multiple canisters of both HLW and spent fuel assemblies in long, horizontal holes in salt was found to require less mining and result in lower storage room temperatures than the storage of single canisters. In the case of storing multiple canisters of HLW, less than half the room salt must be mined and the average room temperature, between 5 and 25 years of storage, was calculated to be 100°F lower than that for single canisters. In the case of storing multiple canisters of spent fuel assemblies, approximately one-third the room salt must be mined and the average room temperature, between 5 and 25 years of storage, was calculated to be more than 35°F lower than that for single canisters.

4.5 Basis of Repository Design

Thermal conditions in the repository must be known in order to evaluate the retrieval and recovery operations. These conditions have been established for storage in salt, but not for storage in the other

Table 4.2

SELECTED STORAGE ARRANGEMENTS FOR 10-YEAR-OLD SPENT FUEL ASSEMBLIES

Option*	Rock Type	Thermal Loading (kW/Acre)	Rows Per Room***	Canister Spacing (ft)	Room Width (ft)	Pillar Width (ft)	Peak Medium Temperature(°F)	Room Temperature (°F)	
								5 Yrs	25 Yrs
1/11	Salt (Retrieval)	60	2	4.0	17.5	141.5	283	157	191
6/16		30	2	8.0	17.5	141.5	190	125	142
NA**		30	2	4.0	17.5	304.5	276	161	165
NA**	Salt (Recovery)	60	2	5.5	17.5	101.0	250	151	184
NA**		30	2	11.0	17.5	101.0	170	115	128
NA**		30	2	5.5	17.5	214.5	226	140	158
3/13	Granite	190	2	6.0	17.5	16.0	422	227	294
8/18		95	2	12.0	17.5	16.0	261	155	188
NA**		95	2	6.0	17.5	49.5	348	178	247
4/14	Basalt	190	2	6.0	17.5	16.0	636	268	418
9/19		95	2	12.0	17.5	16.0	376	175	250
NA**		95	2	6.0	17.5	49.5	513	200	330
5/15	Shale	100	2	4.0	24.0	73.0	568	221	345
10/20		50	2	8.0	24.0	73.0	340	153	220
NA**		50	2	4.0	24.0	170.0	521	218	276

*Vertical/horizontal storage option numbers

**Not applicable

***Distance between rows 5.5 ft

rock types: granite, basalt, and shale. As a result, the present thermal analysis was initiated to provide an approximate set of repository conditions for alternate rock and wastes types.

The "base cases" used to establish repository storage arrangement configurations and the associated thermal conditions for those arrangements are discussed in Sections 4.5.1 - 4.5.5. Conditions assumed in past studies were adopted when possible and are referenced accordingly.

4.5.1 Repository Configuration and Operations

4.5.1.1 Mine Plan

The mine plan is the plan developed for a bedded salt repository.³ This plan and the typical room and pillar configuration are described in Section 3.2. However, the canister placement in each storage room, the storage room cross section, and the width of the pillar between storage rooms are adjusted in order to satisfy requirements of each waste and rock type. The total mine area is fixed at 2,000 acres, exclusive of the external shaft pillar, which will include approximately 100 additional acres.

4.5.1.2 Nuclear Waste Receipts

The HLW and spent fuel assemblies are 10 years old at storage, with the total receipts of HLW and spent fuel assemblies defined by the areal thermal loading. The final ratio of BWR to PWR fuel assemblies is equal to 213,229/144,099, the ratio established for a bedded salt repository.³

4.5.1.3 Vertical Storage Arrangements

The vertical storage arrangements investigated were restricted to a single row of storage holes or two rows of storage holes beneath the floor of the storage room. Only one canister was located in each storage hole. One row of holes was considered for the storage of HLW in

each candidate medium, whereas both one row and two rows of holes were considered for the storage of spent fuel assemblies. The primary reason for the difference in approach for HLW and spent fuel is that a significantly greater number of spent fuel canisters are to be stored for a given areal thermal loading.

4.5.1.4 Horizontal Storage Arrangements

The canisters were considered stored either in a single row of holes in each sidewall or in two parallel rows of holes in one sidewall. Only one canister was considered located in each hole in order to have the thermal conditions in a storage room calculated for a vertical arrangement apply to the associated horizontal arrangement.

The storage of several canisters in long horizontal storage holes in salt was investigated separately. This arrangement was considered because it offers significant economic benefits since less rock needs to be mined.

4.5.1.5 Ventilation of Storage Rooms

The storage rooms were assumed ventilated only during the times personnel entered for storage, inspection, maintenance, and retrieval operations. This procedure is considerably less expensive than continuous ventilation of the storage room and allows the thermal conditions of the storage room to be calculated independent of the ventilation method.

4.5.2 Nuclear Waste Package Description and Decay Heat

Canisters containing HLW and canisters containing spent fuel assemblies were considered. The nominal discharge age is 10 years in both cases. The dimensions of the HLW canister and the spent fuel canister, and the assumed decay heat characteristics of the HLW and spent fuel are described in Section 3.2.

4.5.3 Thermal Properties of Rock Types

The rock types considered in this study include salt, granite, basalt, and shale. The assumed thermal properties of these materials are shown in Table 4.3. These values represent the composite of values used in past studies^{1, 4-7} in the U.S. nuclear waste program.

TABLE 4.3
ASSUMED CONSTANT PROPERTIES OF CANDIDATE STORAGE MEDIA

<u>Property</u>	<u>Salt</u>	<u>Granite</u>	<u>Basalt</u>	<u>Shale</u>
K, Btu hr ⁻¹ ft ⁻¹ F ⁻¹	2.08	1.41	0.76	0.89
p, lb ft ⁻³	133	165	180	176 *
C _p , Btu lb ⁻¹ F ⁻¹	0.22	0.22	0.19	0.20

* The value of 160 used in the mining studies is also in the range of measured values.

4.5.4 Storage Room Cross Sections

Storage room cross sections were selected on the basis of available mine techniques and the spacing requirements of the canisters. Rooms in salt, basalt, and granite are rectangular with a width of 17.5 ft; the room heights are 19 ft for spent fuel and 16 ft for HLW. Rooms in shale are circular and made by a tunneling machine with a built-up floor; the diameter of the room is 20 ft for a single row of vertical canisters and 24 ft for double rows of vertical canisters. For horizontal storage in shale, the room diameter is reduced, but this fact was not taken into account in the thermal analysis.

4.5.5 Design Criteria

4.5.5.1 Areal Thermal Loadings

The areal thermal loadings used for the "Generic Environmental Impact Statement" (GEIS)¹ and for the conceptual designs of salt repositories^{2, 3}

were adopted. Table 4.4 presents the thermal loadings assumed for each waste and rock type. With one exception, these loadings were based on near-field, thermo-mechanical stress studies that addressed storage room stability during an assumed five-year retrievability period. The areal thermal loading for spent fuel in salt is the exception; the loading of 60 kW/acre was used in the conceptual repository design to achieve the same far-field, thermo-mechanical effects achieved with high-level waste in salt at the higher thermal loading.

These design thermal loadings also were halved in the present study in order to evaluate the influence of thermal loading on extended retrieval and recovery operations. The two methods of achieving this reduction were: (a) to remove alternate storage rooms, and (b) to remove alternate canisters in a row.

TABLE 4.4

DESIGN AREAL THERMAL LOADINGS (kW/ACRE)

<u>Medium</u>	<u>HLW</u>	<u>Spent Fuel</u>
Salt ^{2,3}	150	60(*)
Granite ¹	190	190
Basalt ¹	190	190
Shale ¹	130	130

*Calculated to result in the same far-field thermo-mechanical effects obtained with HLW at 150 kW/acre.

4.5.5.2 Extraction Ratio Limitations

The extraction of the rock is restricted by the allowable maximum load for the unmined rock. Table 4.5 presents the maximum allowable extraction ratio established for the different rock types. Allowable extraction ratios were calculated for the general room and pillar arrangement,

using a safety factor of 2.0 to define the load and neglecting the influence of the waste decay heat. However, a reduction was made in the limits calculated for basalt and granite in order to account for pillar damage incurred by drilling and blasting operations.

TABLE 4.5

MAXIMUM ALLOWABLE EXTRACTION RATIOS
FOR CANDIDATE ROCK TYPES

<u>Medium</u>	<u>HLW</u>	<u>Spent Fuel</u>
Salt	25%	25%
Granite(*)	55%	55%
Basalt(*)	55%	55%
Shale	25%	25%

*Calculated limit reduced from 70% to 55% in order to compensate for pillar damage incurred during drilling and blasting operations.

4.5.5.3 Limitations on Thickness of Web Between Storage Holes

The drilling of storage holes with conventional drilling equipment requires the maintenance of a minimum thickness for the web between storage holes. This requirement was specified in terms of a minimum center-to-center storage hole spacing of 4 ft.

4.5.5.4 Guidance Rock Temperature

The structural integrity of the rock type should be maintained. A convenient and easy method to maintain this integrity is to keep rock temperatures below levels where significant changes in structural properties of the rock occur. Table 4.6 presents guidance values for rock temperatures established on this basis. (See Section 7.) These values were only used for guidance since the influence of localized changes on room stability could not be determined readily.

TABLE 4.6

GUIDANCE TEMPERATURES
FOR CANDIDATE ROCK TYPES

<u>Medium</u>	<u>Temperature</u>
Salt	492°F (250°C)
Granite	392°F (200°C)
Basalt	392°F (200°C)
Shale	212°F (100°C)

4.5.5.5 Maximum Allowable Waste Temperatures

The temperature limits of HLW and spent fuel adopted are those recommended by Jenks.⁸ The maximum allowable temperature for glass HLW is 932°F (500°C). The maximum allowable temperature for spent fuel is 707°F (375°C).

4.6 Method of Calculation

Candidate storage arrangements were investigated for each waste and rock type. The calculation procedures used are outlined in Sections 4.6.1 - 4.6.4, beginning with the establishment of a storage arrangement for a given design areal thermal loading and concluding with the selection of the optimum arrangement on the basis of calculated rock temperatures.

4.6.1 Determination of Storage Arrangements

4.6.1.1 Vertical Storage of Waste Canisters

A storage arrangement was established for each design areal thermal loading by first selecting a canister arrangement in a storage room and then calculating the spacing of storage rooms required. The distance ξ

between rows in adjacent storage rooms was calculated using equations derived by considering the area required by each stored canister to achieve the design areal thermal loading. The equations are:

$$\xi = \frac{87,120 Q}{\phi_m (AR)P} - \delta \quad (4.1)$$

for two rows of canisters in each storage room, and

$$\xi = \frac{43,560 Q}{\phi_m (AR)P} \quad (4.2)$$

for a single row of canisters in each storage room.

The terms in these equations are defined:

ξ = distance between rows in adjacent storage rooms (ft).

δ = distance between parallel rows in a storage room (ft).

Q = decay heat of a stored canister; the weighted average of BWR and PWR canisters in the case of storing spent fuel (kW).

ϕ_m = areal thermal loading based on the mine area (kW/acre).

AR = Ratio of the total mine area to the storage area of the mine, including pillars between storage rooms.

P = Canister pitch, which is the center-to-center distance of canisters in a row (ft).

Figure 4.1 presents a graphical description of these terms.

ROOM AND PILLAR ARRANGEMENT

MINE LAYOUT

FIGURE 4.1

GRAPHICAL DEFINITION OF TERMS IN
EQUATIONS USED TO ESTABLISH STORAGE
ARRANGEMENTS

4.6.1.2 Storage of Multiple Waste Canisters in Long Horizontal Holes

Candidate storage arrangements were established for each design areal thermal loading in these cases using the same procedure outlined for cases of vertical storage in Section 4.6.1.1. However, the number of canisters N_c in a storage hole had to be specified. For a given room width W_r , the resulting equation for the center-to-center room spacing λ is:

$$\lambda = \frac{43,560 N_c Q}{\phi_m (AR) P} \quad (4.3)$$

The terms in this equation are defined in Section 4.6.1.1.

Mechanical constraints limit the number of technically feasible arrangements. According to representatives of Joy Manufacturing Co., it is possible to drill 200 ft long holes at a diameter of 2 ft. in the candidate rock types. Therefore, it was assumed that the longest storage hole possible is 200 ft. This restricts the number of canisters that can be stored in a hole, where the governing equation for a 200 ft storage hole is:

$$N_c \geq \frac{1}{\ell} [400 + W_r - \lambda] \quad (4.4)$$

The term ℓ is the length of a storage canister. Assuming the hole can be aligned within one degree and the minimum web thickness between holes is 4 ft, the hole spacing P is also restricted, where the governing equation for a 200 ft storage hole is:

$$p \geq 11.0 \quad (4.5)$$

The arrangements considered in the present study maximized the number of canisters in a 200 ft storage hole using equations (4.4) and (4.5) as constraints.

4.6.2 Calculation of Extraction Ratio

The extraction ratio was calculated for each room and pillar arrangement investigated. The extraction ratio ER is, by definition, the room width W_r divided by the sum of the room width and pillar width W_p . In terms of the parameter defined in Section 4.6.1, the equation for the extraction ratio is:

$$\begin{aligned} ER &= \frac{W_r}{W_r + W_p} \\ &= \frac{W_r}{W_r + (\xi + \delta)} \end{aligned} \quad (4.6)$$

for two rows of canisters in each storage room, and

$$ER = \frac{W_r}{W_r + \delta} \quad (4.7)$$

for a single row of canisters in each storage room.

4.6.3 Calculations of Storage Rock Temperature

4.6.3.1 Applications of Conductive Model

The rock type storage medium temperature was calculated for each candidate storage arrangement using a linearized conduction model for a continuous medium. The assumptions required with this approximate model are:

- o Variations of thermodynamic properties with temperature are negligible.
- o The thermal resistance of the waste package does not significantly affect media temperatures at points of interest.
- o The thermal resistance of the storage room, whether open or backfilled, does not significantly affect rock temperature at points of interest.

The applicability of the model is discussed in terms of these assumptions in Sections 4.6.3.1.1 - 4.6.3.1.3. The conduction model and associated computer code are described in a separate report.⁹

4.6.3.1.1 Variations of Thermodynamic Properties with Temperature

The thermal conductivity, density, and specific heat of each candidate rock type vary significantly with temperatures. Consequently, the constant values of the parameters used were selected to result in higher rock temperatures than actual. This approach was considered to be a reasonable and conservative first approximation.

4.6.3.1.2 Uncoupling of Waste and Storage Rock Temperatures

The suitability of neglecting the thermal resistance of the waste package in calculating the variation in rock temperatures had been investigated in the conceptual design of a bedded-salt repository for spent fuel.⁵ A classical closed-form model was extended to account for a time-dependent, decay-heat source. Analytical relations presented by Carslaw and Jaeger,¹⁰ were used as a basis to calculate the temperature of an infinitely-long assembly stored in an infinite salt medium for a variety of decay-heat variations and assembly conductivities. For all conditions studied, the salt temperature was found to be dependent only upon the decay-heat variation. The results obtained demonstrate that, for a given decay-heat source, the near-field rock temperature will be unaffected by the thermal conductivities associated with the fuel assembly. Hence, the rock temperature can be studied separately.

Two analytical models were used in this preliminary investigation. Both model a cylindrical region with internal heat generation in intimate contact with an infinite medium of finite thermal conductivity and predict transient radial temperature rises from an initial temperature of 0°F. One model assumes that the region of internal heat generation is at uniform temperature. A second model allows radial temperature differences within the region of internal heat generation. The thermal diffusion of bedded salt was taken as 0.0691 ft²/hr and its thermal conductivity was taken as 2.06 Btu/hr-ft-°F.

Table 4.7 shows the calculated transient temperatures for an internal, heat-generation level that represents the decay heat of a one-year-old, pressurized water reactor (PWR) assembly. There is less than a 2°F difference at the assembly-salt interface ($r/a=1$) throughout the transient for the isothermal assembly and the assemblies with different conductivities.

Table 4.8 shows the transient salt temperature layer beyond the assembly-salt interface. There is no significant salt temperature difference throughout the transient for the isothermal assembly and the assemblies with different conductivities.

4.6.3.1.3 Influence of the Thermal Resistance of the Storage Room

The influence of the thermal resistance of the storage room was evaluated by comparing rock temperatures calculated with the approximate model and rock temperatures previously calculated with a detailed, finite-difference model HEATING 5.^{6,11} The storage of spent fuel in salt at 60 kW/acre was considered in each case. Figure 4.2 compares the calculated variation of the maximum salt temperature at the edge of the storage hole and the calculated variation of the average storage room temperature. The largest deviation between results is shown to be 20°F for the 28-year storage period considered in the present study. On the basis of these results and the fact that the thermal resistance of the salt medium deviates most from the thermal resistance of an open or backfilled storage room, it was concluded that the approximate model was acceptable.

4.6.3.2 Representation of Waste Decay Heat in Calculation of Storage Rock Temperatures

The decay heat of the waste canister was represented with a finite-length line source that decayed with time in accordance with the characteristics of the waste canister. In the cases of storing HLW, the initial source strength was 2.1 kW. In the cases of storing spent fuel assemblies, the initial source strength was 0.55 kW, which is the highest initial decay heat of the spent fuel canister packages considered.

TABLE 4.7
TEMPERATURE RISE °F OF PWR (ROD REGION) STORED WHEN 1-YEAR OLD

Radius $a = 0.5833$ ft

High Thermal Conductivity = 80 Btu/h-ft-°F

Medium Thermal Conductivity = 10 Btu/h-ft-°F

Low Thermal Conductivity = 3 Btu/h-ft-°F

$r = 0.0500$				$r/a = 0.0857$	$r = 0.1000$		$r/a = 0.1714$	
Time (hours)	High	Medium	Low	Uniform ¹	High	Medium	Low	Uniform ¹
After Storage	Conductivity	Conductivity	Conductivity	Temperature	Conductivity	Conductivity	Conductivity	Temperature
730.5	302.8	311.2	335.1	300.1	302.8	311.1	334.4	300.1
2,191.5	354.3	362.4	386.0	351.6	254.3	362.3	385.1	351.6
4,383	356.1	363.4	384.9	353.5	356.1	363.3	384.2	353.5
6,574.5	348.9	355.7	375.6	346.5	348.8	355.5	374.9	346.5
8,766	334.3	340.6	358.9	332.1	334.3	340.4	358.3	332.1
10,957.5	323.4	329.4	346.6	321.2	323.4	329.2	346.0	321.2
13,149	311.4	317.0	333.2	309.3	211.4	316.8	332.7	309.3
15,340.5	300.4	305.6	321.0	298.4	300.3	305.5	320.5	298.4
17,532	288.5	293.5	308.0	286.6	288.4	293.3	307.5	286.6

$r = 0.3000$				$r/a = 0.5143$	$r = 0.5833$		$r/a = 1.0000$	
Time (hours)	High	Medium	Low	Uniform ¹	High	Medium	Low	Uniform ¹
After Storage	Conductivity	Conductivity	Conductivity	Temperature	Conductivity	Conductivity	Conductivity	Temperature
730.5	302.4	308.5	326.1	300.1	302.4	300.6	300.0	300.1
2,191.5	353.9	359.8	377.0	351.6	352.9	352.1	351.3	351.6
4,383	355.8	361.0	376.6	353.5	354.9	354.0	353.2	353.5
6,574.5	348.6	353.5	367.9	346.5	347.8	346.9	346.1	346.5
8,766	334.1	340.4	351.8	332.1	333.3	332.4	331.7	332.1
10,957.5	323.2	327.3	339.9	321.2	322.4	321.6	320.9	321.2
13,149	311.1	315.1	326.9	309.3	310.4	309.7	309.0	309.3
15,340.5	300.1	303.9	315.1	298.4	299.5	298.8	298.0	298.4
17,532	288.3	291.8	302.3	286.6	287.7	287.0	286.3	286.6

¹From the first model, which assumes that the heat generating region at $r \leq a$ is at a uniform temperature.

TABLE 4.8
TEMPERATURE RISE °F OF SALT SURROUNDING PWR (ROD REGION) STORED WHEN 1-YEAR OLD

Radius $a = 0.5833$ ft High Thermal Conductivity = 80 Btu/h-ft-°F
Medium Thermal Conductivity = 10 Btu/h-ft-°F
Low Thermal Conductivity = 3 Btu/h-ft-°F

	r = 1.1666				r/a = 2				r = 1.7499				r/a = 3			
Time (hours)	High	Medium	Low	Uniform ¹	High	Medium	Low	Uniform ¹	High	Medium	Low	Uniform ¹	High	Medium	Low	Uniform ¹
After Storage	Conductivity	Conductivity	Conductivity	Temperature	Conductivity	Conductivity	Conductivity	Temperature	Conductivity	Conductivity	Conductivity	Temperature	Conductivity	Conductivity	Conductivity	Temperature
730.5	229.4	229.2	228.8	232.8	187.7	187.7	187.5	190.6	240.5	240.3	240.1	244.2	251.9	251.8	251.4	255.8
2,191.5	281.8	281.4	281.1	286.1	240.5	240.3	240.1	244.2	251.9	251.8	251.4	255.8	251.9	251.8	251.4	255.8
4,383	289.7	289.5	289.1	294.2	251.9	251.8	251.4	255.8	251.9	251.8	251.4	255.8	251.9	251.8	251.4	255.8
6,574.5	287.0	286.8	286.5	291.5	251.9	251.8	251.4	255.8	251.9	251.8	251.4	255.8	251.9	251.8	251.4	255.8
8,766	277.0	276.9	276.5	281.3	244.6	244.2	244.1	248.4	244.6	244.2	244.1	248.4	244.6	244.2	244.1	248.4
10,957.5	269.4	269.3	269.0	273.6	238.8	238.7	238.4	242.6	238.8	238.7	238.4	242.6	238.8	238.7	238.4	242.6
13,149	260.5	260.3	260.0	264.5	231.6	231.3	231.2	235.3	231.6	231.3	231.2	235.3	231.6	231.3	231.2	235.3
15,340.5	252.1	251.9	251.7	256.1	224.7	224.6	224.3	228.3	224.7	224.6	224.3	228.3	224.7	224.6	224.3	228.3
17,532	242.8	242.6	242.3	246.6	216.9	216.7	216.5	220.3	216.9	216.7	216.5	220.3	216.9	216.7	216.5	220.3

	r = 2.9165				r/a = 5				r = 4.6664				r/a = 8			
Time (hours)	High	Medium	Low	Uniform ¹	High	Medium	Low	Uniform ¹	High	Medium	Low	Uniform ¹	High	Medium	Low	Uniform ¹
After Storage	Conductivity	Conductivity	Conductivity	Temperature	Conductivity	Conductivity	Conductivity	Temperature	Conductivity	Conductivity	Conductivity	Temperature	Conductivity	Conductivity	Conductivity	Temperature
730.5	136.3	136.1	136.1	138.2	90.8	90.8	90.8	92.1	142.0	142.0	141.8	144.1	161.2	161.2	160.9	163.6
2,191.5	188.9	188.7	188.5	191.7	142.0	142.0	141.8	144.1	161.2	161.2	160.9	163.6	161.2	161.2	160.9	163.6
4,383	204.6	204.2	204.2	207.7	161.2	161.2	160.9	163.6	161.2	161.2	160.9	163.6	161.2	161.2	160.9	163.6
6,574.5	207.7	207.5	207.4	211.0	167.4	167.2	167.0	169.9	167.4	167.2	167.0	169.9	167.4	167.2	167.0	169.9
8,766	203.7	203.5	203.3	206.8	166.2	166.2	165.9	168.7	166.2	166.2	165.9	168.7	166.2	166.2	165.9	168.7
10,957.5	200.3	200.1	200.0	203.4	165.0	164.8	164.7	167.5	165.0	164.8	164.7	167.5	165.0	164.8	164.7	167.5
13,149	195.3	195.2	194.9	198.4	162.0	161.9	161.6	164.4	162.0	161.9	161.6	164.4	162.0	161.9	161.6	164.4
15,340.5	190.6	190.2	189.9	193.2	158.6	158.6	158.3	161.1	158.6	158.6	158.3	161.1	158.6	158.6	158.3	161.1
17,532	184.3	184.1	183.9	187.2	154.3	154.3	154.1	156.7	154.3	154.3	154.1	156.7	154.3	154.3	154.1	156.7

¹From the first model, which assumes that the heat generating region at $r \leq a$ is at a uniform temperature.

FIGURE 4.2 COMPARISON OF LINE-SOURCE MODEL AND FINITE-DIFFERENCE MODEL HEATING5

4.6.3.3 Selection of Rock Temperatures to be Calculated

The highest temperature achieved in the rock types had to be evaluated for each storage arrangement to determine if the guidance temperature for the rock type would be exceeded. The highest temperature will occur at the edge of the storage hole adjacent to the midpoint of the decay-heat line source. Hence, the rock temperature at this location was calculated at representative storage times in order to determine the peak value achieved during the entire storage period. The storage hole was assumed to have a radius of 1.09 ft in all cases.

The temperature of the storage room during retrieval or recovery, in the selected storage arrangement was of primary concern in the Retrieval Options Study. In the cases of vertical storage, the temperature at selected points on the storage room surfaces were calculated at representative storage times; however, only the average room temperature variations, based on these calculated surface temperatures, are reported. In the cases of horizontal storage, the temperature at the center of the room, which is near the average room temperature, was calculated at representative storage times.

4.6.4 Selection of Optimum Storage Arrangements for Design Areal Thermal Loadings

The procedure used to select optimum storage arrangements for design areal thermal loadings was straight forward. Peak rock temperatures were calculated for candidate storage arrangements for a particular waste and rock type. Then, peak temperature was plotted as a function of extraction ratio. The arrangement selected had a peak rock temperature equal to the guidance temperature for the rock type in order to achieve the minimum extraction ratios; however, if the maximum allowable extraction ratio was exceeded with this arrangement, the arrangement corresponding to the maximum allowable extraction ratio was selected instead. In the case of spent-fuel storage, the choice of a single row or double row of canisters in a storage room was also made on the basis of peak rock temperatures and extraction ratio.

The selection procedure outlined above could not be used for storage of spent fuel in shale at 130 kW/acre. In this exceptional case, the web thickness between storage holes was thinner than allowable and the areal thermal loading was reduced to 100 kW/acre in order to maintain the minimum web thickness at the maximum allowable extraction ratio.

4.6.5 Selection of Storage Arrangements for Reduced Areal Thermal Loadings

Two extremes of reducing the areal thermal loading by half were considered. In one extreme, every other canister in a row was removed; this reduced the rock temperatures but the extraction ratio, which directly reflects operating costs, was not reduced. In the other extreme, every other storage room was removed, with no change in the canister arrangement in the remaining storage rooms; this did not reduce rock temperatures significantly, but it did reduce extraction ratio.

4.7 Discussion of Results

Rock temperatures were calculated for a total of 71 storage arrangements in order to establish those arrangements that satisfy the design criteria outlined in Section 4.6. There were 30 arrangements for high-level wastes and 35 arrangements for spent fuel assemblies. Finally, there were 6 arrangements for the storage of multiple canisters in long horizontal storage holes in salt.

Calculated maximum rock temperature variations and average storage room temperature variations are presented for selected storage arrangements in the Appendix. A storage period of 28 years is represented in each case, except where temperatures at early storage times could not be calculated due to computer code limitations.⁹ The selection of these storage arrangements and the characterization of the selected arrangements are discussed in Sections 4.7.1 through 4.7.3.

4.7.1 Storage of 10-Year-Old, High-Level Waste

4.7.1.1 Selection of Storage Arrangements for Design Areal Thermal Loadings

Figure 4.3 presents peak rock temperatures as a function of extraction ratio for each candidate storage arrangement of high-level waste at the design areal thermal loadings. The calculated results for each candidate storage rock type are represented, with the selected arrangements highlighted with solid symbols. The guidance temperature and extraction ratio limits for each storage rock are represented.

It was assumed that the maximum allowable temperature of the waste, 932°F, was not exceeded in any of the selected arrangements since the decay heat of the waste will be significantly reduced before the peak rock temperature occurs. In the worst case of a peak basalt temperature of 720°F, the decay heat is only 1.5 kW compared to an initial level of 2.1 kW.

4.7.1.2 Storage Arrangements for Reduced Areal Thermal Loadings

Figure 4.4 presents peak rock temperature as a function of extraction ratio for the reduced areal thermal loadings for high-level waste. The guidance temperature and the extraction ratio limit is not exceeded at the reduced loadings with storage in salt or granite. However, the guidance temperatures are exceeded with storage in basalt and shale.

4.7.1.3 Peak Average Storage Room Temperatures for Selected Storage Arrangements

The peak value of the average storage room temperature over a 28-year storage period was evaluated for each selected storage arrangement for high-level waste. Figure 4.5 presents the peak storage room temperature as a function of extraction ratio for the design areal thermal loading and both extreme arrangements used to achieve reduced areal thermal loadings. At the design areal thermal loadings, peak room temperatures range from 285°F for storage in salt to 420°F for storage in basalt. Halving

FIGURE 4.3

CALCULATED PEAK TEMPERATURES AT SELECTED EXTRACTION RATIOS FOR THE STORAGE OF HIGH-LEVEL WASTE AT DESIGN AREAL THERMAL LOADING

FIGURE 4.4

CALCULATED PEAK TEMPERATURES AT SELECTED EXTRACTION RATIOS FOR THE STORAGE OF HIGH-LEVEL WASTE AT REDUCED STORAGE DENSITIES

FIGURE 4.5

CALCULATED PEAK AVERAGE ROOM TEMPERATURES AT SELECTED EXTRACTION RATIOS FOR THE STORAGE OF HIGH-LEVEL WASTE

the areal thermal loadings is shown to reduce the peak room temperature by more than 75°F in all rock types, with no particular thermal advantage gained by maintaining the extraction ratio as compared to reducing the extraction ratio through reduction in the number of storage rooms.

4.7.2 Storage of 10-Year-Old, Spent Fuel Assemblies

4.7.2.1 Selection of Storage Arrangements for Design Areal Thermal Loadings

Figure 4.6 presents peak rock temperatures as a function of extraction ratio for each candidate storage arrangement for spent fuel assemblies at the design areal thermal loadings. The calculated results for each rock type are represented. Two rows of canisters per room were considered for all storage rock types; however, single rows of canisters were also considered for storage in basalt and shale. The guidance temperatures and the extraction ratio limits for the storage rock are represented. Three conclusions were drawn from these results; they are:

- o At a fixed extraction ratio, a double row of canisters per room results in a lower peak rock temperature than a single row of canisters per room. The peak rock temperature given for 190 kW/acre in basalt and 130 kW/acre in shale demonstrate this fact.
- o Peak rock temperatures exceed the guidance temperature, except for storage in salt. Hence, the arrangements were selected on the basis of extraction ratio.
- o The maximum allowable extraction ratio for shale will be exceeded by all storage arrangements for spent fuel assemblies at an areal thermal loading of 130 kW/acre because the canister spacing must be greater than or equal to 4 ft. Consequently, the areal thermal loading for shale was reduced to 100 kW/acre, as shown, in order to achieve an acceptable extraction ratio at the minimum canister spacing of 4 ft.

FIGURE 4.6

CALCULATED PEAK TEMPERATURES AT SELECTED EXTRACTION RATIOS FOR THE STORAGE OF FUEL ASSEMBLIES AT DESIGN AREAL THERMAL LOADINGS

Accounting for these factors, the arrangements for spent fuel assemblies highlighted with solid symbols were selected. The two arrangements in salt correspond to a canister spacing of 4 ft used in the repository conceptual design for both 5 year and 25 year retrieval^{2,12} and a canister spacing of 5.5 ft used in the repository conceptual design for recovery from backfilled rooms and storage holes.¹³

It was assumed that the maximum allowable temperature of a stored spent fuel assembly, 707°F, was not exceeded in any of the selected arrangements.

4.7.2.2 Storage Arrangements for Reduced Areal Thermal Loadings

Figure 4.7 presents peak rock temperatures as a function of extraction ratio for the reduced areal thermal loadings. The guidance temperatures and extraction ratio limits are not exceeded at the reduced loadings with storage in salt, granite, and basalt; however, the guidance temperature is exceeded with storage in shale, even at 50 kW/acre.

4.7.2.3 Peak Average Storage Room Temperatures for Selected Storage Arrangements

The peak value of the average storage room temperature over a 28 year storage period was evaluated for each selected storage arrangement for spent fuel assemblies. Figure 4.8 presents the peak storage room temperatures as a function of extraction ratio for the design areal thermal loadings and both extreme arrangements used to achieve reduced areal thermal loadings. At the design areal thermal loadings, peak room temperatures range from 182°F for storage in salt to 420°F for storage in basalt. Halving the areal thermal loading is shown to reduce the peak room temperature by 25°F for storage in salt and 130°F for storage in basalt. Moreover, a thermal advantage is gained by maintaining the extraction ratio as compared to reducing the extraction ratio through reduction in the number of storage rooms.

FIGURE 4.7

CALCULATED PEAK TEMPERATURES AT SELECTED EXTRACTION RATIOS FOR THE STORAGE OF FUEL ASSEMBLIES AT REDUCED AREAL THERMAL LOADING

FIGURE 4.8

CALCULATED PEAK AVERAGE ROOM TEMPERATURE AT SELECTED EXTRACTION RATIOS FOR THE STORAGE OF FUEL ASSEMBLIES

4.7.3 Storage of Multiple Canisters in Long Horizontal Holes in Salt Formation

The storage of multiple canisters in horizontal holes in salt was considered. Temperatures were calculated for candidate storage arrangements for high-level waste and spent fuel at the design areal thermal loadings. The selection of storage arrangements on the basis of these results are discussed and the selected arrangements compared to the associated vertical storage arrangements in Sections 4.7.3.1 - 4.7.3.3.

4.7.3.1 Multiple Canister Storage of 10-Year-Old, High-Level Waste in Salt

Temperatures were calculated for storage arrangements with storage hole spacings of 11.5, 15.5, and 23.0 ft. These arrangements have 7, 9, and 12 canisters in each storage hole, respectively, for the maximum storage hole length of 200 ft.

By interpolation of the calculated peak salt temperatures, the arrangement, which approaches but does not exceed the salt guidance temperature of 482°F, was found to have 11 canisters in each storage hole; the corresponding storage hole spacing is 20.5 ft.

4.7.3.2 Multiple Canister Storage of 10-Year-Old Spent Fuel Assemblies in Salt

Temperatures were calculated for storage arrangements with storage hole spacing of 12.0, 14.0, and 16.0 ft. These arrangements have 10, 11, and 12 canisters in each storage hole, respectively, for the maximum storage hole length of 200 ft.

The guidance salt temperature of 482°F is not exceeded in any case. However, the arrangement with 10 canisters per storage hole and a storage hole spacing of 12 ft was preferred because it has the minimum extraction ratio of the three candidate arrangements.

4.7.3.3 Comparison of Storing Multiple Canisters in Long Horizontal Storage Holes with Single Canister Vertical Storage Arrangements

Table 4.9 presents a comparison of the selected horizontal multiple canister storage arrangement and the associated single canister vertical storage arrangement for high-level waste in salt. The horizontal storage arrangement requires less than half the mining and has an average storage room temperature approximately 100°F lower than calculated for the vertical storage arrangement.

Table 4.10 presents a comparison of the preferred horizontal multiple canister arrangement and one of the associated vertical arrangements for spent fuel in salt. The horizontal arrangement requires approximately one-third of the mining required by the vertical storage arrangement. The horizontal arrangement also has storage room temperatures that are more than 35°F lower than those in the vertical arrangement.

TABLE 4.9

COMPARISON OF HORIZONTAL AND VERTICAL STORAGE OF HIGH-LEVEL WASTE IN SALT AT 150 kW/ACRE

<u>Storage Conditions</u>	<u>Horizontal</u>	<u>Vertical</u>
Room Cross-Section	17.5 ft x 12 ft	17.5 ft x 16 ft
Storage Hole Spacing	20.5 ft	6 ft
Canisters per Hole	11	1
Room Salt Mined per Canister	27 tons	58 tons
Peak Salt Temperature	468°F	458°F
Average Room Temperature:		
5 years	92°F	223°F
25 years	183°F	282°F

TABLE 4.10

COMPARISON OF HORIZONTAL AND VERTICAL STORAGE
OF SPENT FUEL ASSEMBLIES IN SALT AT 60 kW/ACRE

<u>Storage Condition</u>	<u>Horizontal</u>	<u>Vertical</u>
Room Cross-Section	17.5 ft x 12 ft	17.5 ft x 19 ft
Storage Hole Spacing	12.0 ft	4.0 ft
Canister per Hole	10	1
Room Salt Mined per Canister	17 tons	46 tons
Peak Salt Temperature	216°F	284°F
Average Room Temperatures:		
5 years	101°F	169°F
25 years	154°F	191°F

REFERENCES

1. "Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations, Volume 19, Thermal Analysis," OWI Report Y/OWI/TM-36/19, 1978.
2. "Conceptual Design Report for a National Waste Terminal Repository for Storing Reprocessing Wastes in a Dome Salt Formation," Stearns-Roger Engr. Co. Report for DOE Contract EY77C055367, Vols I and II, January 1979.
3. "Conceptual Design Report for a National Waste Terminal Storage Repository in a Bedded Salt Formation for Spent Unreprocessed Fuel," Kaiser Engineers Report No. 78-57-RE, Vols I and II, December 1978.
4. "Report of Heat Transfer Engineering Studies Conducted in Support of the (NWTSR2) Design," KE Report No. 7701B NWJS 3349, Dec. 1978.
5. "Kaiser Engineers Interoffice Memoranda (for NWTSR2): Heat Transfer," KE Report No. 77018 NWTS 3350, Dec. 1978.
6. "Kaiser Engineers Interoffice Memoranda and Documentation (for NWTSR2): Heat Transfer," KE Report No. 77018 NWTS 3351, Dec. 1978.
7. "The Basalt Storage Program," Rockwell International Report RHO-SA-11, Oct. 1977.
8. Jenks, G. H., "Maximum Acceptable Temperatures of Wastes and Containers during Retrievable Storage," OWI Report Y/OWI/TM-42, August 1977.
9. "Finite-Length Line Source Superposition Model," ONWI Report No. 94, 1980.
10. H. S. Carslaw and J. C. Jaeger, Conduction of Heat in Solids, 2nd Ed, Oxford: Clarendon Press, 1959; pp. 341-344.

11. Oak Ridge National Laboratory, "HEATING5 - An IBM 360 Heat Conduction Program," ORNL/CSD/TM-15, March 1977.
12. "Special Study No. 1: 25-Year Retrievability for a National Waste Terminal Storage Repository in a Bedded Salt Formation for Spent Unreprocessed Fuel," Kaiser Engineers Report No. 78-60-RE, December 1978.
13. "Special Study No. 3: Waste Retrieval from Backfilled Regions for a National Waste Terminal Storage Repository in a Bedded Salt Formation for Spent Unreprocessed Fuel," Kaiser Engineers Report No. 78-56-R, September 1978.

5.0 GEOLOGY AND MINING

Section 5 describes four rock types considered for mined nuclear waste storage: salt, granite, basalt, and shale. It includes a discussion on guidance temperatures for the media. It also discusses the mining techniques, the ground support required, ventilation requirements, and backfill techniques upon which the cost estimates are based. For a more detailed discussion of the rock types the reader is referred to references 1, 2, 3 and 4 which discuss salt, granite, basalt and shale, respectively.

The mine plan utilized for this study is a conceptual plan developed for a repository in bedded salt as part of the NWTSR2⁵ study. This plan and a typical room and pillar configuration are shown in Figures 3.3 and 3.4. These conceptual plans can be adjusted to take into account different rock types, different thermal loadings, and different types of nuclear waste.

5.1 Geology

Because no repository site has been identified, certain assumptions concerning the general geology of a candidate site were made for the purposes of this report. While all of the assumed conditions may not occur together in nature at one site, it is the opinion of Kaiser Engineers that sites do exist within the continental United States where conditions approach those assumed. The four types of rock considered in this report have potential for nuclear waste storage. The conceptual engineering and cost estimating undertaken for this study are based upon the generic rock descriptions contained herein. The temperature estimates for each rock type are subject to field verification when a site is available.

5.1.1 Geological Assumptions

The following assumptions have been made for this study:

- o The formations are persistent and continuous within the repository area.
- o No major faults are present.
- o Water inflow is minimal.
- o The mineralogy of the rocks is generally uniform.
- o The salt and shale formations are horizontal in attitude.
- o Excessive horizontal stresses are not present.
- o The mine workings are located at a depth of 2,000 feet.

5.1.2 Rock Descriptions

5.1.2.1 Rock Salt

Rock salt is defined as an evaporite deposit of halite, anhydrite, and gypsum in varying sequence and proportion. Characteristically, rock salt deposits are a crystalline, fibrous, or even granular aggregate composed mainly of sodium chloride.

Rock salt for a repository should be massive, should have remained relatively undisturbed over a long period of geologic time, and should be free from circulating groundwater or large brine pockets. Many thick salt deposits, both basin and domed types, are known to exist today. A number of these have remained undisturbed and without fluid encroachment for several million years.

5.1.2.2 Granite

Granite is defined as an igneous rock composed of megascopic quartz and feldspars with a 20% to 40% quartz content. Generally light colored, granite and granite-type rocks exhibit the same range of properties. Accessory minerals, such as mica, hornblende,

and other dark minerals, constitute part of their makeup. These accessory minerals generally dictate the name, such as mica granite and hornblende granite.

Ideally, for repository considerations, the rock should be homogeneous and fine-grained, with joint surfaces widely spaced and tight. Unfortunately, relatively large masses of homogeneous, fine-grained granite are not found in nature.

5.1.2.3 Basalt

A basalt is defined as an extrusive igneous rock composed essentially of plagioclase and pyroxene. These dense, fine-grained rocks vary in color from grayish- and greenish-black to black.

Repositories in basalt should probably be located near the middle of the flow, where columnar jointing is tight and the effects of fast surface cooling and erosion are less likely to occur.

5.1.2.4 Shale

Shales, the most widespread of the sedimentary-type rocks, are also among the least understood due to their very fine-grained and diverse mineralogical makeup. Defined as a laminated sedimentary in which clay-size particles are predominant, shales generally consist of about one-third quartz, one-third clay minerals, and one-third miscellaneous substances. The laminations are approximately parallel to the bedding.

Shales for repositories should be free of carbonaceous material and from the swelling type of clays, such as bentonite, which swell on exposure to the air and tend to close excavated openings. Large areas of shale outcrop, with shale thicknesses of thousands of feet, are known in the western United States.

5.1.3 Media Temperatures

Potential effects of increased temperatures in the various media have not been evaluated but the temperatures at which thermal effects may change the media properties are discussed for each rock type. These temperatures were used as a guide in determining the storage configuration. If the media temperatures are calculated to be under the guidance temperatures, no changes are anticipated to the media properties. If the guidance temperatures are exceeded, properties of the media will probably change but the impact of the change is not investigated.

For rock salt, a guidance temperature of 482°F has been used; this is consistent with the criteria for the NWTSR2 conceptual design. The basis for this temperature is the experimental work performed for Project Salt Vault.

As shown in laboratory work⁶, feldspars, which are found in both granite and basalt, have the potential of converting to kaolinite under the action of hot water. Thus, a guidance temperature of 392°F has been used for these rocks. It is likely that water would occur along fracture planes in a granite or basalt rock formation. This water, coupled with the temperature increase caused by the nuclear waste, could be sufficient to permit the feldspar alteration. Alteration to clay minerals, along preexisting fracture surfaces, would weaken the rock in the immediate vicinity of an underground opening and could result in ground support problems.

A guidance temperature of 212°F was selected for shale. This temperature, the boiling point of water, was selected to prevent dehydration of the shale with consequent decrepitation and spalling.

5.2 Mining

The mining technology contemplated for retrieving stored nuclear wastes is primarily concerned with ground support, ventilation, and excavation and replacement of backfill where applicable.

5.2.1 Ground Support

For the 81 "base cases" it is anticipated that storage rooms in salt would be excavated by conventional continuous miners to a rectangular cross section; storage rooms in shale would be developed by a tunnel boring machine to a circular cross section. The circular opening would provide the best design stability for the most generically weak rock considered. Storage rooms in granite and basalt would be excavated using drilling and blasting techniques to a rectangular cross section. The dimensions of the rooms are determined by space requirements for the canisters and are given in Section 4.0 of this report.

Storage room geometries and dimensions for the "broad option" cases are as shown on Drawings M-1 and M-4 of Section 7.

Pillar dimensions for the "base cases" were calculated using formulas for parallel openings in which the dimension parallel to the opening is much greater than that between the openings. A safety factor of twice the allowable stress was used in determining the ratio between the widths of rooms and pillars.

It is assumed that all storage rooms are capable of being reentered. For rooms left standing open for five years in salt, granite, or basalt, no support additional to that needed during the emplacement period is considered. However, for rooms left standing open for five years in shale, it is believed that steel support arches will be needed because of the laminated structure of shale and its tendency to spall.

Additional support will be needed for rooms left standing open for 25 years in salt or shale. Rooms in salt will require steel bolts imbedded in the roof; rooms in shale will require steel support arches. No additional supports are considered for rooms in granite or basalt left standing open for 25 years.

Rooms that have been backfilled and reopened after five years in salt and shale will require roof bolts and steel support arches, respectively. No additional support is considered for granite and basalt under these conditions.

Rooms that have been backfilled and reopened after 25 years in salt and shale will require steel support arches. For rooms in granite and basalt which have been backfilled and reopened after this time period, roof bolts are considered to be adequate.

It is anticipated that rooms from which backfill has been removed may require more support than rooms that have never been backfilled because open rooms will be maintained periodically and stress relief will be effected. Rooms that have been backfilled will have their closure and stress relief restricted and may be in a high state of stress when reexcavated.

5.2.2 Ventilation

Ventilation requirements for cooldown to acceptable working temperatures (125°F for rooms left open and 83°F for retrieval operations in rooms from which backfill has been removed) were manually calculated using intake air to the rooms at a temperature of 71°F. It was assumed that horizontal storage requires a smaller diameter room than vertical storage and thus the ventilation requirements are less.

5.2.3 Excavation and Replacement of Backfill

Backfill is postulated to be run-of-mine and would occupy 90% of the original opening. It will not be hardened or strengthened by the heat. Backfill would be excavated using continuous-miner-type equipment in the case of salt and shale, or front-end-loader-type equipment for granite and basalt. In both cases, the material would be loaded onto an extendable belt for disposal. Ventilation of the hot working place would be effected by erecting a brattice wall down the middle of the room, behind the excavator. Fresh air would be blown through one side, past the equipment, and then returned on the conveyor side. In addition, an independent insulated ducting would be available to supply cool air for spot cooling.

During the excavation period, ground support would be installed as explained in Section 5.2.1. Where steel support arches are to be installed, the storage rooms would be overexcavated to provide sufficient clearance for handling the canisters within the support opening.

Following the retrieval operation, backfill would be replaced using low profile trucks and bulldozers for replacement.

REFERENCES

1. Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations. Volume 4 - Baseline Rock Properties in Salt.
2. Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations. Volume 5 - Baseline Rock Properties in Granite.
3. Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations. Volume 7 - Baseline Rock Properties in Basalt.
4. Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations. Volume 6 - Baseline Rock Properties in Shale.
5. "Conceptual Design Description for a National Waste Terminal Storage Repository in a Bedded Salt Formation for Spent Unreprocessed Fuel," KE Report No. 78-58-R, December 1978.
6. K. B. Krauskopf. Introduction to Geochemistry, McGraw-Hill, New York, 1967, p. 114.

6.0 WASTE HANDLING EQUIPMENT

This section briefly defines the classes of retrieval and recovery and discusses the type of equipment/systems that will be utilized for the various classes of retrieval and recovery of waste packages. It also describes the work effort required for the various classes of retrieval and recovery. The cost of the equipment/systems and work effort are then estimated and included in the rating evaluations for cost, technical feasibility and ease of retrieval. The baseline assumptions for waste handling are included in Section 3.2.4.

6.1 Retrieval and Recovery

Retrieval Class A will be performed by the same machinery used for package emplacement. For Retrieval Classes B through F, the emplacement machinery will be augmented by trepanning type equipment. The recovery process will require a variety of systems, all required to maintain confinement and isolation of contaminated material. Each system will be used to perform one of the following functions: (1) reopening the backfilled mine; (2) locating the package and freeing it in the hole; (3) transferring the package to the surface facility; and, (4) recovering and repackaging broken packages and contaminated media. The fourth function involves very costly systems processes.

6.2 Work Effort

Each established retrieval/recovery classification identifies a specific storage state. Removing the waste canister from each storage state will require a specific work effort that will include mine maintenance, mine reopening, canister removal from the hole, canister transfer from the mine to the surface hot cell and rebackfilling of the storage room where applicable. A brief

description of the retrieval/recovery classifications is given, followed by a discussion of the work effort required. The amount of work effort was then factored into the cost of each of the "base case" options evaluated in Section 7.0. It was also included in the relative cost rankings for the "broad options" cases.

6.2.1 Retrieval

Retrieval in general will be relatively straightforward since the canisters are unbreached. However, great care will be required to avoid rupturing the canisters during retrieval. If analysis indicates that a significant fraction of the canisters are likely to be ruptured during removal, then it may be necessary to plan for a recovery operation rather than a retrieval operation.

6.2.1.1 Retrieval: Class A-1

The mine room and the deposit hole are open; the canister, unbreached and structurally sound, is free in the hole.

The retrieval process for canisters in this state is the reversal of emplacement using the same machinery and work effort. Retrieval rate is the same as the emplacement rate.

6.2.1.2 Retrieval: Class A-2

The mine room can be reopened by routine means, having been protectively backfilled after emplacement; the canister, unbreached and structurally sound, is free in the hole.

The major work effort for Class A-2 will be reopening the mine room and preparing it for the retrieval operation using the same machinery for retrieval that was used for emplacement. The production rate, after the mine is open, will be the same as Class A-1.

6.2.1.3 Retrieval: Class B-1

The mine room and the deposit hole are open; the canister, free in the hole, is unbreached but structurally weak.

Additional equipment, supplementing the machinery used for emplacement, will be required to prevent canister breakdown. More work effort will be required than for retrieval of Class A-1 retrieval; production rates will be less than those for Class A-1.

6.2.1.4 Retrieval: Class B-2

The mine room can be reopened by routine means, having been protectively backfilled after emplacement; the canister, free in the hole, is unbreached but structurally weak.

The Class B-2 condition will require mine reopening as in Class A-2 and supplementary machinery as in Class B-1. The work effort will be similar to that required for Class A-2 and B-1. The retrieval production rate should be the same as Class B-1.

6.2.1.5 Retrieval: Class C-1

The mine room is open; the canister, tight in the deposit hole because of engineered backfill, is unbreached and structurally sound.

Supplementary machinery, specially designed to free the canister in the hole by trepanning or a comparable system, lift it from the hole, remove any residual material from it, and deliver it to a transporter, will be necessary for Class C-1*. The work effort will be high and production rates very low.

*Suggested machine types for this and the following classes are discussed in Reference 1.

6.2.1.6 Retrieval: Class C-2

The mine room can be reopened by routine means, having been protectively backfilled after emplacement; the canister, tight in the deposit hole because of engineered backfill, is unbreached and structurally sound.

The Class C-2 work effort will be the same as that for Class A-2 and will use the same specially designed equipment as that for Class C-1. The mine opening operation and the canister freeing exercise will influence the work effort; the production rate of retrieval will be very low.

6.2.1.7 Retrieval: Class D-1

The mine room is open; the canister, tight in the deposit hole because of engineered backfill, is unbreached but structurally weak.

The Class D-1 condition presents a severe problem. The same equipment required for Class B-1 and C-1, either as a specially designed single machine or as separate self-contained machine units, will be necessary. The rate of production in this class will be extremely low and great care must be taken to prevent canister damage.

6.2.1.8 Retrieval: Class D-2

The mine room can be reopened by routine means, having been protectively backfilled after emplacement; the canister, tight in the deposit hole because of engineered backfill, is unbreached but structurally weak.

Class D-2 has the same work effort requirement as Class D-1 and includes an additional time period for reopening the mine, thus making the extremely low production rate in D-1 even lower.

6.2.1.9 Retrieval: Class E-1

The mine room is open. The canister is tight in the deposit hole because of natural close-in or accidental close-in of the hole due to collapse or spalling; it is unbreached and structurally sound.

The rock or detritus (broken rock) embracing or deforming the canister is large, hard or monolithic, or a combination of these.

The situation differs drastically from Class C-1 because of the rock particle size and the chance for canister deformation. The retrieval effort for this class will need the same equipment as that required for D-1, but in addition, the machinery must be equipped with ancillary devices that can clear the rock from contact with the canister. The work effort will be extremely high and production rates extremely low.

6.2.1.10 Retrieval: Class E-2

The mine room is reopenable by routine means, having been protectively backfilled after emplacement; all other conditions are the same as for Class E-1.

The same work effort and machinery capability as outlined for Class E-1 will be needed for this class plus the mine reopening requirement.

6.2.1.11 Retrieval: Class F-1

The mine room is open. The canister is tight in the deposit hole because of natural close-in or accidental close-in from deposit hole collapse or spalling; it is unbreached but structurally weak. The rock or detritus embracing or deforming the canister is large, hard, or monolithic, or a combination of these.

Retrieval will follow the same process as Classes E-1 and E-2 with the added criteria that extreme care must be exercised to prevent any additional canister damage. Production rates will be in accordance with the condition in which the canister will be found.

6.2.1.12 Retrieval: Class F-2

The mine room can be reopened by routine means, having been protectively backfilled after emplacement; all other conditions are same as for Class F-1.

The same work effort and machinery capability as outlined for Class F-1 will be needed for this class, plus the mine reopening requirement.

6.2.2 Recovery

The execution of reliable recovery of the canisters in Classes A, B, and C will require a thorough analysis and evaluation of the prevailing storage conditions and an engineered plan for the operation. In all classes, specialized machinery, with suitable protective devices, will be needed. Trained operators, directing the machinery by remote control, may be required. The canisters may be found in a condition of change so radical as to dictate that the surrounding rock and the canister be removed from the mine and taken to the surface facility for processing. A major facility change may be necessary to accomplish this task. Canisters may be warped, bent, or sheared by rock movement, and in some cases, fuel rods may be fractured, permitting fuel pellets to invade the rock. This poses a major cleanup task and will affect facilities and facilities operation. The work effort required in any of the recovery classifications will be large and any attempt, at this time, to postulate a production rate would not be practical. The cost ratings for the "broad options" in Section 7 pertaining to recovery include engineering judgments of the work effort required.

6.2.2.1 Recovery: Class A

In this condition, the mine room will be open, packages will have failed and the deposit hole and/or the mine room will be contaminated. A Class A recovery state will generally occur later than a retrieval state.

Any packaged-waste removal from open rooms that requires, for any reason, major provisions or procedures additional to those for retrieval will also be considered a Class A Recovery. The repackaging facilities and effort required will involve large costs.

6.2.2.2 Recovery: Class B

In this condition, the mine room will have been closed by backfill or cave-in, but the access galleries and entry shafts will still be open and functional. In this class, packages will be considered suspect or failed. Provisions and systems for recovery will be comparable to those found in a Class A recovery but capacities and costs will be larger. Handling systems for mined rock must carry greater quantities, and additional shafts and galleries may be necessary.

6.2.2.3 Recovery: Class C

In this condition, the mine will have been decommissioned and all rooms, galleries, and shafts will be backfilled or otherwise closed. All packages will be suspect as failed. Provisions and systems will be comparable to those used in a Class B Recovery but augmented, if necessary, with capabilities for reopening or replacing shafts and galleries. Large volumes of contaminated media may have to be handled requiring major repackaging facilities and new repositories.

REFERENCE

1. "Special Study No. 3: Waste Retrieval from Backfilled Regions for a National Waste Terminal Storage Repository in a Bedded Salt Formation for Spent Unreprocessed Fuel," Kaiser Engineers Report No. 78-56-R, September 1978.

7.0 EVALUATION OF RETRIEVAL OPTIONS

If all of the possible permutations of the parameters listed in Section 3.1 "Guidelines and Constraints" were itemized, the list would include in excess of one million separate options. To simplify the evaluation process, the options investigated have been divided into two categories. The first category is the "base case" group which includes Retrieval Classes A-1 and A-2 retrieval for spent fuel and high level waste 5 and 25 years after emplacement. Horizontal and vertical emplacement in salt, granite, basalt, and shale are considered at various thermal loadings. The selected combinations of parameters were chosen because they result in logical repositories and because specific cost data existed for some of these "base cases." There are 81 of these base-case options as shown in Tables 7.1 and 7.2. The second category of options or "broad options" consists of 424 options.

This section (1) discusses the bases and then provides the capital and operating costs for the base-case options, (2) discusses the bases for the costs for the broad options, (3) lists the evaluation criteria and defines a rating scale for each criterion, (4) evaluates the options in matrix form, and (5) discusses the conclusions reached as a result of the evaluation.

7.1 Cost Estimates for Base-Case Options

7.1.1 Capital Costs

Type 1 capital cost estimates (see Section 3.2.5 for definition) were prepared for 61 of the 81 base cases and are shown in Tables 7.3 and 7.4. They are only those capital costs required to make retrieval possible (i.e., they are costs that are additional to the costs of developing the repository for storage). If the original facilities are sufficient to permit retrieval of the nuclear waste, no capital costs

TABLE 7.1

OPTIONS FOR CLASS A-1 RETRIEVALSpent Fuel - 5 Years Retrieval

<u>Option Number</u>	<u>Rock Type</u>	<u>Thermal Loading kW/Acre</u>	<u>Storage Mode</u>	<u>Pitch Feet</u>	<u>Number of Rooms * Retrieved Per Year</u>
1	Salt	60	Vertical	4	2.05
2	Salt	60	"	5.5	2.82
3	Granite	190	"	6	3.08
4	Basalt	190	"	6	3.08
5	Shale	100	"	4	2.05
6	Salt	30	"	8	4.10
7	Salt	30	"	11	5.64
8	Granite	95	"	12	6.16
9	Basalt	95	"	12	6.16
10	Shale	50	"	8	4.10
11	Salt	60	Horizontal	4	2.05
12	Salt	60	"	5.5	2.82
13	Granite	190	"	6	3.08
14	Basalt	190	"	6	3.08
15	Shale	100	"	4	2.05
16	Salt	30	"	8	4.10
17	Salt	30	"	11	5.64
18	Granite	95	"	12	6.16
19	Basalt	95	"	12	6.16
20	Shale	50	"	8	4.10

Spent Fuel - 25 Years Retrieval

21	Salt	60	Vertical	4	5.48
22	Salt	60	"	5.5	7.54
23	Granite	190	"	6	8.22
24	Basalt	190	"	6	8.22
25	Shale	100	"	4	5.48
26	Salt	60	Horizontal	4	5.48
27	Salt	60	"	5.5	7.54
28	Granite	190	"	6	8.22
29	Basalt	190	"	6	8.22
30	Shale	100	"	4	5.48
31	Salt	30	Vertical	11	15.06

*Established by requirement that waste is retrieved at the same rate it is emplaced.

TABLE 7.1 (Cont)

OPTIONS FOR CLASS A-1 RETRIEVAL

High-Level Waste - 25 Years Retrieval

<u>Option Number</u>	<u>Rock Type</u>	<u>Thermal Loading kW/Acre</u>	<u>Storage Mode</u>	<u>Pitch Feet</u>	<u>Number of Rooms * Retrieved Per Year</u>
32	Salt	150	Vertical	6	3.23
33	Granite	190	"	13.5	7.28
34	Basalt	190	"	13.5	7.28
35	Shale	130	"	8	4.30
36	Salt	75	"	12	6.46
37	Granite	95	"	27	14.56
38	Basalt	95	"	27	14.56
39	Shale	65	"	16	8.60
40	Salt	150	Horizontal	6	3.23
41	Granite	190	"	13.5	7.28
42	Basalt	190	"	13.5	7.28
43	Shale	130	"	8	4.30
44	Salt	75	"	12	6.46
45	Granite	95	"	27	14.56
46	Basalt	95	"	27	14.56
47	Shale	65	"	16	8.60

*Established by requirement that waste is retrieved at the same rate it is emplaced.

TABLE 7.2

OPTIONS FOR CLASS A-2 RETRIEVALSpent Fuel - 25 Years Retrieval

<u>Option Number</u>	<u>Rock Type</u>	<u>Thermal Loading kW/Acre</u>	<u>Storage Mode</u>	<u>Pitch Feet</u>	<u>Number of Rooms* Retrieved Per Year</u>
48	Salt	60	Vertical	4	5.48
49	Salt	60	"	5.5	7.54
50	Granite	190	"	6	8.22
51	Basalt	190	"	6	8.22
52	Shale	100	"	4	5.48
53	Salt	30	"	8	10.96
54	Salt	30	"	11	15.06
55	Granite	95	"	12	16.44
56	Basalt	95	"	12	16.44
57	Shale	50	"	8	10.96
58	Salt	60	Horizontal	4	5.48
59	Granite	190	"	6	8.22
60	Basalt	190	"	6	8.22
61	Shale	100	"	4	5.48
62	Salt	30	"	8	10.96
63	Granite	95	"	12	16.44
64	Basalt	95	"	12	16.44
65	Shale	50	"	8	10.96

High-Level Waste - 25 Years Retrieval

66	Salt	150	Vertical	6	3.23
67	Granite	190	"	13.5	7.28
68	Basalt	190	"	13.5	7.28
69	Shale	130	"	8	4.30
70	Salt	75	"	12	6.46
71	Granite	95	"	27	14.56
72	Basalt	95	"	27	14.56
73	Shale	65	"	16	8.60
74	Salt	150	Horizontal	6	3.23
75	Granite	190	"	13.5	7.28
76	Basalt	190	"	13.5	7.28
77	Shale	130	"	8	4.30
78	Salt	75	"	12	6.46
79	Granite	95	"	27	14.56
80	Basalt	95	"	27	14.56
81	Shale	65	"	16	8.60

*Established by requirement that waste is retrieved at the same rate it is emplaced.

TABLE 7.3

ESTIMATED TOTAL CAPITAL COSTS OF OPTIONS
FOR 25 YEAR CLASS A-1 RETRIEVAL

Costs in Thousands of Dollars

<u>Option</u>	<u>Capital Construction Cost</u>	<u>Total Capital Cost</u>	<u>Number of Canisters</u>	<u>Cost Per Canister</u>
<u>Vertical Storage of Spent Fuel</u>				
21	23,862	43,000	242,437	0.18
22	25,611	46,000	242,437	0.19
23	54,211	98,000	242,437	0.40
24	47,649	86,000	242,437	0.35
25	61,349	111,000	242,437	0.46
<u>Horizontal Storage of Spent Fuel</u>				
26	21,839	39,000	242,437	0.16
27	23,314	42,000	242,437	0.17
28	47,451	86,000	242,437	0.35
29	41,747	75,000	242,437	0.31
30	50,815	92,000	242,437	0.38
<u>Vertical Storage of Spent Fuel</u>				
31	19,926	36,000	242,437	0.15
<u>Vertical Storage of High Level Waste</u>				
32	28,429	51,000	53,472	0.95
33	43,151	78,000	53,472	1.46
34	36,122	65,000	53,472	1.22
35	38,822	70,000	53,472	1.31
36	36,816	67,000	53,472	1.25
37	66,033	119,000	53,472	2.22
38	59,646	108,000	53,472	2.02
39	43,124	78,000	53,472	1.46
<u>Horizontal Storage of High Level Waste</u>				
40	27,600	50,000	53,472	0.94
41	41,293	75,000	53,472	1.40
42	34,490	62,000	53,472	1.16
43	28,534	52,000	53,472	0.97
44	36,093	65,000	53,472	1.21
45	65,227	116,000	53,472	2.17
46	58,085	105,000	53,472	1.96
47	35,296	64,000	53,472	1.19

NOTE: Options 1-20 are not listed since 5 year retrieval requires no additional development over and above the initial development.

TABLE 7.4

ESTIMATED TOTAL CAPITAL COSTS OF OPTIONS
FOR 25 YEAR CLASS A-2 RETRIEVAL

Costs in Thousands of Dollars

<u>Option</u>	<u>Capital Construction Cost</u>	<u>Total Capital Cost</u>	<u>Number of Canisters</u>	<u>Cost Per Canister</u>
<u>Vertical Storage of Spent Fuel</u>				
48	68,921	125,000	242,437	0.52
49	80,840	146,000	242,437	0.60
50	123,286	223,000	242,437	0.92
51	92,994	168,000	242,437	0.69
52	125,217	226,000	242,437	0.93
53	96,483	174,000	242,437	0.72
54	115,727	209,000	242,437	0.86
55	164,149	297,000	242,437	1.22
56	119,528	216,000	242,437	0.89
57	154,772	280,000	242,437	1.16
<u>Horizontal Storage of Spent Fuel</u>				
58	63,580	115,000	242,437	0.47
59	110,187	199,000	242,437	0.82
60	83,652	151,000	242,437	0.62
61	106,812	193,000	242,437	0.77
62	81,281	147,000	242,437	0.61
63	147,983	267,000	242,437	1.10
64	108,693	196,000	242,437	0.81
65	133,411	241,000	242,437	0.99
<u>Vertical Storage of High Level Waste</u>				
66	57,566	104,000	53,472	1.95
67	101,972	184,000	53,472	3.45
68	75,121	136,000	53,472	2.54
69	84,626	153,000	53,472	2.86
70	68,242	123,000	53,472	2.30
71	146,619	265,000	53,472	4.96
72	105,099	190,000	53,472	3.55
73	99,386	180,000	53,472	3.56
<u>Horizontal Storage of High Level Waste</u>				
74	56,186	102,000	53,472	1.90
75	98,099	177,000	53,472	3.32
76	72,428	131,000	53,472	2.45
77	66,541	120,000	53,472	2.25
78	66,386	120,000	53,472	2.24
79	141,547	256,000	53,472	4.78
80	101,529	183,000	53,472	3.43
81	79,359	143,000	53,472	2.68

are incurred. For example, Options 1 through 20 are based on 5-year retrieval which can be accommodated by the original design of the facility; consequently, no additional capital costs are required for retrieval.

The total capital cost is obtained from the capital cost by successively applying 21% for engineering, 45% for contingency and 3% for fee.

7.1.1.1 Mine Development for Retrieval

In certain cases, enlargement of the mine entries and airways will be required to accommodate increased airflows at the same pressure drop as that for the reference design. The same lengths of openings are involved in all cases although the cross-sectional area varies with the change in air requirements. Mine development costs vary with the type of rock and the degree of air volumes; such costs are reflected in the estimate.

7.1.1.2 Shafts

Ventilation shafts were sized such that the pressure drop remained the same as that for the reference design. Shaft construction costs were estimated using information from the U.S. Department of Commerce, PB-227-348, October 1977. These estimates were compared with recent shaft estimates made by Kaiser Engineers and agreed within reasonable limits.

7.1.1.3 Shaft Stations

New shaft stations will be required to accommodate increased air flow; these are included in the capital costs. Stations will be approximately the same in all cases but the type of rock used will affect the cost of development.

7.1.1.4 Surface Structures

Increased filtering capacity for the exhaust air will require larger filters and corresponding larger surface buildings. The surface structure cost was calculated on the basis of the reference design. The cost for increased ventilation needed for cooling was calculated on an individual basis.

7.1.1.5 Mine Equipment

Mine equipment capital costs were calculated using the reference design as a basis. Any increase in the number of rooms to be serviced per year over the reference design will require a proportional increase in equipment costs. However, the same equipment costs are calculated for a lesser number of rooms than designated in the reference design.

7.1.2 Operating Costs

Operating costs, illustrated in Tables 7.5 and 7.6, are those costs required to enter the rooms, retrieve the canisters, and return the room to its original condition prior to retrieval. They include payroll burden of 38%, indirect costs at 5.4%, contingency at 45%, fee of 3%, and also material and equipment replacement costs which vary with the concept. The operating costs do not include any other surface or underground costs not directly associated with retrieval. This methodology permits these operating costs to be added to pre-existing repository operating costs which do not include retrieval. Costs were estimated for retrieval 5 years and 25 years after canister emplacement.

7.1.2.1 Mining

Ventilation flows, consistent with the criteria given in Section 3.2.2, were calculated such that rooms could be cooled down to 125°F (for retrieval) in 70 days and to 83°F (for recovery) in an additional 60 days. The number of rooms from which canisters are to be retrieved in one

TABLE 7.5

ESTIMATED ANNUAL OPERATING COSTS
CLASS A-1 RETRIEVAL

Costs in Thousands of Dollars

<u>Option</u>	<u>Man-Hours</u>	<u>Cost \$</u>	<u>Number of Canisters</u>	<u>Cost Per Canister</u>
<u>Vertical Storage of Spent Fuel - 5 Years Retrieval</u>				
1	77,400	3,200	3,945	0.81
2	79,550	3,300	3,945	0.84
3	80,100	3,300	3,945	0.84
4	80,100	3,300	3,945	0.84
5	110,400	8,800	3,945	2.23
6	90,800	3,400	3,945	0.86
7	90,900	3,400	3,945	0.86
8	92,300	3,500	3,945	0.89
9	92,300	3,500	3,945	0.89
10	156,900	14,100	3,945	3.57
<u>Horizontal Storage of Spent Fuel - 5 Years Retrieval</u>				
11	77,400	3,200	3,945	0.84
12	79,500	3,300	3,945	0.84
13	80,100	3,300	3,945	0.84
14	80,100	3,300	3,945	0.84
15	105,400	7,900	3,945	2.00
16	90,800	3,400	3,945	0.86
17	90,900	3,400	3,945	0.86
18	92,300	3,500	3,945	0.89
19	92,300	3,500	3,945	0.89
20	146,700	13,200	3,945	3.34
<u>Vertical Storage of Spent Fuel - 25 Years Retrieval</u>				
21	167,700	7,100	10,540	0.67
22	182,800	7,600	10,540	0.72
23	186,500	7,800	10,540	0.74
24	186,500	7,700	10,540	0.73
25	240,900	21,500	10,540	2.04
<u>Horizontal Storage of Spent Fuel - 25 Years Retrieval</u>				
26	167,700	6,800	10,540	0.64
27	182,800	7,500	10,540	0.71
28	186,500	7,700	10,540	0.73
29	186,500	7,700	10,540	0.73
30	227,200	19,200	10,540	1.82
<u>Vertical Storage of Spent Fuel - 25 Years Retrieval</u>				
31	169,400	8,900	10,540	0.84

TABLE 7.5 (Cont)

ESTIMATED ANNUAL OPERATING COSTS
CLASS A-1 RETRIEVAL

Costs in Thousands of Dollars

<u>Option</u>	<u>Man-Hours</u>	<u>Cost \$</u>	<u>Number of Canisters</u>	<u>Cost Per Canister</u>
<u>Vertical Storage of High Level Waste - 25 Years Retrieval</u>				
32	100,000	3,700	2,067	1.8
33	129,900	4,500	2,067	2.2
34	129,900	4,500	2,067	2.2
35	156,600	13,400	2,067	6.5
36	124,400	4,400	2,067	2.1
37	185,200	6,000	2,067	2.9
38	185,200	6,000	2,067	2.9
39	238,600	23,700	2,067	11.5
<u>Horizontal Storage of High Level Waste - 25 Years Retrieval</u>				
40	100,000	3,700	2,067	1.8
41	129,900	4,500	2,067	2.2
42	129,900	4,500	2,067	2.2
43	143,300	11,100	2,067	5.4
44	125,400	3,900	2,067	1.9
45	185,200	6,000	2,067	2.9
46	185,200	6,000	2,067	2.9
47	212,100	19,200	2,067	9.3

TABLE 7.6

ESTIMATED ANNUAL OPERATING COSTS
CLASS A-2 RETRIEVAL

Costs in Thousands of Dollars

<u>Option</u>	<u>Man-Hours</u>	<u>Cost \$</u>	<u>Number of Canisters</u>	<u>Cost Per Canister</u>
<u>Vertical Storage of Spent Fuel - 25 Years Retrieval</u>				
48	403,300	24,300	10,540	2.30
49	457,100	29,200	10,540	2.77
50	397,100	15,100	10,540	1.43
51	419,000	15,400	10,540	1.46
52	466,100	28,600	10,540	2.71
53	680,600	41,500	10,540	3.93
54	914,800	52,300	10,540	4.96
55	668,000	24,100	10,540	2.28
56	712,000	24,800	10,540	2.35
57	806,100	37,400	10,540	3.54
<u>Horizontal Storage of Spent Fuel - 25 Years Retrieval</u>				
58	352,100	21,600	10,540	2.05
59	345,500	13,200	10,540	1.25
60	359,500	13,900	10,540	1.32
61	393,800	25,100	10,540	2.38
62	578,100	36,700	10,540	3.48
63	565,000	20,400	10,540	1.93
64	593,000	20,800	10,540	1.97
65	661,600	44,200	10,540	4.19
<u>Vertical Storage of High Level Waste - 25 Years Retrieval</u>				
66	225,900	14,500	2,067	7.01
67	291,300	10,200	2,067	4.93
68	307,700	10,400	2,067	5.03
69	286,600	17,600	2,067	8.51
70	377,200	26,000	2,067	12.58
71	508,100	17,300	2,067	8.37
72	540,900	17,700	2,067	8.56
73	498,600	31,600	2,067	15.28
<u>Horizontal Storage of High Level Waste - 25 Years Retrieval</u>				
74	212,000	12,200	2,067	5.90
75	271,900	9,500	2,067	4.59
76	284,200	9,600	2,067	4.64
77	220,700	14,600	2,067	7.06
78	347,000	21,300	2,067	10.30
79	467,400	15,800	2,067	7.64
80	419,900	16,100	2,067	7.79
81	368,900	26,300	2,067	12.72

year's time was calculated from the storage hole pitch for each type of rock. The time to ventilate, cooldown, excavate backfill if necessary, install roof supports, and rebackfill if necessary, was estimated using the maximum efficiency of the particular operation with no regard for scheduling. Moreover, the estimate indicates the shortest time period permittable by conditions in a room for a complete retrieval cycle.

7.1.2.2 Canister Retrieval

Costs for retrieval were obtained from the reference design NWTSR2.

7.1.2.3 Other Costs

Costs of equipment operation, equipment replacement, canister hoisting, normal ventilation requirements, conveyor, and backfill were also taken from the reference design. Costs from these sources were applied to each type of rock on an equal basis.

7.1.2.4 Total Costs

Comparison costs for the 81 "base cases" are shown on Tables 7-7 and 7-8.

7.2 Cost of Broad Options

The capital and operating costs to incorporate and accomplish retrievability in a repository are based upon engineering judgments for the "broad options". As a result, the costs only represent gross relative rankings of the options.

7.2.1 Cost of Repository

The additional cost to accommodate retrievability for the "broad options" is compared to the cost determined in Special Study #3¹ for the NWTSR2², which is taken as the low cost base with a rating of 10. The

TABLE 7.7

COMPARISON OF COSTS FOR CLASS A-1 RETRIEVALCosts in Thousands of Dollars

<u>Option</u>	<u>Media</u>	<u>Total Capital Cost</u>	<u>Cost Per Canister</u>	<u>Operating Cost Per Year</u>	<u>Cost Per Canister</u>	<u>Total Cost Per Canister</u>
<u>Vertical Storage of Spent Fuel - 5 Years Retrieval</u>						
1	Salt			3,222	0.817	0.82
2	Salt			3,270	0.829	0.83
3	Granite			3,313	0.840	0.84
4	Basalt			3,279	0.831	0.83
5	Shale			8,842	2.241	2.24
6	Salt			3,454	0.875	0.87
7	Salt			3,404	0.863	0.86
8	Granite			3,518	0.892	0.89
9	Basalt			3,493	0.885	0.88
10	Shale			14,074	3.568	3.57
<u>Horizontal Storage of Spent Fuel - 5 Years Retrieval</u>						
11	Salt			3,214	0.815	0.81
12	Salt			3,260	0.826	0.83
13	Granite			3,300	0.836	0.84
14	Basalt			3,270	0.829	0.83
15	Shale			7,944	2.011	2.01
16	Salt			3,448	0.874	0.87
17	Salt			3,404	0.863	0.86
18	Granite			3,583	0.892	0.89
19	Basalt			3,562	0.885	0.89
20	Shale			13,210	3.348	3.35
<u>Vertical Storage of Spent Fuel - 25 Years Retrieval</u>						
21	Salt	43,000	0.18	7,115	0.675	0.85
22	Salt	46,000	0.19	7,562	0.718	0.91
23	Granite	98,000	0.40	7,763	0.736	1.14
24	Basalt	86,000	0.35	7,720	0.732	1.09
25	Shale	111,000	0.46	21,531	2.043	2.50
<u>Horizontal Storage of Spent Fuel - 25 Years Retrieval</u>						
26	Salt	39,000	0.16	6,803	0.646	0.81
27	Salt	42,000	0.17	7,530	0.715	0.89
28	Granite	86,000	0.35	7,721	0.733	1.09
29	Basalt	75,000	0.31	7,684	0.729	1.04
30	Shale	92,000	0.38	19,165	1.818	2.20

TABLE 7.7 (Cont)

COMPARISON OF COSTS FOR CLASS A-1 RETRIEVALCosts in Thousands of Dollars

<u>Option</u>	<u>Media</u>	<u>Total Capital Cost</u>	<u>Cost Per Canister</u>	<u>Operating Cost Per Year</u>	<u>Cost Per Canister</u>	<u>Total Cost Per Canister</u>
<u>Vertical Storage of Spent Fuel - 25 Years Retrieval</u>						
31	Salt	36,000	0.15	8,903	0.845	0.99
<u>Vertical Storage of High Level Waste - 25 Years Retrieval</u>						
32	Salt	51,000	0.95	3,732	1.805	2.76
33	Granite	78,000	1.46	4,539	2.196	3.65
34	Basalt	65,000	1.22	4,494	2.174	3.39
35	Shale	70,000	1.31	13,356	6.461	7.77
36	Salt	67,000	1.25	4,376	2.118	3.36
37	Granite	119,000	2.22	6,029	2.916	5.15
38	Basalt	108,000	2.02	5,998	2.902	4.92
39	Shale	78,000	1.46	23,706	11.469	12.93
<u>Horizontal Storage of High Level Waste - 25 Years Retrieval</u>						
40	Salt	50,000	0.94	3,718	1.799	2.73
41	Granite	75,000	1.40	4,527	2.190	3.59
42	Basalt	62,000	1.16	4,485	2.169	3.33
43	Shale	52,000	0.97	11,088	5.364	6.33
44	Salt	65,000	1.21	3,957	1.913	3.13
45	Granite	116,000	2.17	6,028	2.916	5.09
46	Basalt	105,000	1.96	5,990	2.897	4.86
47	Shale	64,000	1.19	19,197	9.287	10.48

TABLE 7.8

COMPARISON OF COSTS FOR CLASS A-2 RETRIEVAL

<u>Costs in Thousands of Dollars</u>						
<u>Option</u>	<u>Media</u>	<u>Total Capital Cost</u>	<u>Cost Per Canister</u>	<u>Operating Cost Per Year</u>	<u>Cost Per Canister</u>	<u>Total Cost Per Canister</u>
<u>Vertical Storage of Spent Fuel - 25 Years Retrieval</u>						
48	Salt	125,000	0.52	24,275	2.303	2.82
49	Salt	146,000	0.60	29,192	2.770	3.37
50	Granite	223,000	0.92	15,131	1.436	2.35
51	Basalt	168,000	0.69	15,439	1.465	2.16
52	Shale	226,000	0.93	28,632	2.717	3.65
53	Salt	174,000	0.72	41,503	3.938	4.66
54	Salt	209,000	0.86	52,344	4.966	5.83
55	Granite	297,000	1.22	24,147	2.291	3.51
56	Basalt	216,000	0.89	24,821	2.355	3.25
57	Shale	280,000	1.16	37,408	3.549	4.70
<u>Horizontal Storage of Spent Fuel - 25 Years Retrieval</u>						
58	Salt	115,000	0.47	21,632	2.027	2.50
59	Granite	199,000	0.82	13,181	1.251	2.07
60	Basalt	151,000	0.62	13,926	1.321	1.94
61	Shale	193,000	0.77	25,136	2.385	3.15
62	Salt	147,000	0.61	36,665	3.479	4.08
63	Granite	267,000	1.10	20,398	1.935	3.04
64	Basalt	196,000	0.81	20,784	1.972	2.78
65	Shale	241,000	0.99	44,241	4.197	5.19
<u>Vertical Storage of High Level Waste - 25 Years Retrieval</u>						
66	Salt	104,000	1.95	14,493	7.012	8.96
67	Granite	184,000	3.45	10,168	4.919	8.36
68	Basalt	136,000	2.54	10,366	5.015	7.55
69	Shale	153,000	2.86	17,642	8.535	11.39
70	Salt	123,000	2.30	25,975	12.567	14.87
71	Granite	265,000	4.96	17,284	8.362	13.32
71	Basalt	190,000	3.55	17,737	8.581	12.13
73	Shale	180,000	3.56	31,608	15.291	18.65
<u>Horizontal Storage of High Level Waste - 25 Years Retrieval</u>						
74	Salt	102,000	1.90	12,169	5.888	7.79
75	Granite	177,000	3.32	9,465	4.580	7.90
76	Basalt	131,000	2.45	9,575	4.633	7.08
77	Shale	120,000	2.25	14,618	7.072	9.32
78	Salt	120,000	2.24	21,220	10.266	12.51
79	Granite	256,000	4.78	15,844	7.655	12.44
80	Basalt	183,000	3.43	16,134	7.805	11.24
81	Shale	143,000	2.68	26,340	12.783	15.46

cost rating scale is inversely proportional to the cost. Thus, if one option costs twice as much as the NWTSR2, then it is given a cost rating of 5; if it is 10 times as expensive it is given a rating of 1.

7.2.2 Retrieval and Recovery Costs

The cost ratings for retrieval and recovery are also based upon engineering judgments and are inverted similar to the capital costs. The cost from Special Study #3 is again given a rating of 10. However, for Retrieval A through E and Recovery B, some of the options are judged to be less expensive than that determined in Special Study #3. The cost ratings for these options are thus greater than 10.

7.3 Technical Evaluation of "Base-Case" and "Broad" Options

The base-case options and the broad options are evaluated against the criteria listed below. Also shown are the rating scales used for each criteria in this study.

7.3.1 Safety

The safety criteria is a measure of the protection of the human population from radiological exposure and occupational hazards. The criteria includes potential radiological exposure to the public and to workers, as well as occupational hazards to workers. The retrieval/recovery options considered in this study will provide precautions against any abnormal occurrence. No predictable events will cause workers to be exposed beyond accepted standards.

Rating Scale

10. Very low risk levels are easily attained.

9. Low risk levels are reasonably attainable.

8. Low risk levels with some exposure are attainable.
7. Low risk levels with maximum allowable exposure are attainable.
- 6.-0. Ratings of 6 or lower are not safe enough to be considered.
Re-engineering and design would be required to upgrade the safety of the options.

7.3.2 Technical Feasibility

Technical feasibility is a measure of the ability to design, construct, and place in operation in a reasonable time frame, a system that provides predictable and reliable performance.

Rating Scale

10. Based upon well-known proven practices.
- 9.-8. Based upon some well-known proven practices.
7. Technical aspects resolved. Minor problems encountered. Problems readily solved during operation.
6. Technical aspects resolved. Major problems encountered. Problems solved through engineering.
5. Technical aspects resolved. Major problems encountered. Re-engineering and R&D necessary.
4. Successful pilot operation. Requires commercial implementation.
3. Pilot stage. Needs additional test experience and moderate development.

2. Design stage. Pilot operation and test experience required.
1. New, in conceptual stage only.
0. Theoretically infeasible.

7.3.3 Ease of Retrieval

Ease of retrieval, is a relative measure of the work effort and equipment required to accomplish retrieval of canisters. This concerns only the task of attaining access to the canister package (i.e., excavating burial rock where applicable, and trepanning of tight holes where needed, etc.) and the removal and placement of the package into transport equipment in the repository room. This category excludes all removal of backfill from rooms where applicable, and ventilation, and any other activities necessary for attaining access to the site in the storage room.

The rating scale is essentially the relative cost, not necessarily linear, where 10 is the least costly, and 1 is the most costly.

Rating Scale

10. Applies to some vault schemes, where canisters lie un-embedded, so that retrieval requires only pick-up of canisters by shielded transporter system.
- 9.-6. Applies to burial systems where excavating the local burial rock is relatively easy and assured, and to vault systems where covers must be removed or very special vault-travelers are needed. The base-case options for salt media, where canisters are buried vertically beneath room floor, are rated as 7.

5.-2. Applies to moderately difficult and difficult retrieval classes with tight burial holes, and to some postulated schemes with multiple canisters buried end-to-end in deep holes.

1. Applies to very difficult retrieval situations, such as tight holes in hard rock embracing long strings of canisters in long holes. If retrieval were possible, it would require much work effort and highly complex equipment.

0. Would indicate situations where retrieval is not possible.

7.3.4 Probable Intact Retrieval Time

The probability of intact retrieval is expressed in terms of the probable relative elapsed time after emplacement when a significant portion of the canisters become breached. The reasoning is that all retrieval systems which are feasible will be designed to ensure a very high probability approximating 0.999 to 1.0, of intact retrieval of canister packages, for the design retrievability time since retrieval systems could not cope with more than a few breached canisters per year.

The passage of time advances the two primary canister-degradation processes: corrosion, and closing-in of the emplacement rock. Thus, at some point in time, the probability of intact retrieval becomes significantly less than 1.0.

The rating scale is linear with time, with larger numerical values indicating longer time spans. For the salt media, rating values up to about 2.5 (25 years retrieval) are adapted from data contained in the NWTSR2 studies; all other rating values are judgemental only.

Rating Scale - Retrieval Only:

- 10. Represents a time period on the order of 100 years.
- 5. Represents a time period on the order of 50 years. All of the 5 ratings assume the rock formations to be tectonically quite stable.
- 0.5 Represents a time period on the order of five years.

Intermediate rating values are in linear proportion.

Rating Scale - Recovery Only

The Analysis Matrix Sheets also show rating values under the heading "Rec. Time Span", meaning Recovery Time Span for Recovery A, B and C. These are on the same scale of years as used for retrieval, above, with a maximum of 10 rating value, except that the maximum-rated options obviously are possible well beyond a century but of course at high costs. Recovery C, is essentially a new mining program designed to handle highly radioactive debris and rock; it receives a rating of 10 as it is also possible for a long time, but at very great costs, and with costs escalating further for formations which have moved significantly.

7.3.5 Safeguards

Safeguards refer to the protection of nuclear materials from sabotage and theft. Sabotage is defined as the dispersion of radioactivity into the environment, while theft involves the unauthorized removal of material for illicit purposes. In retrieval operations, theft is of less concern than sabotage because the nuclear material is in a form that cannot be easily handled.

Rating Scale

10. System is so foolproof that it doesn't require any guards or personnel.
9. Requires few people for a short period of time.
8. Requires guards and automatic protection systems comparable to a nuclear power plant.
7. Requires many people for a moderate period of time.
6. Requires many people for a long period of time.
- 5.-3. Involves surface equipment and a large number of people on the payroll for a long period of time.
- 2.-0. Requires very large numbers of people for a substantial length of time.

7.3.6 Monitoring

Monitoring refers to the ability to determine the status of radioactivity confinement and instabilities, and displacement and temperatures in the geologic media.

Rating Scale

10. Repository is easily accessible. Individual canisters can be monitored.
- 9.-7. Repository is cool and accessible. Overpacks, each with several canisters, can be monitored.
- 6.-5. Repository is cool. Monitors can be maintained for a long period of time.

4.-3. Repository is accessible for 25 years with special cooling.

2.-0. Repository is inaccessible for monitoring; i.e., rooms are back-filled, monitors are buried.

7.3.7 Criticality

The criticality criteria is a measure of the ability to protect the public from radiological exposure due to critical events in the repository.

Rating Scale

- 10. No foreseeable scenario for criticality. Not credible.
- 9.-7. Elementary provisions required to preclude criticality.
- 6.-5. Moderate provisions required to preclude criticality.
- 4.-3. Major provisions required to preclude criticality.
- 2.-1. Extraordinary precautions required to preclude criticality.
- 0. System is predictably critical.

7.3.8 Licensability

Licensability denotes the capability of a nuclear facility design and operation to meet federal, state, and local requirements with respect to: (a) nuclear safety requirements, (b) quality requirements, (c) siting requirements, and (d) environmental concerns. The licensability of a facility is related to the technical feasibility. Thus, licensability is not rated independently, but considered a part of technical feasibility.

7.4 Analysis Matrix

Two sets of analysis matrices have been developed for the study. Supplementing one matrix set is a set of drawings numbered M-1, Sheets 1 through 7, titled, "Listing of Broad Options for Spent Fuel". Drawings numbered M-2, Sheets 1 and 2, are titled "Analysis Matrix for Base Case Options"; these cover the 81 "base cases." Drawings numbered M-3, Sheets 1 through 9, and titled "Analysis Matrix for Broad Options Listing - Spent Fuel" cover options numbered 82 through 505. The last set is used with the set "Listing of Broad Options for Spent Fuel". An option number selected from the listing will establish a scenario that, when correlated with the same number on "Analysis Matrix for Broad Options Listing - Spent Fuel", will provide a value rating for the selected condition.

The primary variables are: repository emplacement configuration, rock type, canister protection, cooling scheme, backfill timing, or omission of backfill. Other isolated detail variables are also discussed. The repository is assumed to be similar to the NWTSR2 conceptual design with horizontal passages and rooms at depth of 2,000 feet below the earth's surface.

Two major subject items that are not in the tabulated matrices for the "broad options" are high-level waste in canisters and alternative heat-loading densities. However, pertinent factors for high-level waste in canisters that differ from those for spent fuel are demonstrated in the "base case" options. Likewise, the alternative heat-loading densities are in the "base case" options.

The repository emplacement configurations for the "broad options" are in two categories, referred to as rooms and vaults. Rooms are comparable

to those in the NWTSR2 conceptual design with the canisters stored in holes that extend axially from the room. The matrices identify and analyze five schemes that include holes down, holes horizontal, holes upward, long holes horizontal, and long holes down. Vaults are arrangements other than rooms and include schemes where (1) the canisters are laid directly in an open drift or are covered with backfill (behind a movable shield), (2) the canisters are laid beneath a shielding floor partition, and (3) the canisters lie in a sleeve rack that fills a small drift hole. Many other emplacement configurations are possible including a repository consisting of only vertical shafts with storage holes located radially in the shaft wall. Some of these alternative emplacement/retrieval/recovery options will be discussed later. Drawing M-4, titled "Listing of Broad Options for Spent Fuel - Sketches of Schemes," shows various repository emplacement concepts considered in this study.

Methods of providing canister protection in the "broad options" include combinations of large storage holes, storage holes backfilled with protective sand or clay, canisters constructed of corrosion-resistant materials, heavy sleeves, and canisters with light or heavy steel overpacks.

Cooling schemes in the "broad options" include rock heat-sink, as in the repository conceptual design; an air-cooled repository with the same design as a rock heat-sink system but cooled for an extended time period by forced ambient air; and a repository with the same design as a rock heat-sink but force-cooled by refrigerated air, isolated from the environment, and circulating within the repository. Both of the air-cooled types would ultimately have the cooling system closed down and from then on, would be the rock heat-sink type. The air-cooled types are called "convertible" because cooling can be suspended or terminated at any time without exceeding rock-heat-sink conditions.

Backfilling timing ranges from backfilling rooms or vaults immediately following emplacement to never backfilling.

7.5 Evaluation of Options

A review of the analysis matrix contained in Drawing M-2, Sheets 1 and 2, and Drawing M-3, Sheets 1 through 9, allows the following conclusions to be made.

7.5.1 "Base Case" Technical Criteria Evaluation

7.5.1.1 Safety

- o Shale repositories, and retrieval therein, are judged to involve distinctly greater mining hazards than the other rock types. Mining experience shows that shale tends to be relatively unpredictable and subject to roof falls and caving.
- o Recovery is considered to be significantly more hazardous than retrieval, due to the presence of radioactive materials that have leaked from the canisters.

7.5.1.2 Technical Feasibility

- o The highest ratings are reserved for some of the vault and cooled types per Options 82-505, because these types may minimize some of the uncertainties as to rock behavior under extended heating.
- o Shale repositories are rated less feasible because of the relatively greater uncertainties as to rock behavior.
- o Recovery is less feasible because of the greater number of systems and techniques which have not been demonstrated.

7.5.1.3 Ease of Retrieval

- o The granite and basalt rock repositories rate high because of the general stability of these formations.

- o For salt and shale, early backfill of the rooms is credited with improving ease of retrieval. Backfill will support the room roof (after some caving-in) and may actually lessen the amount of material to be removed during retrieval.

7.5.1.4 Probable Intact Retrieval Time

- o For Retrieval A, Options 1-20 are designed for 5-year retrieval, and Options 21-82 are designed for 25-year retrieval; hence, the ratings of 0.5 and 2.5, respectively, are automatic.
- o Retrieval C, D, E, and F are rated as retrievable for longer time spans, with the longest times assigned to the more stable rock types.
- o Recovery B and C are inherently attainable for a long time after emplacement - with high effort and cost.

7.5.1.5 Safeguards

- o Salt, granite and basalt repositories are all rated as high in this category.
- o The shale repository is rated low, because it is envisioned that distinctly more people and more extensive activity will be required to successfully open and maintain a shale repository.

7.5.1.6 Monitoring

- o Monitoring is a repository characteristic, not directly a part of retrieval or recovery.
- o The time of backfilling of the rooms is the primary variable affecting the ability to monitor a repository. For a back-filled room, any individual canister or other localized

monitors must have the information wired or otherwise conducted to accessible spaces, degrading reliability. Thus, the longer the room remains open the higher the rating.

7.5.1.7 Criticality

- o Retrieval and Recovery A are rated 10, being designed to avoid any credible criticality situation.
- o For Recovery B and Recovery C, HLW is rated 10 as being essentially free of criticality possibilities, while spent fuel is rated 6 and 5 because of the possibility of "clumping" fuel during recovery.

7.5.2 "Broad Options" Technical Evaluations

For the "broad options," the complexity of the matrix information precludes simple summary-table presentations. The tabulation below provides supplementary and explanatory information for major rating points and indicates some patterns and trends for these options.

7.5.2.1 Safety

- o All rock-heat-sink and isolated-cooled repositories, and retrieval therein, are rated 10.
- o Repositories and retrieval in shale are rated one point less safe, for the reasons cited for the "base case" options.
- o Air-cooled systems are rated one point less safe because of the (small) potential for releasing radioactive materials into the environment via the ventilating air stream.
- o All recovery classes are rated one point less safe than the corresponding repository and retrieval systems, because of the necessity for handling radioactive materials released by canister leakage or breakage.

7.5.2.2 Technical Feasibility

- o For the repository, and in general for Retrieval A, the following factors in combination contribute to high ratings:
 - Cooling, which by significantly reducing rock temperatures enhances the applicability of state-of-the-art mining and tunneling experience; also, for salt this lessens plastic flow;
 - Stable rock formation, especially granite and basalt;
 - Heavy sleeves, or structurally strong vaults. This is especially applicable to salt.

- o Options rated 9 or 10 include:

Repository - Axial down and horizontal, single depth, cooled, in granite and basalt; and simple vault, cooled, in salt, granite, basalt and shale.

Retrieval - Axial down and horizontal, single depth, in granite and basalt; and axial down and horizontal, single depth, with heavy sleeves, in salt and shale.

- o For Repository and Retrieval A, intermediate ratings of approximately 6 through 8 apply to options which have fewer of the high-rating attributes listed above, and for which other factors are judged to require substantial, but not overwhelming, investigation and developmental efforts.
- o For Repository and Retrieval A, ratings of 5 and below apply, for example, to multiple length vertical rock-heat-sink repositories in granite and basalt. For this type of repository, the equipment systems required to emplace several canisters in a deep hole, and the drilling and equipment to prepare the

hole, all to operate within the confines of a reasonable-height room, is envisioned as being seriously complex.

- o For Repository and Retrieval A, repositories in shale are down-rated an average of one point, for the reasons cited for the "base cases".
- o For retrieval, some of the vault systems are rated relatively high, because (1) there is no excavation required for freeing the canisters, or, (2) such excavation is quite predictable and amenable to assured design of equipment systems.
- o For Recovery A, the ratings tend to follow the ratings for the more difficult retrieval types, but in a number of cases Recovery A is rated higher than retrieval. This occurs because retrieval is charged with retrieving the canisters intact if at all possible, and for Retrieval A a brisk rate is required. Recovery A presupposes failed canisters and hence, can be designed to be a more straightforward excavation operation with much slower rate requirements. Recovery A also includes a repackaging facility which, while complex and costly, is considered to be within state-of-the-art knowledge.
- o For Recovery B and Recovery C, the technical feasibility ratings are generally independent of the other ratings in this category. Recovery B and C will, in general, be tasks of mining radioactive rock and debris, and of segregating and packaging the waste. Design of the packaging facility is considered to be within the state-of-the-art and thus, ratings are moderate to intermediate for a number of the options. All feasible Recovery B and C systems and operations will be very costly.

7.5.2.3 Ease of Retrieval

- o Vault systems receive the highest ratings, because there is (1) no excavation required for freeing the canisters, or (2) such excavation is predictable and relatively easy.
- o For Retrieval A, storage in salt and shale, with heavy sleeves, enhance ease of retrieval; typical ratings are 8. Comparable emplacement in granite and basalt is typically rated 8 without need for sleeves.
- o Retrieval A for horizontal emplacement of multiple canisters is considered relatively easy with typical rating 8, based on the concept that the holes will be open at both ends to permit easy access.
- o Retrieval Classes C through F are generally rated as more difficult than Retrieval A. For the long multiple-canister holes, tight holes may create difficulty; examples are Options 119-125 (vertical, salt) which are rated 1, and Options 140-146 (horizontal, salt) which are rated 2.

7.5.2.4 Probable Intact Retrieval Time

- o The term "intact retrieval" applies strictly only to retrieval. However, the matrix tabulations also show, under the heading "Recovery Time Span," ratings on a comparable scale for recovery, where the meaning is the time span during which recovery can clean out essentially all of the radioactive material from the rock. Recovery B and C are both rated at 10; the actual time will be very long, and costs will be very high.
- o For Retrieval, and generally for Recovery A, the following factors in combination contribute to high ratings:

- Cooling, which by significantly reducing rock temperatures, lessens or minimizes rock plastic flow and/or spalling, cracking, or other degradation;
 - Stable rock formation, especially granite and basalt;
 - Heavy sleeves, or structurally strong vaults, are especially applicable to salt;
 - Corrosion-resistant or overpacked canisters, where overpacking means planned overpacking of all packages to provide an additional barrier. Also, special bedding of canisters in inert material, such as sand or clay, as a protection against corrosion;
 - Backfilling of rooms, especially for salt and shale, to prevent major distortion of the formations due to plastic flow.
- o For Retrieval A in salt, low ratings are shown for options which rely only on large burial holes to prevent close-in damage to canisters, or which leave rooms open and un-cooled and subject to early roof collapse.
 - o For Retrieval A in shale, comparable repository types are generally rated higher than for salt, with cooling given credit for extending time spans where applicable.
 - o For Retrieval A, in granite and basalt, comparable repository types are generally rated higher than for either salt or shale. For these rock types, close-in is considered to be non-existent, and basic stability of holes, rooms and vaults is assumed to be high.

- o Recovery A is often rated higher than the comparable retrieval situations. This recovery class is not charged with preserving canister integrity, but rather must be extensively equipped so as to deal with leaking canisters including stuck packages. These systems will thus be able to perform for longer times than the retrieval systems.

7.5.2.5 Safeguards

- o The ratings are essentially the same as described for Options 1-81 above, except that options utilizing cooling systems are downrated.

The Convertible Air-Cooled (once-through) Repository systems will require substantial equipment installation and personnel above-ground over a long time; these will require significant safeguards. The Convertible Isolated-Cooled (i.e., refrigerated) Repository systems will require less, but significant, equipment and personnel above-ground, and are thus given intermediate ratings.

7.5.2.6 Monitoring

- o This category is a repository characteristic only. The highest rating of 9 is shown for cooled horizontal long holes, with multiple canisters, with the holes lined and sealed to form a tight overpack. This combination can be monitored as a unit, and the rooms are cool and accessible for servicing of the monitoring sensors and signal systems.
- o Other options are rated lower, depending on general practicality, and ease of access to the monitoring equipment. At the low end of the range, rated 2, are options where rooms are backfilled early, such as to preclude useful access to much of the necessary equipment.

7.5.2.7 Criticality

- o The ratings are essentially as described above for Options 1-81. Recovery, especially Recovery C, has ratings as low as 3. The low ratings reflect situations where complete mining of rock mixed with radioactive materials may be required, and where great care would have to be taken to avoid "clumping" of the fissionable material into critical masses.

7.5.3 General Trends and Conclusions

7.5.3.1 Extended Retrieval Time

The time span over which canisters can, with reasonable assurance, be retrieved intact is extended when: (1) the repository is in a more stable rock type; (2) active cooling is provided for the rooms or vaults; (3) mechanical protection (i.e., heavy sleeves or the equivalent) is provided for the canisters; (4) corrosion protection is provided for the canisters; and, (5) the heat-loading density is reduced.

The storage timespan might well be extendible to 50-100 years by using one or more of the above concepts.

For basalt, granite, and shale, some extra investment in original room or vault construction, such as roof supports or lowered heat-loading density, may permit the attainment of long-term retrievability. However, since neither mining nor tunneling experience includes circumstances where rock is heated significantly after a bore/room is open, the effects of heat on these rock types are not well enough known at this time for assured predictability.

7.5.3.2 Recovery

Recovery after canister failure, that is Recovery A, Recovery B, and Recovery C, appear to be very costly undertakings, particularly, Recovery

B and C for salt. Recovery must include the capability of recovering breached canisters, together with contaminated rock and fill from the emplacement site, and handling and repackaging these in a suitable way for re-emplacment in another repository or for transport to other reprocessing facilities.

In salt storage, plasticity of the rock may ultimately lead to gross crushing of the canisters and subsequent spreading of the remains into the rock. Both Recovery B and Recovery C would involve very difficult excavation (considering the high radioactivity levels encountered) and the potential requirement to handle large quantities of contaminated bulk material. With the volumes expanded by the large amounts of contaminated rock and fill material, the recovery exercise would be a very large undertaking. For some emplacement configurations, especially the room-to-room, long horizontal holes, Recovery B and C may not be at all technically feasible because of the excessively large extraction ratios that will be encountered during recovery. Some type of long-wall mining would be needed, which may not be feasible for the highly radioactive material.

In salt storage, backfilling the rooms before excessive movement of the formation has occurred may defer the onset of gross canister crushing or, at least, defer a major release of radioactive material. Accurate time predictions would be needed for establishing the condition in which a mine could be expected to be found after a selected period of time. Recovery B and Recovery C, after significant salt formation movement, would likely be large and costly undertakings.

All Recovery B and Recovery C operations must be designed to avoid any criticality accident. It appears at this time that remains of canisters and broken-up fuel assemblies may require piecemeal handling to prevent the remains from forming a critical mass.

7.5.3.3 Retrieval versus Recovery

Some of the canister protection provisions, as identified, have characteristics that enhance retrievability while aggravating Recovery B and Recovery C tasks. The heavy sleeves and overpacks and the sleeve-racks for the emplacement sites can deteriorate and their remains may make it extremely difficult to recover broken canisters. Heavy steel sleeves, for example, can be very difficult to cut out, even though corroded and deformed, and can be very difficult to reduce to repackable sizes in the remotely operated repacking hot-cells.

7.5.3.4 Backfilling of Rooms and Vaults

In the NWTSR2 Special Study No. 3¹ early backfilling of the rooms was a strategy to limit the distortion of the salt formation caused by plastic flow, to insure a 25-year recovery of intact canisters, and to economize on the handling of excavated rock. This was retrieval, following remining of the rooms. For this study, this is classed as Retrieval Type 2, (i.e., A-2, B-2, C-2 etc.).

In general, for the plastic rock (salt) and probably for the less stable of the other rock types (i.e., shale), backfilling of the rooms prior to gross distortion of the formation caused by close-in should ease the task of remining drifts or opening new drifts for the purpose of recovery. However, as discussed in Section 7.5.3.2, Recovery B or C for these rock types, after a lengthy storage period, is likely to be such a large undertaking that the backfilling factor may be negligible.

For the "simple vault" scheme, shallow backfilling over the canisters could provide protection against falling roof rock. It could also reduce risk of criticality in the distant future by filling the void between canisters and reducing the probability of them being squeezed together.

Backfilling of rooms and vaults also provides economy in materials handling during repository excavation by reducing the amount of excavated rock that must be hoisted to the surface. Further, disposing of excavated material, especially salt, on the earth's surface is environmentally undesirable. These are significant but not large factors. Roughly estimated, the energy required to hoist all the excavated material to the surface (2,000 ft) is a few MW-years. Based on general mining experience, hoisting energy at worst will be only a small portion of total mine energy consumption.

The importation of "foreign" material, such as sand or clay, for room backfill may permit easier remining of the rooms or vaults because of their characteristics, including softness. However, this would force surface disposal of all excavation and make necessary rather large and costly supply and transportation tasks. For applicable vault schemes in some rock types, especially salt, the use of clay or sand for canister bedding and cover may well be worthwhile as a corrosion-protection measure and to ensure practical backfill removal for retrieval/recovery. Otherwise, the use of large amounts of "foreign" backfill appears to be uneconomical.

7.5.3.5 Corrosion Life of Canister

It appears that canister corrosion life in excess of 50 years² can be attained with low-cost, carbon-steel-type canister material augmented for some rock types (especially salt) by backfilling canister emplacement holes or sites with inert clay, sand, or buffer materials.

It also appears that in salt storage if each canister is surrounded with several inches of sand, clay or buffer material, a small island of dry, noncorrosive protection may be created for each canister. An accelerated simulated condition test program would quickly provide useful empirical data.

Pinholing corrosion of spent fuel canisters is unlikely to release anything except gases. Fuel assemblies contain hazardous amounts of radioactive noble gases for more than 100 years, so that ruptured cladding, plus canister pinholing, could release radioactive gases. However, it may well be that the storage hole cover or enclosure, plus the incremental nature of corrosion, will meter such gas release to provide a useful tell-tale rather than a serious safety hazard. In the case of vitrified high-level waste, pinholing will release extremely low levels of radioactivity.

If canisters are all overpacked as a corrosion resistance measure, this will significantly increase the canister life. The canister will be protected until the overpack experiences a substantial failure.

If such packages were emplaced where accessible, it is conceivable that the interspaces could be pressurized and periodically sampled for pressure loss to detect overpack failure; such monitoring would obviously be a large task.

7.5.3.6 Criticality Considerations

A preliminary analysis^{3,4} indicates that as long as the emplacement sites are free of liquid water and the canisters are reasonably intact, spent fuel canister arrays will not become critical.

Chlorine in salt acts as a natural absorber (poison) for neutrons. Thus, even if water is present in a salt repository, in the form of brine, spent fuel canisters will not become critical.^{5,6}

A single spent PWR fuel assembly, if mangled and mashed into a compact mass, may present some risk of becoming critical depending upon the leaching that has taken place, the composition of the mass and surrounding materials. The presence of water will make criticality more likely. Thus, Recovery B and Recovery C operations must include design, operational, and monitoring steps to preclude clumping of the fuel rods.

If several fuel assemblies are laid side to side and mashed into a compact mass of the original canister length, there can be some risk of their becoming critical if a mine is flooded during the retrieval period. This seems to indicate that spent fuel canisters, if laid side by side in a vault arrangement, could become critical at some future date if a geological movement caused the original vault space to become closed tight with its canisters mashed and water intrusion postulated. The heat release from such criticality could be intense but is of a brief, self-limiting duration.⁵ To prevent such occurrences, spent fuel canisters will require some separation by a rock or backfill to preclude such distant-future criticality. High-level waste canisters will not become critical because there is not enough fissile materials remaining in the waste.⁶

7.5.3.7 Canister Physical Protection - Engineered Barriers

When stored in salt, canisters must either avoid or be protected from the close-in effects of the salt plastic flow, which is magnified as temperatures increase. Large-hole schemes for room emplacement and simple and compound vault schemes are all designed to provide clearance space to permit the salt to close in for a period of time before the canisters are pinched. The large-hole schemes predict up to 25 years of freedom, and because vault schemes have considerably more clearance space, they can provide more freedom time before close-in occurs.

Resistance to salt close-in will require heavy sleeves (possibly 2 inch wall steel) and the compound vault and "catacombs" vault arrangement protected by heavy concrete may also have the capability to resist plastic flow close-in. However, barriers such as heavy sleeves are very costly, and due to uncertainties as to actual salt pressures and especially localized shearing forces, it may not be possible to assuredly predict avoidance of crushing of sleeves or barriers. The criteria adopted for the NWTSR2 studies assumed such barriers could not guarantee prevention of package crushing.

Plastic flow is not considered a characteristic of basalt or granite. However, the rock may shatter and fracture locally because of thermal expansion. Storage hole sleeves or vault concrete may prevent spalled-off rock from damaging or causing a pinching of canisters. Shale should generally behave similarly to basalt or granite except that dehydration may cause some localized crumbling that can be controlled by the same methods employed for salt.

A concern related to all rock types is that local slip plane movements tend to introduce immense forces into the rock which in turn can crush or shear virtually any material that attempts to resist the movement. The vault concept permits a substantially greater formation displacement before canisters are affected. An even greater tolerance to movement is provided by the compound vault concept with its heavy engineered barrier that surrounds loosely-fitted canisters. Slip plane movements that can occur at any time may be prematurely introduced because of stresses caused by thermal expansion effects.

7.5.3.8 Shielded Canisters

If canisters were individually shielded, they could be individually handled and emplaced by means of conventional equipment. This is, at first glance, a costly concept.

7.5.3.9 Filled Canisters

In the case of spent fuel storage, filling of canisters with sand or other inert rock types will reduce canister internal temperatures and provide some protection to the fuel assemblies against vibration damage during transport. This practice could defer canister crushing somewhat because of resistance to close in and might prevent some canister damage caused by falling or fallen rock in the storage hole or vault arrangements.

Sand fill was planned for the NWTSR2 repository conceptual design.³ It appears not to be vital to heat transfer, so the presence or absence of sand fill is of negligible importance to this study.

7.5.3.10 Locally Overheated Repository Schemes

Some repository schemes may be within acceptable far-field thermal effects, but excessive local rock temperatures may induce early excessive plastic flow (as for salt), or rock dehydration (as for shale), or other adverse behavior of the local rock. If recoverability time span, or recoverability, were judged unimportant, such schemes may have a practical use.

The merit of such schemes is not considered in any matrix analyses in this study, but further investigation may be warranted.

7.5.3.11 Horizontal Storage of Multiple Canisters per Hole in Salt

As stated in Section 4.7, the storage of multiple canisters of both HLW and spent-fuel assemblies in long, horizontal holes in salt was found to require less mining and result in lower storage room temperatures than the storage of single canisters.

For a salt repository, the amount of mined room salt is on the order of 50% and 30% of that of single canisters for HLW and spent fuel, respectively. The room temperatures are 100°F and 35°F lower for HLW and spent fuel, respectively. Thus, the cost of mining and ventilation equipment is significantly less for a repository containing multiple horizontal storage holes as compared to a repository containing single horizontal or vertical storage holes.

REPOSITORY MEDIUM - SALT BEDDED AND DOME, UNLESS NOTED
MAX SALT TEMP-482 °F

GENERAL NOTE:
FOR SALT AT ELEVATED
TEMPERATURES, ROOF SETS
ARE CONSIDERED INEFFECTIVE
FOR LONG-TERM SERVICE.

* 5 YR	60 KW/ACRE	10 YR	SF
25 YR	36 KW/ACRE	10 YR	SF

ROOM COOLING MAY BE OF LIMITED EFFECTIVENESS.

* IIB IS PROBABLY OF LITTLE
VALUE. IIC WILL BE OMITTED.

NOTE RE. 4:
AXIAL DIPSLOPE WITH 2-LEVEL
MINE WOULD BE SIMILAR -
PROBABLY FOR SOME SALT ONLY

REMARKS

- NON-VIABLE CONCEPT FOR SALT - APPEARS TO REQUIRE IMPRACTICAL ROOM CONFIGURATIONS AND EMPLACEMENT AND RETENTION OF CANISTERS AND BACKFILL WOULD REQUIRE

WOULD REQUIRE

* SLEEVE EXTENSION
TO FLOOR COULD
HAVE SIDE SLOT
FOR LOADING

FIG. R3

SEALED AT BOTH ROOM ENDS)

B. CONVERTIBLE AC REPOSITORY

D. NO BACKTILL

- NOTE
INTERMEDIATE BACKFILL
TIME (B) IS NOT
SIGNIFICANT HERE
(TYP.)

* SLEEVE EXTENSION TO FLOOR
COULD HAVE SIDE SLOT FOR
LOADING

REPOSITORY MEDIUM - GRANITE, BASALT ESSENTIALLY THE SAME EXCEPT AS NOTED (CONT.)
MAX ROCK TEMP 392°F

REPOSITORY MEDIUM - SHALE
MAX ROCK TEMP 212°F

(SEE NOTES SH. 7)

REPOSITORY MEDIUM - SHALE (CONT.)
MAX ROCK TEMP 212°F

STORAGE SCHEME SUB ALT. I CANISTER PROTECTION SUB ALT. II COOLING SCHEME SUB ALT. III STORAGE AREA BACKFILL REMARKS

1.2 AXIAL DOWN
IN TRENCHES

PROBABLY NON-VIABLE CONCEPT - TRENCH CAVING IS PROBABLY EXCESSIVE
AND UNMANAGEABLE - PRACTICAL TRENCH BACKFILL PROBABLY REQUIRES
SECTIONALIZING BULKHEADS & HOLES

1.3 AXIAL DOWN
MULTIPLE DEPTH

65 KW/ACRE FOR 10
YR OLD SPENT FUEL
(65 KW/ACRE HLW)

CANISTERS 6 DEEP
(100) ON 16.5' @S

ROOMS 24' @ 96' @S
1396 CANISTERS/4000'
160 CANISTERS/LOCAL
ACRE

NEEDS SUBSTANTIAL
ROOF SETS AND LAGGING

FIG. R2B

1.4 AXIAL HORIZONTAL
VERY LONG HOLES

65 KW/ACRE FOR 11
YR OLD SPENT FUEL
(65 KW/ACRE HLW)

ROOMS 24' @ 200' @S
10 CANISTERS/HOLE
HOLE 13.33' @ (13'-4")
160 CANISTERS/LOCAL
ACRE

NEEDS SUBSTANTIAL
ROOF SETS AND LAGGING

FIG. R3B

1.5 AXIAL HORIZONTAL
SINGLE DEPTH

65 KW/ACRE FOR 10
YR OLD SPENT FUEL
(65 KW/ACRE HLW)

ROOMS 24' @ 96' @S
CANISTERS HIGH-LOW
AT 5.5' PITCH
ONE ROW IN EACH SIDEWALL
1396 CANISTERS/4000'
160 CANISTERS/LOCAL
ACRE

NEEDS SUBSTANTIAL
ROOF SETS AND LAGGING

FIG. R4B

1.6 AXIAL UP
SINGLE DEPTH
VERTICAL OR
STEEP SLOPE

65 KW/ACRE 10 YR
SPENT FUEL
(65 KW/ACRE HLW)

ROOMS 24' @ 48' @S
CANISTERS TWO ROWS
WITH PITCH 5.5'
1396 CANISTERS/4000'
160 CANISTERS/LOCAL
ACRE

UP-HOLES WEAKEN ROOF,
BUT HEAVY SETS AND
LAGGING REQUIRED ANY-
WAY SO MAY NOT BE
MAJOR FACTOR

FIG. R5B

1.7 AXIAL UP
MULTIPLE DEPTH VERTICAL
OR STEEP SLOPE

65 KW/ACRE 10 YR
SPENT FUEL
(65 KW/ACRE HLW)

ROOMS 24' @ 48' @S
CANISTERS TWO ROWS
WITH PITCH 5.5'
1396 CANISTERS/4000'
160 CANISTERS/LOCAL
ACRE

UP-HOLES WEAKEN ROOF,
BUT HEAVY SETS AND
LAGGING REQUIRED ANY-
WAY SO MAY NOT BE
MAJOR FACTOR

FIG. R5B

1.8 HORIZONTAL BURIAL
BELOW FLOOR

65 KW/ACRE 10 YR
SPENT FUEL
(65 KW/ACRE HLW)

ROOMS 24' @ 48' @S
CANISTERS TWO ROWS
WITH PITCH 5.5'
1396 CANISTERS/4000'
160 CANISTERS/LOCAL
ACRE

UP-HOLES WEAKEN ROOF,
BUT HEAVY SETS AND
LAGGING REQUIRED ANY-
WAY SO MAY NOT BE
MAJOR FACTOR

FIG. R5B

1.9 HORIZONTAL OR
VERTICAL BURIAL
IN WALL ALCOVES

65 KW/ACRE 10 YR
SPENT FUEL
(65 KW/ACRE HLW)

ROOMS 24' @ 48' @S
CANISTERS TWO ROWS
WITH PITCH 5.5'
1396 CANISTERS/4000'
160 CANISTERS/LOCAL
ACRE

UP-HOLES WEAKEN ROOF,
BUT HEAVY SETS AND
LAGGING REQUIRED ANY-
WAY SO MAY NOT BE
MAJOR FACTOR

FIG. R5B

NON-VIABLE CONCEPT - UPWARD EMPLACEMENT OF MULTIPLE DEPTH CANISTERS
APPEARS TO REQUIRE IMPRACTICAL EQUIPMENT AND SYSTEMS

ESSENTIALLY SAME AS VAULT 2.2 OR 2.3

MARGINAL CONCEPT, PROBABLY NOT PRACTICAL OR USEFUL - REQUIRES EITHER
VERY WIDE ROOM EXCAVATION TO PROVIDE CONTINUOUS ALCOVES OR ROOM
AISLE NARROW AFTER BACKFILL - AND RETENTION OF CANISTERS AND
BACKFILL WOULD REQUIRE SYSTEMS NOT PLAUSIBLY ENVISIONED.

* NOTE:
ROOM COOLING MAY
BE INEFFECTIVE
FOR ROCK COOLING -
IIC IS OMITTED
HERE.

* SLEEVE EXTENSION TO
FLOOR COULD INCORPORATE
SIDE SLOT FOR LOADING

KAISER
ENGINEERS

BATTELLE/ONMI

RETRIEVAL OPTIONS STUDY
LISTING OF BROAD OPTIONS
FOR SPENT FUEL

JOB No. 79033

DWG. No. M-1 SH-6

R.

REPOSITORY MEDIUM - SHALE (CONT.)
MAX ROCK TEMP 212°F

SUB ALT I
STORAGE SCHEME
CANISTER PROTECTION

SUB ALT II
COOLING SCHEME

SUB ALT II
STORAGE AREA BACKFILL

REMARKS

2. VAULT SCHEMES

2.1 SIMPLE VAULT W/O BACKFILL

65 KW/ACRE 10 YR
SPENT FUEL (65
KW/ACRE HLW)

CANISTERS ON FLOOR LONGI-
TUDINAL @ 16' X 5.8'
AVG CANS SIDE (5-6-6-6-3-2)
ALTERNATING OR TRANSVERSE
@ 2.8' PITCH

DISTANT - FUTURE CRITICALITY MAY
PRECLUDE SPENT FUEL STORAGE

EMPLACEMENT BY RETREATING
SHIELD JUMBO
ROOF & WALLS SMOOTH
LINED & CROUTED. MUST
BE STRUCTURALLY STRONG

VAULT 20' @ PREBACKFILLED
4' DEEP @ WITH GRADED
AND COMPACTED MATERIAL
VAULTS 96' @ 2' E - E
1396 CANISTERS/4000 FT
160 CANISTERS/LOCAL ACRE

FIG. V6B

2.2 SIMPLE VAULT WITH BACKFILL

DESCRIPTION SAME AS
2.1 EXCEPT:
(ALSO) BACKFILL
MUST BE CRUSHED &
SCREENED TO 1" SIZE (1)

EMPLACEMENT AND
BACKFILL BY RETREATING
SHIELD JUMBO

DISTANT - FUTURE CRITICALITY
MAY PRECLUDE S.F. STORAGE

FIG. V6B (PLUS BACKFILL)

2.3 COMPOUND VAULT WITH SHIELDING BARRIER OVER/AROUND CANISTERS

65 KW/ACRE 10 YR S.F.
(65 KW/ACRE HLW)

4" THICK CONCRETE FLOOR BARRIER.
CANISTERS LONGITUDINAL @ 16' X 5.8' AVERAGE
CANS WIDE.
VAULT 20' @ PREBACKFILLED 4' DEEP WITH
GRADED COMPACTED MATERIAL.
VAULTS 96' @ 2' E - E
1396 CANISTERS PER 4000', 160 CANS/LOCAL ACRE.

DISTANT - FUTURE CRITICALITY
MAY PRECLUDE S.F. STORAGE

REQUIRES SUBSTANTIAL
ROOF SETS & LAGGING

FIG. V7B

2.4 CATACOMBS VAULT WITH VENTILATABLE SLEEVE-STACK

65 KW/ACRE 10 YR SPENT FUEL
(65 KW/ACRE HLW)

SLEEVE STACK PROTECTS
CANISTERS, MINIMIZES
HEAT TRANSFER INTO
ROCK, AND PROVIDES
VENT CONDUIT

ASSUME VAULT 8' @
WITH 6 CANISTERS, W/VAULTS
@ 100' @ 2' E - E
1400 CANISTERS/4000'
150 CANISTERS/LOCAL ACRE

(AIRFLOW PROBABLY SECTIONALIZED
INTO 1500 - 2000' RUNS)

FIG. V8B

GENERAL FOR SHALE:

SUB ALTERNATES IA & IB - LARGE HOLES - ARE NOT CONSIDERED ON PREMISE THAT HOLE WALLS WILL CRUMBLE SO THAT HOLES WILL SOON BECOME SNUG ANYWAY (UNLESS SLEEVED).

SUB ALTERNATES ID & IF - CORROSION RESISTANT CANISTERS AND/OR BACKFILL IN SNUG/SLEEVED HOLES ARE NOT CONSIDERED ON THE PREMISE THAT WARM SHALE (PROPERLY SELECTED) WILL PROVIDE RELATIVELY CORROSION-FREE ENVIRONMENT FOR ORDINARY OR NEAR-ORDINARY STEEL.

SUB ALTERNATE III-B - BACKFILL PRIOR TO PREDICTED CLOSE-IN - IS NOT CONSIDERED BECAUSE FOR SHALE, ROOF-SETS & LAGGING ARE NEEDED INITIALLY, AND WILL RESIST CLOSE-IN FOR CONSIDERABLE TIME

SUB ALTERNATE IJ - CORROSION-RESISTANT CANISTERS FOR VAULT STORAGE IS NOT CONSIDERED ON PREMISE THAT IN THIS ENVIRONMENT, STEEL WILL HAVE LONG CORROSION LIFE.

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174
DF: R0876210
SF: SYH10415

UNCL. DISK: 174

STORAGE SCHEME								OTHER STORAGE SCHEME FEATURES	NOTES	REPOSITORY							RETRIEVAL A FREE HOLE - SOUND CAN		RET B FH-WEAK CAN	RETRIEVAL C-D-E-F C-D TIGHT SOFT HOLE - E-F TIGHT HARD HOLE					RECOVERY A FAILED CANS IN OPEN ROOMS					RECOVERY B CLOSED ROOMS - FAILED/SUSP. CANS					RECOVERY C REPOSITORY DECOMMISSIONED																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																					
OPTION NO.	ROCK TYPE	WASTE TYPE	KW/ACRE	RET. TIME YR	ROOM BACK-FILL	STORAGE MODE	CANISTER PITCH FT.			1. COST 10-01	2. SAFETY 0-10	3. TECH. FEAS. 0-10	5. SAFEGUARDS 0-10	6. MONITORING 0-10	7. CRITICALITY 0-10	8. CRITICALITY FACTORS	SYSTEM DESCRIPTION	A-1 OR A-2	1. COST 17-1	3. TECH. FEAS. 0-10	4. RET. EASE ETC 0-10	RET. TIME SPAN 0-10	ADDITIONAL SYSTEM REQUIREMENTS (+A)	SYSTEM DESCRIPTION C & D	3. TECH. FEAS. 0-10	4. RET. EASE ETC 0-10	SYSTEM DESCRIPTION E & F	3. TECH. FEAS. 0-10	4. RET. EASE ETC 0-10	RET. TIME SPAN 0-10	BLANK	CAN EARLY FAIL RISK 10-1	SYSTEM DESCRIPTION	1. COST 10-01	COST FACTORS	2. SAFETY 0-10	3. TECH. FEAS. 0-10	REC. TIME SPAN 0-10	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST 10-01	2. SAFETY 0-10	3. TECH. FEAS. 0-10	REC. TIME SPAN 0-10	5. SAFEGUARDS 0-10	7. CRITICALITY 0-10	SYSTEM DESCRIPTION	1. COST 10-01	RECTIME SPAN 0-10	7. CRITICALITY																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
1	SALT	SPENT FUEL	60	5	NO	VERTICAL	4								CARBON STL. CANISTERS IN CLEARANCE HOLES (LARGE HOLES FOR SALT) - NO HEAVY SLEEVES ALL ROCK HEAT SINK ALL BACKFILLED AT DECOMM.							INVERSE ENPLACMNT																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		

STORAGE SCHEME								OTHER STORAGE SCHEME FEATURES	NOTES	REPOSITORY							RETRIEVAL A FREE HOLE- SOUND CAN		RET B FH-WEAK CAN	RETRIEVAL C-D-E-F C-D TIGHT SOFT HOLE - E-F TIGHT HARD HOLE				RECOVERY A FAILED CANS IN OPEN ROOMS					RECOVERY B CLOSED ROOMS - FAILED/SUSP. CANS					RECOVERY C REPOSITORY DECOMMISSIONED					A																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																							
OPTION NO.	ROCK TYPE	WASTE TYPE	KW/ ACRE	RET. TIME YR	ROOM BACK- FILL	STORAGE MODE	CANISTER PITCH FT.			1. COST 10-0-1	2. SAFETY 0-10	3. TECH. FEAS. 0-10	4. RET. EASE 0-10	5. SAFEGUARDS 0-10	6. MONITORING 0-10	7. CRITICALITY 0-10	8. SYSTEM DESCRIPTION	9. A-1 OR A-2	1. COST 17-1	3. TECH. FEAS. 0-10	4. RET. EASE 0-10	5. RET. TIME SPAN 0-10	6. ADDITIONAL SYSTEM REQMENTS (+A)	SYSTEM DESCRIPTION C & D	3. TECH. FEAS. 0-10	4. RET. EASE 0-10	5. SYSTEM DESCRIPTION E & F	3. TECH. FEAS. 0-10	4. RET. EASE 0-10	5. RET. TIME SPAN 0-10	RELATIVE CAN EARLY FAIL RISK 10-1	SYSTEM DESCRIPTION	1. COST 10-0-1	COST FACTORS	2. SAFETY 0-10	3. TECH. FEAS. 0-10	4. RET. TIME SPAN 0-10	5. SAFEGUARDS		SYSTEM DESCRIPTION	1. COST 10-0-1	2. SAFETY 0-10	3. TECH. FEAS. 0-10	4. RET. TIME SPAN 0-10	5. SAFEGUARDS 0-10	7. CRITICALITY 0-10	SYSTEM DESCRIPTION	1. COST 10-0-1	REC TIME SPAN 0-10	7. CRITICALITY	BLANK																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											
42	BASALT	HIGH LEVEL WASTE	190	25	NO	HORIZONTAL	13.5								CARBON STL. CANISTERS IN CLEARANCE HOLES (LARGE HOLES FOR SALT) NO HEAVY SLEEVES ALL ROCK HEAT SINK ALL BACKFILLED AT DECOMM.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															

STORAGE SCHEME			OTHER STORAGE SCHEME FEATURES	NOTES	REPOSITORY							RETRIEVAL A		RET B	RETRIEVAL C-D-E-F				RECOVERY A				RECOVERY B				RECOVERY C																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									
ROCK TYPE: SALT												FREE HOLE- SOUND CAN		FH-WEAK CAN	CD TIGHT SOFT HOLE - EF TIGHT HARD HOLE				FAILED CANS IN OPEN ROOMS				CLOSED ROOMS - FAILED/SUSP. CANS				REPOSITORY DECOMMISSIONED																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									
BEDDED & DOME UNLESS NOTED MAX. ROCK TEMP 482°F																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
SCHEME TYPE			CANISTER PROTECTION & COOLING		ROOM BACKFILL								SYSTEM DESCRIPTION		A-1 OR A-2	SYSTEM DESCRIPTION		SYSTEM DESCRIPTION	SYSTEM DESCRIPTION		SYSTEM DESCRIPTION		SYSTEM DESCRIPTION		SYSTEM DESCRIPTION		SYSTEM DESCRIPTION		SYSTEM DESCRIPTION		SYSTEM DESCRIPTION		SYSTEM DESCRIPTION																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
						1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. MONITORING FEASIBILITY	7. CRITICALITY	8. CRITICALITY FACTORS	9. SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MON

1		2		3		4		5		6		7		8		9		10																																																																																																																																																																																																																																																															
STORAGE SCHEME				REPOSITORY				RETRIEVAL A		RET B		RETRIEVAL C-D-E-F		RECOVERY A		RECOVERY B		RECOVERY C																																																																																																																																																																																																																																																															
ROCK TYPE: SALT				OTHER NOTES				FREE HOLE - SOUND CAN		FH-WEAK CAN		CD TIGHT SOFT HOLE - EF TIGHT HARD HOLE		FAILED CANS IN OPEN ROOMS		CLOSED ROOMS - FAILED/SUSP. CANS		REPOSITORY DECOMMISSIONED																																																																																																																																																																																																																																																															
BEDDED & DOME UNLESS NOTED MAX. ROCK TEMP 482°F				SCHEME FEATURES				1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		A-1 OR A-2 1. COST 17- 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION C & D		3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION E & F		3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-0.1 2. SAFETY 0-0 3. TECH FEAS 0-0 4. RET TIME SPAN 0-0 5. SAFEGUARDS 0-0 6. MONITORING 0-0 7. CRITICALITY 0-0		SYSTEM DESCRIPTION		1. COST 10-	

1			2			3			4			5			6			7			8			9			10																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
STORAGE SCHEME			OTHER STORAGE SCHEME FEATURES			NOTES			REPOSITORY			RETRIEVAL A			RET B			RETRIEVAL C-D-E-F			RECOVERY A			RECOVERY B			RECOVERY C																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
ROCK TYPE: GRANITE & BASALT ESSENTIALLY SAME EXCEPT AS NOTED MAX ROCK TEMP 392°F NOMINAL																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
SCHEME TYPE			CANISTER PROTECTION & COOLING			ROOM BACKFILL			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS 0-10			4. RET EASE 0-10			5. SAFEGUARDS 0-10			6. MONITORING 0-10			7. CRITICALITY 0-10			SYSTEM DESCRIPTION			1. COST 10-0.1			2. SAFETY 0-10			3. TECH FEAS		

STORAGE SCHEME			OTHER STORAGE SCHEME FEATURES	NOTES	REPOSITORY							RETRIEVAL A				RETRIEVAL C-D-E-F				RECOVERY A					RECOVERY B					RECOVERY C							
ROCK TYPE: GRANITE & BASALT ESSENTIALLY SAME EXCEPT AS NOTED MAX ROCK TEMP 482°F NOMINAL					1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	5. MONITORING	6. FEASIBILITY FACTORS	7. CRITICALITY	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. SAFEGUARDS	
SCHEME TYPE	CANISTER PROTECTION & COOLING	ROOM BACKFILL																																			
A	1.4 AXIAL HORIZONTAL VERY LONG HOLES 150 KW/ACRE 10 YR SPENT FUEL	302	A. LARGE HOLES W/STD CANISTER A. ROCK HEAT SINK	EARLY	HOLES 24-30" W/STEEL CASING	RETRIEVAL BY HOLE-GROUP ONLY	2.10	6.9	2	10	BF CLOSERS EARLY	10	INVERSE EMPLACMENT	A-2	7.7	8.4	4	ADD EXTRACTOR DOLLY	C-D NOT APPLICABLE TIGHT HOLE WILL ALWAYS BE HARD	INVERSE EMPLACMENT PLUS HOT HARD DEEP TREFAN E & F	8	INVERSE EMPLACMENT PLUS HOLE CLEANSE	3	PKG FOR CAN PLUS HOT DEBRIS LONG HOLES	9.7	4.8	8	LONG-WALL MINING FOR BROADSIDE RECOVERY	0.5	9.8	10.6	6	RE-OPEN MINE PLUS RECOVERY B	0.4	10.6		
		303		AT DECOM		1.8	10	6.9	5	ROOMS LONG OPEN-MAY NEED LAGGING	10	A-1	12.7	8.4	4			1	7	8	6	9.7	4.8	8	0												
		304		NONE		1.8	10	6.9	5		10	A-1	12.7	8.4	4			1	7	8	6	9.7	4.8	8	0												
		305	CONVERTIBLE P. A.C. REPOSITORY	AT DECOM		1.5	9	7.5	6		10	A-1	12.7	8.4	4			1	7	8	6	9.7	4.8	8	0												
		306		NONE		1.5	9	7.5	6		10	A-1	12.7	8.4	4			1	7	8	6	9.7	4.8	8	0												
		307	CORROSION-RESISTANT CANISTERS OMITTED - CARBON STEEL IS LONG-LIVED																																		
		312	G. OVERPACK SLEEVE A. ROCK HEAT SINK	EARLY	SECTIONAL STEEL CASING WELDED TIGHT & SEALED AT BOTH ENDS 24-30" O.D.	1.8	10	6.9	2	BF CLOSERS EARLY	10	A-2	7.5	8.4	4			1	7	8	6	INVERSE EMPLACMENT PLUS SLEEVE CLEANSE	3	9.8	4.8	8	UNDEGRADES ALL PILLARS ANYWAY IS IMPRACTICAL FOR HARD ROCK	0.5	9.8	10.6	6						
		313		AT DECOM		1.5	10	6.9	8	ROOMS LONG OPEN-MAY NEED LAGGING	10	A-1	12.5	8.4	4			1	7	8	6	9.8	4.8	8	0												
		314		NONE		1.5	10	6.9	8		10	A-1	12.5	8.4	4			1	7	8	6	9.8	4.8	8	0												
		315	CONVERTIBLE B. A.C. REPOSITORY	AT DECOM		1.3	9	7.5	9		10	A-1	12.5	8.4	4			1	7	8	6	9.8	4.8	8	0												
316		NONE		1.3	9	7.5	9		10	A-1	12.5	8.4	4			1	7	8	6	9.8	4.8	8	0														
1.5 AXIAL HORIZONTAL SINGLE DEPTH 10 YR OLD SPENT FUEL	317	A. LARGE HOLES W/STD CANISTER A. ROCK HEAT SINK	EARLY	HOLES W/LIGHT STEEL CASING IF APPLICABLE 6" DIA CLEAR	2.10	7.9	2	10	BF CLOSERS EARLY	10	INVERSE EMPLACMENT	A-2	7.9	8.4	4	ADD EXTRACTOR	C-D NOT APPLICABLE TIGHT HOLE WILL ALWAYS BE HARD	INVERSE EMPLACMENT PLUS HOT HARD TREFAN E & F	8	INVERSE EMPLACMENT PLUS HOLE CLEANSE	3	PKG FOR CAN PLUS HOT MATERIALS	9.7	4.8	8	CLEAR ROOMS PLUS HOT HARD TREFAN PLUS PKG FOR CAN PLUS MATS. SEVERE CASE NEED HOT HARD TREFAN	0.5	9.8	10.6	6	RE-OPEN MINE PLUS RECOVERY B	0.4	10.6				
	318		AT DECOM		1.8	10	7.9	6	ROOMS LONG OPEN-MAY NEED LAGGING	10	A-1	10.9	8.4	4			7	5	7	8	5	9.7	4.8	8	0.5	9.8	10.6	6									
	319		NONE		1.8	10	7.9	6		10	A-1	10.9	8.4	4			7	5	7	8	5	9.7	4.8	8	0.7	9.8	10.6	6									
	320	CONVERTIBLE B. A.C. REPOSITORY	AT DECOM		1.5	9	8.5	6		10	A-1	12.9	8.4	4			7	5	7	8	5	9.7	4.8	8	0.5	9.8	10.6	6									
	321		NONE		1.5	9	8.5	6		10	A-1	12.9	8.4	4			7	5	7	8	5	9.7	4.8	8	0.7	9.8	10.6	6									
	322	CONVERTIBLE C. I.C. REPOSITORY	AT DECOM	SUB-COOLED BY REFRIG	1.3	10	9.8	6		10	A-1	12.9	8.4	4			7	5	7	8	5	9.7	4.8	8	0.5	9.8	10.6	6									
	323		NONE		1.3	10	9.8	6		10	A-1	12.9	8.4	4			7	5	7	8	5	9.7	4.8	8	0.7	9.8	10.6	6									
	324	CORROSION-RESISTANT CANISTERS OMITTED - CARBON STL IS LONG-LIVED																																			
	331	D. SNUG HOLES W/CORR PROT A. ROCK HEAT SINK	EARLY	HOLE BACKFILLED WITH SILE/CLAY REQS SPECIAL METHOD FOR HORIZONTAL	2.10	7.9	2	10	BF CLOSERS EARLY	10	A-2	5				INVERSE EMPLACMENT PLUS HOT SOFT TREFAN C & D	8	7	8	7	INVERSE EMPLACMENT PLUS HOT SOFT TREFAN	2	PKG FOR CAN PLUS HOT MATERIALS	9.7	4.8	8	CLEAR ROOMS PLUS HOT SOFT TREFAN PLUS PKG FOR CAN PLUS MATS. SEVERE CASE MAY NEED HOT HARD TREFAN	0.5	9.8	10.6	8						
	332		AT DECOM		1.8	10	7.9	6	ROOMS LONG OPEN-MAY NEED LAGGING	10	C-1	9					8	7	8	7	9	9.7	4.8	8	0.5	9.8	10.6	8									
	333		NONE		1.8	10	7.9	6		10	C-1	9					8	7	8	7	9	9.7	4.8	8	0.7	9.8	10.6	8									
	334	CONVERTIBLE B. A.C. REPOSITORY	AT DECOM		1.5	9	8.5	6		10	C-1	10					8	8				5	9.7	4.8	8	0.5	9.8	10.6	8								
	335		NONE		1.5	9	8.5	6		10	C-1	10					8	8				5	9.7	4.8	8	0.7	9.8	10.6	8								
	336	CONVERTIBLE C. I.C. REPOSITORY	AT DECOM	SUB-COOLED BY REFRIG	1.3	10	9.8	6		10	C-1	10					8	8				5	9.7	4.8	8	0.5	9.8	10.6	8								
	337		NONE		1.3	10	9.8	6		10	C-1	10					8	8				5	9.7	4.8	8	0.7	9.8	10.6	8								
338	G. OVERPACK SLEEVES A. ROCK HEAT SINK	EARLY	OVERPACK IN CARBON STEEL	1.8	10	7.9	2	BF CLOSERS EARLY	10	INVERSE EMPLACMENT PLUS OVERPACK OPENER	A-2	7.8	8.4	4	ADD EXTRACTOR	C-D NOT APPLICABLE TIGHT HOLE WILL ALWAYS BE HARD	E-F NOT APPLICABLE FOR OVERPACK SLEEVE	7	INVERSE EMPLACMENT PLUS OVERPACK OPEN AND CLEANSE	3	PKG FOR CAN PLUS HOT DEBRIS	9.8	4.8	8	CLEAR ROOMS PLUS HOT HARD TREFAN PLUS PKG FOR CAN PLUS OPACKS PLUS MATS. SEVERE CASE MAY NEED HOT HARD TREFAN	0.5	9.8	10.6	7								
339		AT DECOM		1.5	10	7.9	6	ROOMS LONG OPEN-MAY NEED LAGGING	10	A-1	10.8	8.4	4			7	7	8	5	9.8	4.8	8	0.5	9.8	10.6	7											
340		NONE		1.5	10	7.9	6		10	A-1	10.8	8.4	4			7	7	8	5	9.8	4.8	8	0.7	9.8	10.6	7											
341	CONVERTIBLE B. A.C. REPOSITORY	AT DECOM		1.3	9	8.5	7		10	A-1	12.8	8.4	4			7	7	8	5	9.8	4.8	8	0.5	9.8	10.6	7											
342		NONE		1.3	9	8.5	7		10	A-1	12.8	8.4	4			7	7	8	5	9.8	4.8	8	0.7	9.8	10.6	7											
343	CONVERTIBLE C. I.C. REPOSITORY	AT DECOM	SUB-COOLED BY REFRIG	1.0	10	9.8	7		10	A-1	12.8	8.4	4			7	7	8	5	9.8	4.8	8	0.5	9.8	10.6	7											
344		NONE		1.0	10	9.8	7		10	A-1	12.8	8.4	4			7	7	8	5	9.8	4.8	8	0.7	9.8	10.6	7											
1.5 AXIAL UP-SLOPE			THIS SCHEME HAS SIGNIFICANT PROBLEMS IN MINING AND OTHER MATTERS. HENCE IT IS NOT ANALYZED HERE.		PROBLEMS INCLUDE: 1. UP-HOLES WEAKEN MINE ROOM ROOFS AND HIGH TEMPS IN ROOM MAY AGGRAVATE ROCK FRACTURING AND FALLING. 2. CANISTERS MUST BE RETAINED IN HOLES AND MUST BE RESTRAINED AGAINST DROP AT RETRIEVAL																																
1.7 AXIAL UP-SLOPE			THIS SCHEME APPEARS TO REQUIRE IMPRACTICAL EQUIPMENT AND SYSTEMS NOT ANALYZED HERE																																		
1.8 HORIZ BURIAL BELOW FLOOR			ESSENTIALLY SAME AS VAULT - 2-2 OR 2-3																																		
1.9 BURIAL IN WALL ABOVE			REQUIRES WIDE UNSUPPORTED ROOF - SYSTEMS FOR EMPLACEMENT & BURIAL ARE NOT																																		

STORAGE SCHEME			OTHER STORAGE SCHEME FEATURES		NOTES		REPOSITORY							RETRIEVAL A		RET B	RETRIEVAL C-D-E-F				RECOVERY A				RECOVERY B					RECOVERY C							
ROCK TYPE: GRANITE & BASALT														FREE HOLE - SOUND CAN		FH - WEAK CAN	CD TIGHT SOFT HOLE - EF TIGHT HARD HOLE				FAILED CANS IN OPEN ROOMS				CLOSED ROOMS - FAILED/SUSP. CANS					REPOSITORY DECOMMISSION							
ESSENTIALLY SAME EXCEPT AS NOTED																																					
MAX ROCK TEMP 392°F NOMINAL																																					
SCHEME TYPE			CANISTER PROTECTION & COOLING		ROOM BACKFILL									SYSTEM DESCRIPTION		SYSTEM DESCRIPTION	SYSTEM DESCRIPTION				SYSTEM DESCRIPTION				SYSTEM DESCRIPTION					SYSTEM DESCRIPTION							
2.1 SIMPLE VAULT			H. STD. CANISTERS A. ROCK HEAT SINK		NONE		DISTANT - FUTURE CRITICALITY MAY PRECLUDE S.F. STORAGE RETRIEVAL BY VAULT GROUPS ONLY							INVERSE EMPLACMENT		ADD EXTRACTOR	C-D NOT APPLICABLE NO HOLES TO BE TIGHT				E-F NOT APPLICABLE NO HOLES TO BE TIGHT				SIMILAR TO RETRIEVAL A-B PLUS CLEANUP				CLEAR VAULT WITH SHIELD PLUS PKGS FOR CANS PLUS HOT MATERIALS					REOPEN MINE PLUS RECOVERY B			
2.2 SIMPLE VAULT			H. STD. CANISTERS A. ROCK HEAT SINK		EARLY		RETRIEVAL BY VAULT GROUPS ONLY							INVERSE EMPLACMENT PLUS BACKFILL HANDLING WITH PRECAUTIONS RE CONTAMINATION											3				1 9 6 10 6 7					0.9 10 8			
2.3 COMPOUND VAULT			H. STD. CANISTERS A. ROCK HEAT SINK		EARLY		DISTANT - FUTURE CRITICALITY MAY PRECLUDE S.F. STORAGE HERE IT IS ASSUMED SMALL CONC. SEPARATORS WILL ENSURE DILUTION							INVERSE EMPLACMENT		A-2 9 9 10 7									4				9 8 7 8					REOPEN MINE PLUS RECOVERY B			
2.4 CATACOMBS VAULT			H. STD. CANISTERS A. ROCK HEAT SINK		NONE		DISTANT - FUTURE CRITICALITY MAY AFFECT DETAIL DESIGN RETRIEVAL BY VAULT SUB-GROUPS ONLY							FISHING PULLOUT FROM LONG CELL		A-1 12 7 8 10	ADD EXTRACTOR DOLLY								10				0.7 9 4 10 6 8					0.6 10 8			

1. FOR CRITERIA ITEMS NOT SHOWN, SAME ITEM SHOWN TO THE LEFT NEXT - APPLIES

2. COST RATINGS ARE RELATIVE AND BY ENGRG JUDGEMENT ONLY - W/O ESTIMATING BACKUP - UNLESS OTHERWISE NOTED

3. CRITERIA ITEM NO. 8 - LICENSABILITY - IS NOT SHOWN HERE - REFER TO TEXT

CONSTRUCTION APPROVAL

APPROVAL

DATE

SCALE

DATE

PROFESSIONAL SEAL

KAISER ENGINEERS

KAISER ENGINEERS, INC.

300 LAKESIDE DRIVE

P.O. BOX 2000

OAKLAND, CALIFORNIA 94612

RETRIEVAL OPTIONS STUDY

ANALYSIS MATRIX FOR BROAD OPTIONS LISTING

SPENT FUEL

JOB No. 79033

DWG. No. M-5 SH-2

REVISION

STORAGE SCHEME			OTHER STORAGE SCHEME FEATURES	NOTES	REPOSITORY							RETRIEVAL A		RET B	RETRIEVAL C-D-E-F				RECOVERY A					RECOVERY B					RECOVERY C																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																					
ROCK TYPE: SHALE MAX ROCK TEMP 212°F NOMINAL					1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	6. MONITORING	7. CRITICALITY	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH FEAS	4. RET EASE	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY

STORAGE SCHEME			OTHER STORAGE SCHEME FEATURES	NOTES	REPOSITORY							RETRIEVAL A		RET B	RETRIEVAL C-D-E-F				RECOVERY A					RECOVERY B					RECOVERY C																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
ROCK TYPE: SHALE MAX ROCK TEMP 212°F NOMINAL					1. COST	2. SAFETY	3. TECH. FEAS.	4. RET. TIME SPAN	5. SAFEGUARDS	6. MONITORING	7. CRITICALITY	SYSTEM DESCRIPTION	1. COST	3. TECH. FEAS.	4. RET. TIME SPAN	5. SAFEGUARDS	SYSTEM DESCRIPTION	3. TECH. FEAS.	4. RET. TIME SPAN	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. RET. TIME SPAN	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. RET. TIME SPAN	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST	2. SAFETY	3. TECH. FEAS.	4. RET. TIME SPAN	5. SAFEGUARDS																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											
SCHEME TYPE	CANISTER PROTECTION & COOLING	ROOM BACKFILL									A-1 OR A-2																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						

1. FOR CRITERIA ITEMS NOT SHOWN, SAME ITEM SHOWN TO THE LEFT NEXT - APPLIES 2. COST RATINGS ARE RELATIVE AND BY ENGR JUDGEMENT ONLY - W/O ESTIMATING BACKUP - UNLESS OTHERWISE NOTED 3. CRITERIA ITEM NO. 8 - LICENSABILITY - IS NOT SHOWN HERE - REFER TO TEXT		CONSTRUCTION APPROVAL APPROVAL DATE SCALE: - DESIGNED BY: FA PURDY 8-28-79 DRAWN BY: FAP 9-11-79 CHECKED BY: APPROVED BY: APPROVED BY:		PROFESSIONAL SEAL KAISER ENGINEERS 300 LAKESIDE DRIVE P.O. BOX 9000 OAKLAND, CALIFORNIA 94617 BATTELLE/ONWI RETRIEVAL OPTIONS STUDY ANALYSIS MATRIX FOR BROAD OPTIONS LISTING SPENT FUEL JOB No. 79033 DWG. No. M-5 OH.-8	
---	--	--	--	---	--

STORAGE SCHEME			OTHER STORAGE SCHEME FEATURES	NOTES	REPOSITORY							RETRIEVAL A		RET B	RETRIEVAL C-D-E-F				RECOVERY A					RECOVERY B					RECOVERY C															
ROCK TYPE: SHALE MAX. ROCK TEMP 212°F NOMINAL					1. COST 10-01	2. SAFETY 0-10	3. TECH FEAS 0-10	5. SAFEGUARDS 0-10	6. MONITORING 0-10	7. CRITICALITY 0-10	CRITICALITY FACTORS	SYSTEM DESCRIPTION	A-1 OR A-2	1. COST 10-01	3. TECH FEAS 0-10	4. RET EASE ETC 0-10	RET TIME SPAN 0-10	ADDITIONAL SYSTEM REQMENTS (+A)	SYSTEM DESCRIPTION C & D	3. TECH FEAS 0-10	4. RET EASE ETC 0-10	RET TIME SPAN 0-10	BLANK	CAN EARLY FAIL RISK 10-1	SYSTEM DESCRIPTION	1. COST 10-01	COST FACTORS	2. SAFETY 0-10	3. TECH FEAS 0-10	RET TIME SPAN 0-10	5. SAFEGUARDS	SYSTEM DESCRIPTION	1. COST 10-01	2. SAFETY 0-10	3. TECH FEAS 0-10	RET TIME SPAN 0-10	5. SAFEGUARDS 0-10	7. CRITICALITY 0-10	SYSTEM DESCRIPTION	1. COST 10-01	RET TIME SPAN 0-10	7. CRITICALITY	BLANK	
2. VAULT SCHEMES 2.1 SIMPLE VAULT WITH BACKFILL 65 KW/ACRE 10 YR SF 2.2 COMPOUND VAULT WITH BACKFILL 65 KW/ACRE 10 YR SF 2.3 COMPOUND VAULT WITH SLEEVE ROCK 65 KW/ACRE 10 YR SF 2.4 CATACOMBS VAULT WITH SLEEVE ROCK 65 KW/ACRE 10 YR SF			489	H. STD CANISTERS	A. ROCK HEAT SINK	NONE	VAULTS MUST BE LINED SMOOTH & STRONG	DISTANT-FUTURE CRITICALITY MAY PRECLUDE SPENT FUEL STORAGE RETRIEVAL BY VAULT-GRAB ONLY	4	8	8	9	VAULT SECTIONS OPEN BUT NOT FOR ENTRY	INVERSE EMPLACMENT	A-1	12	8	9	**3	ADD EXTRACTOR	C-D NOT APPLICABLE NO HOLES TO BE TIGHT	EF NOT APPLICABLE NO HOLES TO BE TIGHT	10	SIMILAR TO RETRIEVAL A-B PLUS CLEANUP	5	PACKAGING FOR CANISTER PLUS HOT MATERIAL ALSO FOR OVERPACK WHERE APPLICABLE	8	7	10	8	CLEAR VAULT WITH SHIELD PLUS PEGG FOR CANS PLUS HOT MATERIALS	0.5	7	7	10	6	4	REDRAW OR REDEVELOP MOVE PLUS RECOVERY B	0.4	10	3			
			490	K. OVERPACKED CANISTERS	A. ROCK HEAT SINK	NONE																																						
			491		B. CONVERTIBLE A.C. REPOSITORY	NONE																																						
			492		C. I.C. REPOSITORY	NONE	SUB-COOLED BY REFRIG																																					
			493	H. STD. CANISTERS	A. ROCK HEAT SINK	EARLY																																						
2.3 COMPOUND VAULT WITH SLEEVE ROCK 65 KW/ACRE 10 YR SF			494	H. STD. CANISTERS	A. ROCK HEAT SINK	EARLY		DISTANT-FUTURE CRITICALITY MAY PRECLUDE S.F. STORAGE. IT IS ASSUMED SMALL CONC. SEPARATION WILL ENHANCE DILUTION	3	8	8	9	B.F. CLOSELY MONITORED EARLY UPPER VAULT IS LONG OPEN	INVERSE EMPLACMENT	A-2	5	9	10	7																									
			495			AT DECOM																																						
			496			NONE																																						
			497		B. CONVERTIBLE A.C. REPOSITORY	AT DECOM																																						
			498			NONE																																						
2.4 CATACOMBS VAULT WITH SLEEVE ROCK 65 KW/ACRE 10 YR SF			499		CONVERTIBLE C.I.C. REPOSITORY	AT DECOM	SUB-COOLED BY REFRIG		2	8	9	8																																
			500			NONE																																						
			501	H. STD. CANISTERS	A. ROCK HEAT SINK	NONE																																						
			502		CONVERTIBLE C. I.C. REPOSITORY	NONE																																						
			503	K. OVERPACKED CANISTERS	A. ROCK HEAT SINK	NONE																																						
			504		CONVERTIBLE B. A.C. REPOSITORY	NONE																																						
			505		CONVERTIBLE C. I.C. REPOSITORY	NONE	SUB-COOLED BY REFRIG		2.5	8	8	8																																
			506																																									

*NOTE: VAULT SCHEMES APPEAR TO REQUIRE CONSIDERABLY LESS EXCAVATION THAN ROOMS (SUBJECT TO THERMAL ANALYSES), BUT REQUIRE HEAVY CONCRETE LININGS (FOR 2.1 & 2.2) AND OTHER HEAVY CONCRETE (FOR 2.3 & 2.4). HENCE COST OF VAULTS IS TAKEN AS A LITTLE LESS THAN ROOMS.

**NOTE: RETRIEVAL TIME SPANS FOR 2.1 & 2.2 END WHEN VAULT LININGS SIGNIFICANTLY CRACK OR SHIFT - VALUES SHOWN ARE VERY ROUGH. THIS ALSO APPLIES TO RECOVERY A

NO. DATE

REVISION

BY

APP.

APP.

1. FOR CRITERIA ITEMS NOT SHOWN, SAME ITEM SHOWN TO THE LEFT NEXT - APPLIES

2. COST RATINGS ARE RELATIVE AND BY ENGR JUDGEMENT ONLY - W/O ESTIMATING BACKUP - UNLESS OTHERWISE NOTED

3. CRITERIA ITEM NO. 8 - LICENSABILITY - IS NOT SHOWN HERE - REFER TO TEXT

CONSTRUCTION APPROVAL

APPROVAL

DATE

SCALE: -

DATE

DESIGNED BY FA PURDY 8-28-79

DRAWN BY FAP 9-11-79

CHECKED BY

APPROVED BY

APPROVED BY

DESCRIPTION

COST ACCOUNT

WORK COVERED BY THIS DRAWING CHARGED TO COST ACCOUNT ABOVE

INFORMATION CONFIDENTIAL: ALL PLANS, DRAWINGS, SPECIFICATIONS AND/OR INFORMATION FURNISHED HEREWITH ARE AND SHALL REMAIN THE PROPERTY OF KAISER ENGINEERS, AND SHALL BE HELD CONFIDENTIAL AND SHALL NOT BE USED FOR ANY PURPOSE OR PURPOSES OTHER THAN THOSE FOR WHICH THEY HAVE BEEN SUPPLIED AND PREPARED.

PROFESSIONAL SEAL

KAISER ENGINEERS, INC. 300 LAKESIDE DRIVE P.O. BOX 2000 OAKLAND, CALIFORNIA 94612

BATTLE/ONWINS

RETRIEVAL OPTIONS STUDY ANALYSIS MATRIX FOR BROAD OPTIONS LISTING SPENT FUEL

JOB No. 79033

DWG. No. M-5 SH-1

AXIAL SINGLE	DOWN DEPTH
24	2

(LONGITUDINAL)
SIMPLE VAULT W/O
V 6 A

CATACOMBS VAULT
V B B

LEGEND:

R	-	ROOM
V	-	VAULT
A	-	RECTANGULAR
B	-	CIRCULAR
NO	-	R OR V TYPE

[illegible]

REFERENCES

1. "Special Study No. 3: Waste Retrieval from Backfilled Regions for a National Waste Terminal Storage Repository in a Bedded Salt Formation for Spent Unreprocessed Fuel," KE Report No. 7856-R, September 1978.
2. "Management of Commercially Generated Radioactive Waste," Draft EIS, DOE/EIS-0046D, Vol. 1 of 2.
3. "Conceptual Design Description for a National Waste Terminal Storage Repository in a Bedded Salt Formation for Spent Unreprocessed Fuel," KE Report No. 7858-R, December 1978, pp. 7-72.
4. "Report of Nuclear Engineering Analytical Support for the NWTSR2 Design," KE Report No. 77018 NWTN 3358, December 1978, p. 39.
5. "Draft Environmental Impact Statement Waste Isolation Pilot Plant," U.S. Department of Energy, DOE/EIS-0026-D, Vol. 1 of 2, April 1979, pp. 9-144.
6. E. J. Allen, "Criticality Analysis of Aggregation of Actinides from Commercial Nuclear Waste in Geological Storage," ORNL/TM-6458, August 1978.

APPENDIX

CALCULATED ROCK TEMPERATURE VARIATIONS FOR SELECTED STORAGE ARRANGEMENTS

Rock temperatures were calculated for a total of 71 storage arrangements in order to establish those arrangements that satisfy the design criteria outlined in Section 4.6. There were 30 arrangements for high-level wastes and 35 arrangements for spent fuel assemblies, and 6 arrangements for the storage of multiple canisters in long horizontal storage holes in salt.

Calculated maximum rock temperature variations and average storage room temperature variations are presented for selected storage arrangements in this appendix. A storage period of 28 years is represented in each case (3 years longer than the 25 year retrieval period to allow for possible extensions due to decommissioning), except where temperatures at early storage times could not be calculated due to computer code limitations¹.

A.1 Storage of 10-Year-Old, High-Level Waste

Maximum rock temperature and average storage room temperature were plotted as a function of time for each of the storage arrangements for high-level waste selected as a "base case." The thermal conditions that must be accommodated in any of the "base case" retrieval options for high-level waste were determined from these plots. These plots are presented as Figures A.1 - A.12, with storage arrangements in salt, basalt, granite, and shale, respectively represented.

A.2 Storage of 10-Year-Old, Spent Fuel Assemblies

Maximum rock temperature and average storage room temperature were plotted as a function of time for each of the storage arrangements for spent fuel assemblies selected as a "base case." The thermal

conditions that must be accommodated in any of the "base case" retrieval options for spent fuel were determined from these plots. These plots are presented as Figures A.13 - A.27 with the storage arrangements in salt, basalt, granite, and shale respectively represented.

A.3 Multiple Canister Storage of 10-Year-Old, High-Level Waste in Salt

Temperatures were calculated for storage arrangements with multiple high-level waste canisters in horizontal storage holes spaced 11.5, 15.5, and 23.0 ft apart. These arrangements have 7, 9, and 12 canisters in each storage hole, respectively, for a maximum storage hole length of 200 ft.

Figures A.28 - A.30 present the calculated maximum temperature of the salt near the storage hole and the average storage room temperature as a function of time. By interpolation of the calculated maximum salt temperature, the arrangement, which approaches but does not exceed a guidance salt temperature of 482°F, was found to have 11 canisters in each storage hole; the corresponding storage hole spacing is 20.5 ft.

A.4 Multiple Canister Storage of 10-Year-Old, Spent Fuel Assemblies in Salt

Temperatures were calculated for storage arrangement with multiple canisters in horizontal storage holes spaced 12.0, 14.0, and 16.0 ft apart. These arrangements have 10, 11, and 12 canisters in each storage hole, respectively, for the maximum storage hole length of 200 ft.

Figures A.31 - A.33 present the calculated maximum temperature of the salt near the storage hole and the average storage room temperatures as a function of time. All arrangements investigated are

satisfactory since the guidance salt temperature of 482°F is not exceeded in any case. However, the arrangement with 10 canisters per storage hole and a storage hole spacing of 12 ft was preferred because it has the minimum extraction ratio of the three candidate arrangements.

FIGURE A.1 VERTICALLY STORED HIGH LEVEL WASTE IN SALT: 150 kW/ACRE

RUN NO. P1990D41 141 A

RUN NO. P1990D42 142 A

Vertically Stored High Level
Waste in Salt: 75kW/acre

p = 12.0 ft.
d = 94.5 ft.

FIGURE A.2 VERTICALLY STORED HIGH LEVEL WASTE IN SALT: 75 kW/ACRE

RUN NO. P1990D42 142 A

FIGURE A.3 VERTICALLY STORED HIGH LEVEL WASTE IN SALT: 75 kW/ACRE

RUN NO. P1990D75 120 A

FIGURE A.4 VERTICALLY STORED HIGH LEVEL WASTE IN BASALT: 190 kW/ACRE RUN NO. P1990R7 79A

FIGURE A.6 VERTICALLY STORED HIGH LEVEL WASTE IN BASALT: 95 kW/ACRE

RUN NO. P1990R9 82A

FIGURE A.7 VERTICALLY STORED HIGH LEVEL WASTE IN GRANITE: 190 kW/ACRE

RUN NO. P1990R13 92A

FIGURE A.8 VERTICALLY STORED HIGH LEVEL WASTE IN GRANITE: 95 kW/ACRE

RUN NO. P1990R14 95A

FIGURE A.9 VERTICALLY STORED HIGH LEVEL WASTE IN GRANITE: 95 kW/ACRE

RUN NO. P1990R15 96A

FIGURE A.10 VERTICALLY STORED HIGH LEVEL WASTE IN SHALE: 130 kW/ACRE

RUN NO. P1990R1 131A

FIGURE A.11 VERTICALLY STORED HIGH LEVEL WASTE IN SHALE: 65 kW/ACRE

RUN NO. P1990R2 74A

FIGURE A.12 VERTICALLY STORED HIGH LEVEL WASTE IN SHALE: 65 kW/ACRE

RUN NO. P1990R3 150A

FIGURE A.13 VERTICALLY STORED FUEL ASSEMBLIES IN SALT: 60 kW/ACRE

RUN NO. P1990D6 206A

FIGURE A.14 VERTICALLY STORED FUEL ASSEMBLIES IN SALT: 60 kW/ACRE

RUN NO. P1990D5 120A

FIGURE A.16 VERTICALLY STORED FUEL ASSEMBLIES IN SALT: 30 kW/ACRE

RUN NO. P1990D76 126A

FIGURE A.17 VERTICALLY STORED FUEL ASSEMBLIES IN SALT: 30 kW/ACRE

RUN NO. P1990D2 131A

FIGURE A.18 VERTICALLY STORED FUEL ASSEMBLIES IN SALT: 30 kW/ACRE

RUN NO. P1990D77 127A

FIGURE A.19 VERTICALLY STORED FUEL ASSEMBLIES IN BASALT: 190 kW/ACRE

RUN NO. P1990R10 86A

FIGURE A.20 VERTICALLY STORED FUEL ASSEMBLIES IN BASALT: 95 kW/ACRE

RUN NO. P1990R11 87A

FIGURE A.21 VERTICALLY STORED FUEL ASSEMBLIES IN BASALT: 95 kW/ACRE

RUN NO. P1990R12 88A

FIGURE A.22 VERTICALLY STORED FUEL ASSEMBLIES IN GRANITE: 190 kW/ACRE RUN NO. P1990R16 160A

FIGURE A.23 VERTICALLY STORED FUEL ASSEMBLIES IN GRANITE: 95 kW/ACRE RUN NO. P1990R17 99A

FIGURE A.24 VERTICALLY STORED FUEL ASSEMBLIES IN GRANITE: 95 kW/ACRE RUN NO. P1990R18 100A

FIGURE A.25 VERTICALLY STORED FUEL ASSEMBLIES IN SHALE: 100 kW/ACRE

RUN NO. P1990R4 122A

FIGURE A.26 VERTICALLY STORED FUEL ASSEMBLIES IN SHALE: 50 kW/ACRE

RUN NO. P1990R5 123A

FIGURE A.27 VERTICALLY STORED FUEL ASSEMBLIES IN SHALE: 50 kW/ACRE

RUN NO. P1990R7 77A

FIGURE A.28 HORIZONTALLY STORED HIGH LEVEL WASTE IN SALT: 150 kW/ACRE RUN NO. P1990D98 257A

FIGURE A.29 HORIZONTALLY STORED HIGH LEVEL WASTE IN SALT: 150 kW/ACRE RUN NO. P1990D90 258A

FIGURE A.30 HORIZONTALLY STORED HIGH LEVEL WASTE IN SALT: 150 kW/ACRE RUN NO. P1990D91 259A

FIGURE A.31 HORIZONTALLY STORED FUEL ASSEMBLIES IN SALT: 60 kW/ACRE

RUN NO. P1990D86 246A

FIGURE A.32 HORIZONTALLY STORED FUEL ASSEMBLIES IN SALT: 60 kW/ACRE

RUN NO. P1990D87 255A

FIGURE A.33 HORIZONTALLY STORED FUEL ASSEMBLIES IN SALT: 60 kW/ACRE

RUN NO. P1990D88 254A

REFERENCE

1. "Finite-Length Line Source Superposition Model," ONWI Report No. 94, 1980.

DISTRIBUTION LIST

ACRES AMERICAN INCORPORATED
A S BURGESS

ADDISON HIGH SCHOOL
NED ELLIS

AEROSPACE CORPORATION
BARRETT R FRITZ

AIF INCORPORATED
TOM HUNT

ALLIED GENERAL NUCLEAR SERVICES
P F HIGHBERGER
G F MOLEN

AMERICAN COUNCIL ON EDUCATION
SHELDON E STEINBACH

ANALYTIC SCIENCES CORPORATION
JOHN W BARTLETT
C KOPLIK

ARGONNE NATIONAL LABORATORY
THOMAS H BRAID
REX COUTURE
KEVIN FLINN
SHERMAN FRIED
ARNOLD M FRIEDMAN
LESLIE J JARDINE
J H KITTEL
STEPHEN LAWROSKI
W J MECHAM
ALICE E PACKARD
RALPH POHTO
MARTIN SEITZ
MARTIN J STEINDLER

ARTHUR D. LITTLE, INCORPORATED
CHARLES R HADLOCK

ATOMIC ENERGY OF CANADA LTD
S A MAYMAN
EVA ROSINGER
M TOMLINSON

**ATOMIC ENERGY RESEARCH
ESTABLISHMENT**
H A C MCKAY

ATOMIC INDUSTRIAL FORUM, INC.
PAUL PETTIT

AUTOMATION INDUSTRIES INC
THOMAS T BRADSHAW
T M ROBERTSON

BATTELLE COLUMBUS DIVISION
BEVERLY S AUSMUS
U YOUNG PARK
THOMAS M TRAINER
KENNETH S WURM
W J ZIELENBACH

**BATTELLE HUMAN AFFAIRS RESEARCH
CENTERS**
CARLA GINNIS
BARBARA KEEN
SALLY SMITH

**BATTELLE PACIFIC NORTHWEST
LABORATORIES**
W F BONNER
DON J BRADLEY
GARRY H BRYAN
L L BURGER
J B BURNHAM
LARRY L CADWELL
JOHN P CORLEY
W J DEUTSCH
HARVEY DOVE
SHIRLEY GYDESEN
O F HILL
FLOYD N HODGES
J H JARRETT
MAX R KREITER
DONALD E LARSON
R D NELSON
CALVIN R PALMER
A M PLATT
J M RUSIN
R JEFF SERNE
PETER UERPMANN
E C WATSON
J H WESTSIK, JR
R D WIDRIG
L D WILLIAMS

BATTELLE SPOKANE OFFICE
GARY BENSON

BECHTEL NATIONAL INC
DENNIS A BITZ
J COLLINGS
D B CRANDALL
D S DUNCAN
C HARPER
J B KEMP
C W KUHLMAN
R A LANGLEY JR
R C LOVINGTON
N A NORMAN

BIRGER JARLISGATAN 41A
LARS B NILSSON

**BOEING ENGINEERING AND
CONSTRUCTION COMPANY**
GEORGE DYMMEL
E S KEENE
GARRY L QUINN

BOOZ, ALLEN AND HAMILTON INC
JOHN R SIEGEL

BRIGHAM YOUNG UNIVERSITY
MORRIS S PETERSEN

**BROOKHAVEN NATIONAL
LABORATORY**
P AUD-ISAACS
K CZYSCINSKI
RICHARD E DAVIS
A J FRANCIS
DOUGLAS HILL
CARL J KLAMUT
P W LEVY
THOMAS LUHMAN
RICHARD F PIETRZAK
DONALD SCHWEITZER
PETER SOO
K J SWYLER
HELEN TODOSOW (2)

BROWN UNIVERSITY
B GILETTI

**BUNDESANSTALT FUR
GEOWISSENSCHAFTEN**
MICHAEL LANGER

BUNDESMINISTERIUM FUR FORSCHUNG
ROLF-PETER RANDL

**BURNS AND ROE INDUSTRIAL SERVICES
CORPORATION**
JOHN PIRRO

C C R EURATOM
EUGENE SCHMIDT

CALIFORNIA DEPT OF CONSERVATION
JAMES F DAVIS

**CALIFORNIA DIVISION OF MINES AND
GEOLOGY**
PERRY Y AMIMOTO

CALIFORNIA ENERGY COMMISSION
G SIMON
A J SOINSKI

CALIFORNIA GOVERNORS OFFICE
WILSON CLARK

CATALYTIC INC
C J BURG

CGS INC
DONALD MCKAY

**CHALMERS UNIVERSITY OF
TECHNOLOGY**
BERT ALLARD

**CLINCH RIVER BREEDER REACTOR
PROJECT OFFICE**
KEVIN SALWEN

COLORADO SCHOOL OF MINES
S S GOLDICH
W HUSTRULID

**COMMISSARIAT A L'ENERGIE
ATOMIQUE**

M Y SOUSSELIER

CONNECTICUT ENERGY DIVISION
TOM FITZPATRICK

CORTLAND COUNTY HEALTH DEPT
J V FEUSS

**D'APPOLONIA CONSULTING ENGINEERS
INC**

R D ELLISON
AMIRA HAMDY
ALLEN K KUHN
DALE E STEPHENSON
LISA STEVENS

DALTON-DALTON-LITTLE-NEWPORT
STEVE NACHT

DAMES & MOORE

ATG LIBRARY
ROBERT R BLICKWEDEHL
SALLY IRONFIELD
LIBRARY
O L OZTUNOLI
B SAGAR
LES SKOSKI
JOHN WILLIAMS
RICHARD M WINAR

DARTMOUTH COLLEGE
JOHN B LYONS

**DAWCON MANAGEMENT CONSULTING
SERVICE**
DAVID A WEBSTER

DEPARTMENT OF ENVIRONMENT
RADIOACTIVE WASTE MANAGEMENT
DIVISION

DETROIT EDISON
ALLEN WEGELE

EARTH RESOURCE ASSOCIATES
SERGE GONZALES

EARTH SCIENCE LABORATORY

EBASCO SERVICES INC.
A SALEEM
RAYMOND H SHUM

EG & G IDAHO INC

B L BARNES
EARL FRAY
JOHN HINCKLEY
J A HUNTER
C R CHUCK JOHNS
DENNIS D KEISER
G B LEVIN
M D MCCORMACK
LYNN A ROWETT
RICHARD TALLMAN
JANE WELCH

ELECTRIC POWER RESEARCH INSTITUTE
CHAIM BRAUN

ELSAM
ARNE PEDERSEN

ENERGY SYSTEMS PRODUCT NEWS
MICHAEL BROWN

ENVIRONMENTAL POLICY INSTITUTE
DAVID M BERICK

ENVIROSPHERE COMPANY
JOSEPH FRANCO
L T SKOBLAR

EXXON NUCLEAR COMPANY INC
GARY WAYMIRE

**EXXON NUCLEAR IDAHO COMPANY
INC**
G G SIMPSON

FALCON RESEARCH AND DEVELOPMENT
WILLIAM J GALYEAN

FLORIDA POWER AND LIGHT COMPANY
JAMES R TOMONTO

FMC CORPORATION
MIKE WALLIS

FORD, BACON & DAVIS UTAH INC
DARRELL H CARD
ROBERT F OVERMYER
BURTON J THAMER

FOSTER-MILLER ASSOCIATES INC
JOHN W COLBURN, JR

**FOUNDATION SCIENCES
INCORPORATED**
LOU BATTAMS

FUGRO INCORPORATED
J CARL STEPP

GENERAL ATOMIC COMPANY
ROBERT M BURGOYNE
R J CAMPANA
G W HANNAMAN
DOUGLAS D ORVIS
R F TURNER

GENERAL COURT OF MASSACHUSETTS
TIMOTHY J BURKE

GEOLOGICAL SOCIETY OF AMERICA
JOHN C FRYE

GEOLOGICAL SOCIETY OF CANADA
B SANFORD
J S SCOTT

GEOLOGICAL SURVEY OF SWEDEN
OTTO BROTZEN

GEORGIA INSTITUTE OF TECHNOLOGY
GEOFFREY EICHHOLZ
J W POSTON
A SCHNEIDER
CHARLES E WEAVER

GEOTECHNICAL ENGINEERS INC
RICHARD W TURNBULL

**GESELLSCHAFT FUR KERNFORSCHUNG
M B H**
HELMUT KRAUSE

GIBBS & HILL
JACK BADMAN

GILBERT/COMMONWEALTH
JERRY L ELLIS

GRAND COUNTY COMMISSION

GRAND COUNTY PUBLIC LIBRARY

GRUY FEDERAL INC
LAVERNE B COBB

GULF STATES UTILITIES COMPANY
E LINN DRAPER JR ,

**HAHN-MEITNER-INSTITUT FUR
KERNFORSCHUNG BERLIN**
KLAUS ECKART MAASS
GUENTER MALOW
EDWIN SCHIEWER

HALEY & ALDRICH INC
ALLEN W HATHEWAY

**HANFORD ENGINEERING DEVELOPMENT
LABORATORY**
ALBERT G BLASEWITZ

HANFORD SCIENCE CENTER
ANN COWAN

HARVARD UNIVERSITY
R SIEVER

HARWELL LABORATORY
J D MATHER

HDR SCIENCES
ERENE V PECAN

HIRAM COLLEGE
JAMES W COWDEN

IDAHO DEPT OF HEALTH AND WELFARE
BOB FUNDERBURG

IDAHO OFFICE OF ENERGY
WAYNE HARL

IIT RESEARCH INSTITUTE
E R BANGS

**ILLINOIS ATOMIC ENERGY
COMMISSION**
DAN L WILLIAMS

ILLINOIS DEPT OF PUBLIC HEALTH
MILTON ZUKOR

**ILLINOIS INSTITUTE OF NATURAL
RESOURCES**

ANTHONY LIBERATORE

INSTITUT FUR TIEFLAGERUNG
KLAUS KUHN

INSTITUTE FOR ENERGY ANALYSIS
LIBRARY
H G MACPHERSON
A M WEINBERG

INSTITUTE OF GEOLOGICAL SCIENCES
NEIL A CHAPMAN

INSTITUTE OF GEOPHYSICAL SCIENCES
DAVID A GRAY

**INTERA-ENVIRONMENTAL
CONSULTANTS INC**
DONNA G HEARD
ROBERT WILEMS

**INTERNATIONAL ATOMIC ENERGY
AGENCY**
FRANK F A O'HARA

**INTERNATIONAL ENERGY ASSOCIATES
LTD**
LIBRARY
KIICHIRO SAIDO

**INTERNATIONAL ENGINEERING
COMPANY, INC**

INTERNATIONAL MARITIME ASSOC INC
CHRISTOPHER J O'SHEA

INTERNATIONAL SALT COMPANY
DILIP K PAUL

IOWA STATE COMMERCE COMMISSION
ANDREW VARLEY

IRT CORPORATION
R GALLOWAY
D NITTA
W E SELPH
J STOKES

JACKSON CLARION-LEDGER
MARK SCHLEIFSTEIN

JAMES F. MACLAREN LTD.
VALARIE CASSADAY

**JAPAN ATOMIC ENERGY RESEARCH
INSTITUTE**
TARO ITO

JGC CORPORATION
MASAHIKO MAKINO

JLM ASSOCIATES
J L MAGRUDER

JOHNS HOPKINS UNIVERSITY
JARED L COHON

JOINT RESEARCH CENTRE
F GIRARDI

KAISER ENGINEERS INCORPORATED
STEPHEN C BROWN
W J DODSON
J S RITCHIE

KAMAN SCIENCES CORPORATION
PAUL A ELLIS

KANSAS NUCLEAR NEWS
MAX MCDOWELL

KANSAS STATE GEOLOGICAL SURVEY
WILLIAM W HAMBLETON

KBS
TONIS PAPP

KERNFORSCHUNG KARLSRUHE
REINHARD KRAEMER

**KEYSTONE CENTER FOR CONTINUING
EDUCATION**
ROBERT W CRAIG
TERRY R LASH

LAW ENGINEERING TESTING COMPANY
JAMES L GRANT
DAVID PAULS

LAWRENCE BERKELEY LABORATORY
JOHN A APPS
LEWIS COHEN
N EDELSTEIN
ORAH GOLDHAM
JANE LONG
R SILVA
W STROMDAHL
WILLIAM THUR
J WANG
CHARLES R WILSON
PAUL A WITHERSPOON

LAWRENCE LIVERMORE LABORATORY
L B BALLOU
M BUETTNER
JERRY J COHEN
DAVID G COLES
TERRY DONICH
A DUBA
R ELSON
H C HEARD
ALFRED HOLZER, JR
DANA ISHERWOOD
D D JACKSON
F R KOVAR
NAI-HSIEN MAO
CAMILLE MINICHINO (3)
WILLIAM J O'CONNELL
P L PHELPS
A L RAMIREZ
L D RAMSPOTT (2)
APRIL SCARPETTI

RANDOLPH STONE
W G SUTCLIFFE
DONALD TOWSE

LEHIGH UNIVERSITY
D R SIMPSON

LOS ALAMOS SCIENTIFIC LABORATORY
K E APT
J R BRIDWELL
ERNEST A BRYANT
GEORGE A COWAN
B CROWE
BRUCE R ERDAL
A J GANCARZ
WAYNE R HANSEN
CLAUDE HERRICK
D C HOFFMAN (2)
W C LUTH
A E NORRIS
DONALD T OAKLEY
ROBERT E RIECKER
MARGARET ANNE ROGERS
JOE SMYTH
ROSEMARY J VIDALE
KURT WOLFSBERG

**LOS ALAMOS TECHNICAL ASSOCIATES
INC**
R J KINGSBURY

**LOUISIANA DEPT OF NATURAL
RESOURCES**
FRANK A ASHBY, JR

LOUISIANA GEOLOGICAL SURVEY
CHARLES S GROAT

LOUISIANA NUCLEAR ENERGY DIVISION
L HALL BOHLINGER (3)

**LOUISIANA OFFICE OF COMMERCE
AND INDUSTRY**

LOUISIANA OFFICE OF CONSERVATION
R T SUTTON

**LOUISIANA OFFICE OF SCIENCE,
TECHNOLOGY AND ENVIRONMENTAL
POLICY**

LOUISIANA OFFICE OF STATE PLANNING
LIBRARY

**LOUISIANA STATE HOUSE OF
REPRESENTATIVES**
ART SOUR

**LOUISIANA STATE SENATE COMMITTEE
ON NATURAL RESOURCES**
SAMUEL B NUNEZ, JR

LOUISIANA STATE UNIVERSITY
ROBERT L THOMS

LOUISIANA TECH UNIVERSITY
NORMAN WITRIAL

LOUISIANA TECH UNIVERSITY LIBRARY
U S REGIONAL DOCUMENTS
REPOSITORY

**LOWENSTEIN, NEWMAN, REIS, AXELRAD
& TOLL**
M BAUER

MASSACHUSETTS GOVERNOR'S OFFICE
BARRY KAPLOVITZ

**MASSACHUSETTS OFFICE OF ENERGY
RESOURCES**
PATRICK FORRESTER

**MASSACHUSETTS OFFICE OF POLICY &
MANAGEMENT ANALYSIS**
JANIS D STELLUTO

**MATERIALS RESEARCH LABORATORY
LTD**
S SINGH

MCMMASTER UNIVERSITY
ROBERT H MCNUTT

MEMBERS OF THE GENERAL PUBLIC

ROHIT AHUJA
LINDSAY AUDIN
JEFF L BARBER
BOB BISHOP
JEFFREY L BLACKFORD
DANIEL T BOATRIGHT
DAVID H BOLTZ
LINDA BOXBERGER
JAMES BOYD
LARRY BRADLEY
JERRY L CALLEN
WILLIAM E CONAWAY
CHARLES CROMWELL
CHARLES R DAVIS
H G DAVIS
CHAD DOBSON
JOHN ROGER DRAKE
JERRY L ELLIS
JAMES G FEINSTEIN
RICHARD L FOUKE
HYMER L FRIEDEL
HOWARD F GANDT
SHIRLEY M GIFFORD
CAROL GILBERT
DARYL GLAMANN
EDWIN D GOEBEL
T GREENWOOD
ALF H GRENNARD
ED HELMINSKI
CHARLES KILLGORE
JAMES A KOSTER
SCOTT KRAMER
KURT KRAUS
K K LANDES
DAVID A LEE
FRED L LOE
LOUIS MIRON
J B MUCKERHEIDE
JOHN NESBITT
CHERYL A PELHAM
J B ROBBINS - PENNIMAN

M A SABET
FRANK STEINBRUNN
KEN STOFFLET
M J SZULINSKI
CHARLOTTE J TOULOUSE
R F WALTERS
GEORGE WEHMANN
SANDRA WHEELER
RICK WINDHOLZ
A H WOPSHALL, JR

MERRA

**MICHIGAN DEPT OF NATURAL
RESOURCES**
ARTHUR E SLAUTER

MICHIGAN DEPT OF PUBLIC HEALTH
DON VAN FAROWE

MICHIGAN GOVERNOR'S OFFICE
JONATHAN CAIN
WILLIAM C TAYLOR

**MICHIGAN LEGISLATIVE OFFICE OF
SCIENCE ADVISOR**
GAIL MELSON

MICHIGAN STATE UNIVERSITY
B W WILKINSON

**MICHIGAN TECHNOLOGICAL
UNIVERSITY**
J KALLIOKOSKI

**MICHIGAN TOXIC SUBSTANCE
CONTROL COMMISSION**

**MISSISSIPPI AIR AND WATER
POLLUTION CONTROL COMMISSION**
CHARLES T BRANCH

**MISSISSIPPI DEPT OF NATURAL
RESOURCES**
CHARLES L BLALOCK

**MISSISSIPPI FUEL AND ENERGY
MANAGEMENT COMMISSION**
P T BANKSTON

**MISSISSIPPI GEOLOGICAL, ECONOMIC
AND TOPOGRAPHICAL SURVEY**
WILLIAM H MOORE

MISSISSIPPI GOVERNOR'S OFFICE
CHARLES DEATON

**MISSISSIPPI MINERAL RESOURCES
INSTITUTE**
CONRAD GAZZIER

**MISSISSIPPI MUSEUM OF NATURAL
SCIENCE**

MISSISSIPPI STATE BOARD OF HEALTH
EDDIE S FUENTE

MITRE CORPORATION
ALI GHOVANLOU

MITSUBISHI METAL CORP.
JOAN C ABENA

MOBAY CHEMICAL CORPORATION
KENNETH H HASHIMOTO

MONROE COUNTY PUBLIC LIBRARY

MONSANTO RESEARCH CORPORATION
K V GILBERT

MORRISON-KNUDSEN CO., INC.
SERGI KAMINSKY

NASA LEWIS RESEARCH CENTER
EARL C BOITEL

NASA MARSHALL SPACE FLIGHT CENTER
C C PRIEST

NATIONAL ACADEMY OF SCIENCES
JOHN POMEROY

NATIONAL ATOMIC MUSEUM
GWEN SCHREINER

NATIONAL BUREAU OF STANDARDS
RILEY M CHUNG
LEWIS H GEVANTMAN

**NATURAL RESOURCES DEFENSE
COUNCIL**
THOMAS B COCHRAN

NEFCO
JAMES T KING

**NETHERLAND SEWELL AND ASSOCIATES
INCORPORATED**
CLARENCE M NETHERLAND

**NEVADA GOVERNORS OFFICE OF
PLANNING COORDINATION**

**NEW MEXICO DEPT OF ENERGY AND
MINERALS**
ERNEST CORIZ
LAWRENCE KEHOE

**NEW MEXICO ENVIRONMENTAL
EVALUATION GROUP**
ANN BANCROFT

NEW YORK DEPT OF PUBLIC SERVICE
ROBERT D VESSELS

**NEW YORK STATE ELECTRIC & GAS
CORP**
F S DOOLITTLE

NEW YORK STATE ENERGY OFFICE
T K DE BOER (15)
JAMES L LAROCCA

NEW YORK STATE GEOLOGICAL SURVEY
JAMES F DAVIS
ROBERT H FAKUNDINY
ROBERT H FICKIES

NEW YORK UNIVERSITY MEDICAL CENTER
MERRIL EISENBUD

NORTH CAROLINA DEPT OF NATURAL AND ECONOMIC RESOURCES
STEPHEN G CONRAD

NORTH CAROLINA DEPT OF NATURAL RESOURCES & COMMUNITY DEVELOPMENT

NORTH CAROLINA PUBLIC STAFF UTILITIES COMMISSION
N S PARATE

NTR GOVERNMENT SERVICES
THOMAS V REYNOLDS

NUCLEAR ASSURANCE CORPORATION
F GARY KING
CAROL THORPU

NUCLEAR CENTER
R H THOMPSON

NUCLEAR ENERGY AGENCY
F GERA

NUCLEAR INFORMATION AND RESOURCE SERVICE
ERIC M FERSHT

NUCLEAR SAFETY ASSOCIATES INC
JOSEPH LIBERMAN
WALTON A RODGER

NUCLEAR SERVICES CORPORATION
FRANCIS J KENESHEA

NUCLEAR SYSTEMS ASSOCIATES INC

NUCLEAR WASTE WATCHERS
HELEN LETARTE

NUCLEONICS WEEK/NUCLEAR FUEL
MIKE KNAPIK

NUS CORPORATION
W G BELTER
STELLA H BREGMAN
RODNEY J DAVIS
J DI NUNNO
PETER H FELDHAUSEN
M I GOLDMAN
BRUCE D GUILBEAULT
PAT MACHLEDT
SUSAN A MURTHA
BARRY N NAFT
TERRY RITTER
DAVID E RUITER
L J STINNETT

OAK RIDGE NATIONAL LABORATORY
C F BAES
J O BLOMEKE
C CANONICO
H C CLAIBORNE
C S FORE
KATHY FORE
GEOLOGIC DISPOSAL TECHNOLOGY PROGRAM
TOM GRIZZARD
A G GROFF
R HAHN
G H JENKS
C JOHNSON
T F LOMENICK
A L LOTT
J G MOORE
M S MORAN
KARL J NOTZ
A J SHOR
E G ST CLAIR

OECD-NEA
J P OLIVIER

OHIO DEPARTMENT OF ENERGY
DENNIS P MCNAMEE

OHIO DEPT OF ENERGY
ROBERT RYAN

OHIO DEPT OF NATURAL RESOURCES
HORACE R COLLINS

OHIO POWER SITING COMMISSION
HAROLD KOHN

OHIO STATE UNIVERSITY
R N CHRISTENSEN
F UPHAM

ONTARIO HYDRO
R W BARNES
C F LEE
P P K M RAO

PACIFIC GAS AND ELECTRIC COMPANY
GENE BLANC
RAYMOND L BLUM

PARSONS, BRINCKERHOFF, QUADE, AND DOUGLAS, INC.
T R KUESEL

PB-KBB INC.
MARK E STEINER

PENNSYLVANIA STATE UNIVERSITY
J V BIGGERS
DENNIS DAVIS
WILLIAM A JESTER
GERALD L PALAU
K K S PILLAY
D M ROY
MICHAEL ZOLENSKY

PHYSIKALISCH-TECHNISCHE BUNDESANSTALT
HELMUT ROTHMEYER

POINT BEACH NUCLEAR POWER PLANT
GLENN A REED

PORTLAND GENERAL ELECTRIC
BILL BABCOCK
J W LENTSCH

POTOMAC ALLIANCE
FRED MILLAR

POWER
SHELDON D STRAUSS

POWER REACTOR AND NUCLEAR FUEL DEVELOPMENT CORPORATION

PRINCETON UNIVERSITY
HARTMUT KRUGMANN
PETER MONTAGUE
G E PINDER
WESLEY SHRUM

PROJECT REACH INCORPORATED
ROBERT BATES

PUBLIC LAW UTILITIES GROUP

PURDUE UNIVERSITY
DEAN D KNUDSEN

RALPH M PARSONS COMPANY
ALVIN E SMITH

RE/SPEC INC
G D CALLAHAN
PAUL F GNIRK
W C MCCLAIN
L C VAN SAMBEEK

RIDIHALGH, EGGERS, AND ASSOCIATES
J RIDIHALGH

ROCKWELL HANFORD OPERATIONS
H BABAD
G S BARNEY
T A CURRAN
R A DEJU
GEORGE C EVANS (2)
L R FITCH
R J GIMERA
M R KASPER
BETTY KING
KARL LARUE
C W MANRY
ROCKWELL INTERNATIONAL
MICHAEL J SMITH
K THIRUMALAI
DAVE A TURNER
P A YBARRA

ROCKWELL INTERNATIONAL
CAROL JANTZEN
LAWRENCE J SMITH

ROCKWELL INTERNATIONAL ENERGY SYSTEMS GROUP
HARRY PEARLMAN
HOWARD L RECHT

**ROGERS & ASSOCIATES ENGINEERING
CORP**

KIRK K NIELSON
ARTHUR SUTHERLAND

ROGERS AND GOLDEN

S. E. LOGAN AND ASSOCIATES

STANLEY E LOGAN

S. M. STOLLER CORPORATION

R W KUPP

SALT LAKE CITY PUBLIC LIBRARY

SAN JUAN COUNTY COMMISSION

SAN JUAN COUNTY LIBRARY

SANDIA NATIONAL LABORATORIES

G C ALLEN
C L CHRISTENSEN
DEPARTMENT 4510
DIVISION 4542
R G DOSCH
JOE A FERNANDEZ
LESLIE R HILL
THOMAS E HINKEBEIN
T O HUNTER
R M JEFFERSON
O E JONES
R E KLETT
ALLEN R LAPPIN
R LINCOLN
REGINA L LINK
R W LYNCH
MARTIN A MOLECKE
J T NEAL
E J NOWAK
RICHARD E PEPPING
G F RUDOLFO
A R SATTLER
L W SCULLY
SCOTT SINNOCK
A W SNYDER
DANIEL M TALBERT
L D TYLER
SHARLA G VANDEVENDER
W D WEART

SAVANNAH RIVER LABORATORY

J L CRANDALL
R G GARVIN
H J GROH
E J HENNELLY
F D KING
HALKARD MACKEY
I W MARINE
WILLIAM R MCDONELL
P H PERMAR
A H PETERS
W C REINIG
JOHN A STONE
S V TOPP

SCANDPOWER, INC.

PETER A MORRIS

SCIENCE APPLICATIONS INC

C W CRAVEN
RALPH FULLWOOD
LAWRENCE HARRIS, JR
RONALD HOFMANN
DEAN C KAUL
DAVID H LESTER
JOHN E MOSIER
WILLIAM R RHYNE
RICHARD W STAROSTECKI
ALFRED SUGARMAN
KRISHAN K WAHI
HOMER YOOK

SCIENCE APPLICATIONS, INC

DERMOT ROSS-BROWN

SCIENTIFIC RESEARCH & EVALUATION

RONALD C CALLEN

**SENECA COUNTY DEPARTMENT OF
HEALTH**

BRIAN DOMBROWSKI

SIERRA CLUB

DREW DIEHL
MICHAEL PAPARIAN

SIERRA CLUB - MISSISSIPPI CHAPTER

SOIL AND MATERIAL ENGINEERS, INC.

DONALD F CARTER

**SOUTH CAROLINA DIVISION OF
ENERGY RESOURCES**

LARRY LEFEBVRE
KELLY SMITH

**SOUTH DAKOTA SCHOOL OF MINES
AND TECHNOLOGY**

C J GESSNER

SOUTHERN SCIENCE APPLICATIONS INC.

K D KIRBY

**SOUTHERN TIER WEST REGIONAL
PLANNING AND DEVELOPMENT BOARD**

**SOUTHWEST RESEARCH AND
INFORMATION CENTER**

ALISON MONROE

SRI INTERNATIONAL

RONALD K WHITE

STANFORD UNIVERSITY

RONALD A HOWARD
P KRUGER

**STEARNS-ROGER ENGINEERING
COMPANY**

ARTHUR CRILL
VERYL ESCHEN
J C MATTERN

STOCK EQUIPMENT COMPANY

JAMES N SILTANEN

STONE & WEBSTER ENGINEERING CORP

J PECK
A PORT

STUDSVIK ENERGITEKNIK AB

AKE HULTGREN
ROLF SJOBLOM

SYRACUSE UNIVERSITY

J E ROBINSON

SYSTEMS SCIENCE AND SOFTWARE

PETER LAGUS

TARGET TECHNOLOGY LTD.

**TECHNICAL RESEARCH CENTRE OF
FINLAND**

SEPPO VUORI

TEKNEKRON RESEARCH, INC.

H POLHEMUS

TENNESSEE DEPT OF PUBLIC HEALTH

ROBERT H WOLLE

TENNESSEE ENERGY AUTHORITY

ED SPITZER
JACK THOMAS

TENNESSEE GOVERNOR'S OFFICE

KEEL HUNT

**TEOLLISUUDEN VOIMA OY (TVO-
POWER COMPANY)**

JUKKA-PEKKA SALO

TERRA TEK

KRISHNA SINHA
M D VOEGELE

TEXAS A & M UNIVERSITY

J HANDIN
GARY ROBBINS
JAMES E RUSSELL

**TEXAS ADVISORY COMMISSION ON
INTERGOVERNMENTAL RELATIONS**

TEXAS CHRISTIAN UNIVERSITY

JACK L WALPER

TEXAS DEPT OF HEALTH

JOE NANUS

**TEXAS ENERGY & NATURAL RESOURCES
ADVISORY COUNCIL**

GARY HAMILTON
R DANIEL SMITH

**TEXAS LIEUTENANT GOVERNOR'S
OFFICE**

CAROL TOMBARI

TRANSNUCLEAR, INC.

BILL R TEER

**TRW INCORPORATED - ENERGY
SYSTEMS GROUP**

PETER ALEXANDER
E R CHRISTIE
E MERTES

BERT N ROSENBERG

**TUN ISMAIL ATOMIC RESEARCH
CENTRE, (TIARC)**

U.K. DEPT OF ENVIRONMENT

A G DUNCAN
A F E WISE

U.S. BUREAU OF LAND MANAGEMENT

GRAND COUNTY RESOURCE AREA
SAN JUAN RESOURCE AREA

**U.S. DEPT OF AGRICULTURE -
AGRISTARS**

MICHAEL R HELFERT

U.S. DEPT OF COMMERCE

DAVID S CLIMER

**U.S. DEPT OF ENERGY - ALBUQUERQUE
OPERATIONS OFFICE**

D DAVIS
ROGER DINTAMAN
R LOWERY
JOE MCGOUGH
PUBLIC READING ROOM

**U.S. DEPT OF ENERGY - ASST GENERAL
COUNSEL FOR ENVIRONMENT**

S H GREENLEIGH

U.S. DEPT OF ENERGY - AUSTIN

**U.S. DEPT OF ENERGY - CHICAGO
OPERATIONS OFFICE**

R NACK
PUBLIC READING ROOM

**U.S. DEPT OF ENERGY - DENVER PROJECT
OFFICE**

JACK O'BRIEN
HARRY SMITH

**U.S. DEPT OF ENERGY - EDUCATIONAL
PROGRAMS DIVISION**

H H YOUNG

**U.S. DEPT OF ENERGY -
ENVIRONMENTAL AND SAFETY
ENGINEERING DIV**

WILLIAM E MOTT

**U.S. DEPT OF ENERGY - GRAND
JUNCTION OPERATIONS OFFICE**

FRANK ECKERSON
J ELLIS

**U.S. DEPT OF ENERGY - IDAHO
OPERATIONS OFFICE**

TRAVIS N BEARD
J AMRIC

D MAJUMDAR
CARL R ROBERTSON
PUBLIC READING ROOM
J WHITSETT

**U.S. DEPT OF ENERGY - MATERIALS
SCIENCE DIVISION**

R J GOTTSCHALL

**U.S. DEPT OF ENERGY - MORGANTOWN
ENERGY RESEARCH CENTER**

WILLIAM K OVERBEY, JR

**U.S. DEPT OF ENERGY - NEPA AFFAIRS
DIVISION**

ROBERT J STERN

**U.S. DEPT OF ENERGY - NEVADA
OPERATIONS OFFICE**

R O BETTERIDGE
J R BOLAND
J B COTTER
D DUNCAN
M E GATES
J R GILPIN
K N JOY
M P KUNICH
H L MELANCON
R M NELSON, JR
R W NEWMAN
A J ROBERTS
PUBLIC READING ROOM
R W TAFT
T E WADE

**U.S. DEPT OF ENERGY - NUCLEAR
ENERGY DIVISION**

J L GILBERT

**U.S. DEPT OF ENERGY - NUCLEAR
ENVIRONMENTAL APPLICATION
BRANCH**

ROBERT W BARBER

**U.S. DEPT OF ENERGY - NUCLEAR FUEL
CYCLE DIVISION**

W WADE BALLARD, JR

**U.S. DEPT OF ENERGY - NWTS PROGRAM
OFFICE**

M BARAINCA
MAXWELL BLANCHARD
L CASEY
RAM LAHOTI
J O NEFF
R SCHAAL
R WUNDERLICH

**U.S. DEPT OF ENERGY - OAK RIDGE
OPERATIONS OFFICE**

S W AHREND
DEWEY E LARGE
PUBLIC READING ROOM

**U.S. DEPT OF ENERGY - OFFICE OF
ENERGY RESEARCH**

ROGER LEGASSIE

**U.S. DEPT OF ENERGY - OFFICE OF
HEALTH & ENVIRONMENTAL RES., EV-30**

W W BURR, JR

**U.S. DEPT OF ENERGY - OFFICE OF
NUCLEAR WASTE MANAGEMENT**

DONALD H GROELSEMA
E F MASTAL
SHELDON MEYERS
A F PERGE
A G PETTIT
R G ROMATOWSKI
MURIEL SCARBOROUGH
EARL WAHLQUIST

**U.S. DEPT OF ENERGY - OFFICE OF
PLANS AND EVALUATION**

SUSAN DENNY
JOHN THEREAULT

**U.S. DEPT OF ENERGY - OFFICE OF
TRANSPORTATION AND FUEL STORAGE**

O P GORMLEY

**U.S. DEPT OF ENERGY - OFFICE OF
WASTE ISOLATION**

GLEN BOYER
C R COOLEY
WARREN EISTER
MARK W FREI
C H GEORGE
COLIN A HEATH
KEITH KLEIN
CYRUS KLINGSBERG
TOM LONGO
CARL NEWTON
H SMEDES
J SMILEY
R STEIN
D L VIETH
S WELLS

**U.S. DEPT OF ENERGY - OFFICE OF
WASTE PRODUCTS**

J C DEMPSEY
G K OERTEL
JAMES TURI

U.S. DEPT OF ENERGY - REGION I

DUANE DAY

U.S. DEPT OF ENERGY - REGION II

CHARLES BAXTER
LENORE LEDMAN

U.S. DEPT OF ENERGY - REGION III

GEORGE GORMAN

U.S. DEPT OF ENERGY - REGION IV

DAVID ALANIZ

U.S. DEPT OF ENERGY - REGION IX

PUBLIC READING ROOM
JAMES RUSSELL

U.S. DEPT OF ENERGY - REGION V

PHILLIP T ZENI

U.S. DEPT OF ENERGY - REGION VI
WILLIAM NIKOLIS

U.S. DEPT OF ENERGY - REGION VII
JAMES L MAAS

U.S. DEPT OF ENERGY - REGION VIII
JANE L C GOSNEY
SIGRID HIGDON

U.S. DEPT OF ENERGY - REGION X
LEE JOHNSON

**U.S. DEPT OF ENERGY - RICHLAND
OPERATIONS OFFICE**
T A BAUMAN
R B GORANSON (3)
PUBLIC READING ROOM
D J SQUIRES
F R STANDERFER (2)

**U.S. DEPT OF ENERGY - SAN FRANCISCO
OPERATIONS OFFICE**
C D JACKSON
JOHN MUHLESTEIN
PUBLIC READING ROOM

**U.S. DEPT OF ENERGY - SAVANNAH
RIVER OPERATIONS OFFICE**
LAWRENCE W FRY
E S GOLDBERG
T B HINDMAN
PUBLIC READING ROOM
R P WHITFIELD

U.S. DEPT OF ENERGY - SEATTLE
LIBRARY

**U.S. DEPT OF ENERGY - STATE PLANNING
COUNCIL**
JAMES VOSS

**U.S. DEPT OF ENERGY - TECHNICAL
INFORMATION CENTER (317)**

U.S. DEPT OF ENERGY - WIPP PROJECT
EUGENE BECKETT

U.S. DEPT OF ENERGY HEADQUARTERS
PUBLIC READING ROOM

U.S. DEPT OF LABOR
ALEX G SCIULLI

U.S. DEPT OF STATE
D HAFEMEISTER
R A SCRIBNER

**U.S. ENVIRONMENTAL PROTECTION
AGENCY**
A S GOLDIN
ANDREW J LETER
PETER E MCGRATH
JOHN L RUSSELL
D S SMITH

U.S. FOREST SERVICE

U.S. GENERAL ACCOUNTING OFFICE
JAMES L HOWARD

U.S. GEOLOGICAL SURVEY
ANNE E GARTNER
EUGENE H ROSEBOOM JR

**U.S. GEOLOGICAL SURVEY - BATON
ROUGE**
R L HOSMAN

U.S. GEOLOGICAL SURVEY - COLUMBUS
ALBERT M LA SALA, JR

U.S. GEOLOGICAL SURVEY - DENVER
ALBERT H BALCH
M S BEDDINGER
JEFFE CLEVELAND
WILLIAM W DUDLEY, JR
JULES FRIEDMAN
L M GARD
ROBERT J HITE
D L HOOVER
FITZHUGH T LEE
DON R MABEY
E RUSH
WILLIAM S TWENHOFEL
RICHARD WADDELL
R D WATTS
WILLIAM WILSON

U.S. GEOLOGICAL SURVEY - HOUSTON
JERRY CARR

U.S. GEOLOGICAL SURVEY - ITHACA
TODD S MILLER

U.S. GEOLOGICAL SURVEY - JACKSON
E H BOSWELL
CHARLES A SPIERS

**U.S. GEOLOGICAL SURVEY - LOS
ANGELES**
JEANI L CRICHLOW

**U.S. GEOLOGICAL SURVEY - MENLO
PARK**
F D BYERLEE
GERRY CZAMANSKE
ARTHUR H LACHENBRUCH
CAROLYN OLSON
ROBERT POTTER
JACOB RUBIN
DONALD W WHITE

**U.S. GEOLOGICAL SURVEY - PORT
TOWNSEND**
HAROLD L JAMES

U.S. GEOLOGICAL SURVEY - RESTON
PAUL B BARTON, JR
G D DEBUCHANANNE
WALTER B LANGBEIN
H WILLIAM MENARD
EDWIN ROEDDER
PETER R STEVENS
DAVID B STEWART
NEWELL J TRASK JR
E-AN ZEN

**U.S. GEOLOGICAL SURVEY
-WASHINGTON**
WILLIAM A OLIVER, JR

**U.S. HOUSE SUBCOMMITTEE ON
ENERGY AND POWER**
JOHN DINGELL

**U.S. HOUSE SUBCOMMITTEE ON
ENERGY AND THE ENVIRONMENT**
ANDREA DRAVO
MORRIS K UDALL

**U.S. HOUSE SUBCOMMITTEE ON
ENERGY AND WATER DEVELOPMENT**
TOM BEVILL
MERWYN GREER

**U.S. HOUSE SUBCOMMITTEE ON
ENERGY DEVELOPMENT AND
APPLICATIONS**
RICHARD L OTTINGER

**U.S. HOUSE SUBCOMMITTEE ON
ENERGY RESEARCH AND PRODUCTION**
JOHN P ANDELIN
JACK BAGLEY
EZRA D HEITOWIT
STEPHEN LANES
ROBERT LEACHMAN
VIVIEN LEE
MIKE MCCORMICK
ALLAN MERSE
LOUIS VENTRE

**U.S. HOUSE SUBCOMMITTEE ON
SCIENCE, RESEARCH AND TECHNOLOGY**
GEORGE E BROWN, JR

**U.S. HOUSE SUBCOMMITTEE ON SPACE,
SCIENCE AND APPLICATIONS**
DON FUQUA

**U.S. HOUSE SUBCOMMITTEE ON
TRANSP., AVIATION AND
COMMUNICATION**
THOMAS R HARKIN

U.S. NATIONAL PARK SERVICE

**U.S. NUCLEAR REGULATORY
COMMISSION**
MICHAEL BELL
LEON BERATAN
ROBERT BUDNITZ
J BUNTING
PATRICIA A COMELLA
ENRICO F CONTI
SETH M COPLAN
MICHAEL C CULLINGFORD
F L DOYLE
JAY B DURST
RALPH J JONES
CLYDE JUPITER
MALCOLM R KNAPP (3)
LINDA L LEHMAN
LIBRARY
JOHN B MARTIN (3)
CHARLES R NICHOLS

EDWARD O'DONNELL
G W ROLES
SHELDON SCHWARTZ
KEITH G STEYER
EVERETT A WICK

**U.S. SENATE APPROPRIATIONS
COMMITTEE**

J BENNETT JOHNSTON

**U.S. SENATE SUBCOMMITTEE ON
ENERGY RESEARCH AND DEVELOPMENT**

WILLIS SMITH
A LEE WALLACE, III

UHDE GMBH

D OLINGER

UNC NUCLEAR INDUSTRIES

GLEN JONES

UNION CARBIDE CORPORATION

D C KAMINSKI
B E PRINCE

UNION OF CONCERNED SCIENTISTS

LOIS TRAUB

**UNITED ENGINEERS AND
CONSTRUCTION**

DONALD GARDNER

**UNIVERSITY OF ALABAMA AT
BIRMINGHAM**

J WALTER MASON

UNIVERSITY OF ARIZONA

JAAC DAEMEN
CHARLES LYON
JAMES G MCCRAY
ROY G POST
THOMAS R SCOTSE
DAVID L SOUTH

**UNIVERSITY OF CALIFORNIA AT
BERKELEY**

NEVILLE G W COOK
D R OLANDER
THOMAS H PIGFORD
KARI SAARI

**UNIVERSITY OF CALIFORNIA AT LOS
ANGELES**

D OKRENT

**UNIVERSITY OF CALIFORNIA AT
RIVERSIDE**

SUDHIR AGGARWAL

UNIVERSITY OF DELAWARE

FRANK A KULACKI

UNIVERSITY OF FLORIDA

DAVID E CLARK

UNIVERSITY OF GEORGIA

DAVID B WENNER

UNIVERSITY OF INDIANA

J B DROSTE
HAYDN H MURRAY
CHARLES J VITALIANO

UNIVERSITY OF KANSAS

LOUIS F DELLWIG

UNIVERSITY OF LOUISVILLE

MARVIN FLEISCHMAN

UNIVERSITY OF MICHIGAN

RICHARD C PORTER

UNIVERSITY OF MINNESOTA

S L CROUCH
C M ST JOHN
D H YARDLEY

UNIVERSITY OF MISSISSIPPI

MINERAL RESOURCES INSTITUTE
VELON MINSHEW

UNIVERSITY OF MISSOURI

TRUMAN STAUFFER

**UNIVERSITY OF MISSOURI AT
COLUMBIA**

W D KELLER

UNIVERSITY OF NEW MEXICO

DOUGLAS G BROOKINS
R EWING
K KEIL

UNIVERSITY OF OKLAHOMA

KENNETH S JOHNSON

UNIVERSITY OF PITTSBURGH

B L COHEN

UNIVERSITY OF RHODE ISLAND

EDWARD P LAINE

UNIVERSITY OF SOUTHERN MISSISSIPPI

OSCAR L PAULSON JR

**UNIVERSITY OF TENNESSEE AT
KNOXVILLE**

J B FUSSELL

UNIVERSITY OF TEXAS AT AUSTIN

L F BROWN
S J DUTTON
T C GUSTAVSON

C R HANDFORD

E C JONAS
JOE D LEDBETTER
M W PRESLEY

UNIVERSITY OF UTAH

GARY M SANDQUIST

**UNIVERSITY OF UTAH RESEARCH
INSTITUTE**

DUNCAN FOLEY
HOWARD P ROSS

UNIVERSITY OF WASHINGTON

M A ROBKIN

**UTAH ADVISORY COUNCIL ON SCIENCE
AND TECHNOLOGY**

JAMES W BUNGER

**UTAH GEOLOGICAL AND
MINERALOGICAL SURVEY**

DONALD T MCMILLAN (2)

UTAH STATE PLANNING OFFICE

KENT BRIGGS

UTAH STATE UNIVERSITY

JAY C ANDERSON

WOODWARD-CLYDE CONSULTANTS

F R CONWELL (2)
HANS M EWOLDSSEN
ASHOK PATWARDHAN
CHARLES L TAYLOR
WESTERN REGION

WP-SYSTEM AB

IVAR SAGEFORS

WYLE LABORATORIES

SCIENTIFIC SERV & SYSTEMS GROUP

WYOMING GEOLOGICAL SURVEY

DANIEL N MILLER

XEROX PALO ALTO RESEARCH CENTER

L CHARLES HEBEL

ZIDAX INTERNATIONAL

A D BARANYI