QA: L

Civilian Radioactive Waste Management System
Management & Operating Contractor

License Application Design Selection
Enhanced Design Alternative V: Very High Thermal Loading

B00000000-01717-2200-00224 REV 00

June 1999

Prepared for:

U.S. Department of Energy
Yucca Mountain Site Characterization Office
P.O. Box 30307
North Las Vegas, Nevada 89036-0307

Prepared by:

TRW Environmental Safety Systems, Inc.
1261 Town Center Drive
Las Vegas, Nevada 89134

Under Contract Number
DE-AC08-91RW00134

Civilian Radioactive Waste Management System
Management & Operating Contractor

License Application Design Selection
Enhanced Design Alternative V: Very High Thermal Loading

B00000000-01717-2200-00224 REV 00

Prepared By:

C.L. Linden
Repository Subsurface Design

6/22/99
Date

Checked By:

C.R. Gorrell
Product Checking Group

06/22/99
Date

Approved By:

D.G. McKenzie III – Responsible Manager
Repository Subsurface Design

6/22/99
Date

EXECUTIVE SUMMARY

The major goals of Enhanced Design Alternative (EDA) V are to keep the temperature of the cladding on the spent nuclear fuel (SNF) within the waste package below 350°C (Section 4.2.3), the temperature of the emplacement drift walls below 225°C (Section 4.2.3), and to keep the emplacement drifts dry for several thousand years. In addition, the design would produce relatively consistent heat output from waste package to waste package and ensure that waste package thermal outputs are spread more evenly across the repository. The design would also provide defense in depth (Section 5.3). The goals of this design would be achieved by the combination of design features described below.

This EDA would have an areal mass loading (AML) of 150 metric tons of uranium equivalent (MTU) per acre (Section 4.1.16) as opposed to the 85 MTU/acre in the Viability Assessment (VA) reference design. To achieve this loading and the elements necessary to the EDA's overall goals, the design would require approximately 420 acres of emplacement area, within the lower repository block (Appendix A, Section A.2).

A conceptual layout was developed for EDA V (Section 5.4.3). The layout, as shown in Figure 2, contains openings that are sized and arranged in a similar configuration as the VA reference design. A total of 54 emplacement drifts will be required for emplacement of the 70,000 MTU of spent nuclear fuel and high level waste packages. A total of four ventilation shafts, one intake and three exhausts are anticipated for the layout in order to provide sufficient air quantities to the emplacement drifts. Two exhaust mains will be located below the level of the emplacement drifts to provide exhaust from the emplacement drifts.

In addition, the evaluation has confirmed that the decision to close the repository is possible 50 years after start of emplacement (Section 5.7.5). The licensing and preclosure period encompassed by the Mined Geologic Repository (MGR) extends from the year 2002 through 2066 (Section 6.2.2). This schedule is based on the VA reference design schedule with the monitoring period shortened such that the total preclosure period from the start of emplacement is 50 years.

The spent nuclear fuel (SNF) would be blended to produce a targeted average and maximum thermal load. That is, the waste would be specifically sorted according to its type, heat output, and age and then put into packages with other similarly selected waste for the purpose of controlling the heat output of each waste package (WP). Blending would be done to create an average pressurized water reactor (PWR) heat output per waste package of 9.8 kW and a maximum of 11.8 kW. With blending, the heat output from the different waste packages is more consistent from package to package, thus resulting in a more nearly uniform linear heat-generation rate in the drift and from drift to drift for the repository as a whole. This will possibly reduce the waste package cladding temperatures for the hottest waste packages. The inclusion of waste blending in the EDA V conceptual design may increase the amount of surface waste handling and will also increase costs due to an addition of approximately 3,750 MTU of surface storage (Section 5.5).

The waste package itself, a single corrosion resistant material (CRM) package, would have an interior cylindrical shell of stainless steel (Section 5.5.2). This interior shell would be interference-fitted to an exterior cylindrical shell made of corrosion-resistant, high-nickel alloy, A22. The EDA V waste package from a thermal perspective is based on the 21-PWR waste package, but there are waste packages for boiling water reactor (BWR), defense high-level waste glass and U.S. Department of Energy (DOE) waste forms to be emplaced as well. The WP should allow the structure to maintain its function much longer than for the VA reference design, due to the corrosion resistance of the outer shell.

The waste packages would be emplaced according to the line-loading method. With line loading, the waste packages are almost touching (10 cm apart), so that the packages approach thermal equilibrium with one another, evening out the temperature profile along the drift (Section 5.4.1). Line loading, while efficient in its use of drift space, produces a higher drift temperature than point loading does. However, the thermal load of the repository can be maintained by spacing the drifts further apart. The local thermal load, must, of necessity, increase and this is most important to the thermal performance over the first few decades after repository closure. In this design, the drifts, themselves 5.5 meters in diameter (Section 5.4.1), would be spaced 32 meters apart (center point to center point) (Appendix A, Section A.1.2), as opposed to the 28 meter spacing of the VA reference design. Combined with blending, this spacing of the drifts would help to accomplish the thermal goals detailed above, but the design would also require preclosure ventilation to maintain those goals.

Following emplacement of waste packages into a drift, the drift would be ventilated until closure of the repository (Section 5.8). Fans, ventilation regulators, and excavated main drifts, shafts and/or ramps, which are shown in the layout (Figure 2) and used for cost estimating (Section 6.2.1) in this report would deliver approximately two to five cubic meters per second of air to the emplacement drifts containing waste packages. Thermal calculations indicate that additional ventilation, up to 10 cubic meters per second, could contribute to performance. This continuous ventilation would aid in reducing air and drift temperatures. It is anticipated that the host rock would remain drier and cooler during the preclosure phase as compared with a repository without ventilation. This preclosure ventilation would help keep the waste packages and drift walls cooler, and is a part of the overall strategy to meet the thermal requirements (Section 5.7).

Just prior to closure of the repository, a drip shield would be placed over each waste package (Section 5.3). The drip shield would resemble a "mail-box" design with overlapping sections and would rest on the invert, with no contact with the waste package itself. The drip shield's purpose is to divert water away from the waste package, protecting the entire length of the waste package as well as its ends. Because the drip shield would be made of grade 7 Titanium (2-cm thick), it would help to avoid common mode corrosion failures with the waste package, potentially increasing the defense in depth.

The evaluation of EDA V has shown that the design goal of keeping the temperature of the drift wall below 225°C (Section 4.2.3) can be met (Section 5.7.5). The goal of keeping the temperature of the waste package cladding below 350°C (Section 4.2.3) has not been confirmed in this document, but is anticipated to be met. Further analysis would be required if EDA V were to develop beyond the conceptual stage.

Based on the preliminary, central estimate, performance assessment, the safety margin for EDA V is 24.98 mrem per year (Section 6.1.1). The peak dose rate within 10,000 years is 0.02 mrem per year at approximately 7,000 years after closure. The peak dose rate within 1 million years is 200 mrem per year at 720,000 years. It would take approximately 300,000 years to reach the screening dose rate of 25 mrem per year.

Within the first 10,000 years, parts of the repository environment could have aggressive corrosion conditions for a relatively long period of time (Section 6.1.2.3). Calculations have indicated that the waste package temperatures do not cool to below 100°C until after 3,000 years and the relative humidity has increased to greater than 80% within less than 1,000 years. This temperature and humidity profile may lead to localized corrosion on some of the waste packages in the aggressive environment, which introduces uncertainties in the post-closure function. A corrosive environment could be detrimental to both waste isolation and public and environmental safety. These conditions also indicate that EDA V has not met the design goal of keeping the drifts dry for several thousand years because relative humidity returned to greater than 80% within less than 1,000 years. Further studies would be required if EDA V progresses beyond the conceptual stage.

In regards to licensing and regulatory issues, the uncertainties of the post-closure functions (Section 6.1.2.3) could present complexities that may be difficult to overcome. Specifically, it would be difficult to demonstrate the post-closure objective to drive water off for the length of time anticipated and needed to establish complete pillar dry out.

Enhanced Design Alternative V provides defense in depth (Section 6.1.3) including an enhancement of the natural barriers by relocating the repository to the Lower Block, the inclusion of a drip shield, modification to the waste package construction, and the concept of high thermal loading. The number of defense in depth layers indicated make it unlikely that radioactive waste can be transported away from the repository within a 10,000-year time frame.

No unusual issues were identified for the construction, operations, and maintenance for the EDA V conceptual design (Section 6.3). The flexibility of EDA V is demonstrated in the concept's ability to accommodate an increased capacity, if so authorized (Section 6.4.1). EDA V is less flexible in regards to shortening the preclosure period to less than 50 years (Section 6.4.2.2) and accepting younger fuel, such as five year old fuel (Section 6.4.3.1). These types of design changes could lead to potential problems with maintaining the waste package cladding temperature in these situations.

Enhanced Design Alternative V does show some flexibility in regards to late design changes (Section 6.4.4). The layout and design would have to change, but some of the analyses could be simplified by using lower temperature profiles in the emplacement drift.

The total cost estimate for EDA V was based upon design element details provided that affect the MGR subsurface, surface, waste package, and engineered barrier related costs (Section 6.2.1). The total life cycle cost for EDA V is $20.0 billion with a net present value of $10.8 billion.

CONTENTS

CONTENTS (Continued)

Page

CONTENTS (Continued)

Page

CONTENTS (Continued)

Page

CONTENTS (Continued)

Page

FIGURES

Page

TABLES

1. INTRODUCTION

The objective of this technical report is to provide the information needed for the License Application Design Selection (LADS). The LADS Group will evaluate Enhanced Design Alternative (EDA) V, Very High Thermal Loading (CRWMS M&O 1999a, pp. 14 to 16 of 16), with respect to the LADS Phase II Evaluation Criteria (CRWMS M&O 1999c). The goals for this EDA are as follows:

- Maintain the waste package (WP) cladding below 350°C,
- Maintain the drift wall temperature below 225°C, and
- Keep the emplacement drift walls dry for several thousand years. This would be accomplished by:
  - Avoiding warm and moist conditions in the emplacement drifts, and
  - Establishing complete pillar dry out. (The pillar is defined as the rock remaining between the emplacement drifts.)

The scope of this document will develop the technical basis for the LADS Group evaluation of EDA V against the LADS Phase II Evaluation Criteria (CRWMS M&O 1999c) by providing information for the following discussions.

- Enhanced Design Alternative Description
  - Initial Concept Parameters
  - Design Elements
  - Conceptual Repository Layout
  - Waste Package Design
  - Thermal Evaluation
- Safety/License Probability
- Cost and Schedule
- Construction, Operations, and Maintenance
- Design Flexibility

2. QUALITY ASSURANCE

This technical document activity has been evaluated (CRWMS M&O 1998d) in accordance with QAP-2-0, *Conduct of Activities*, and has been determined to be subject to the requirements of the *Quality Assurance Requirements and Description* (QARD) (DOE 1998a). *The Classification of Permanent Items*, QAP-2-3, evaluation entitled *Classification of the Preliminary MGDS Repository Design* has identified features (such as waste packages and drip shields) of this analysis as important to radiological safety and waste isolation (CRWMS M&O 1999r). This document was prepared in accordance with QAP-3-5, *Development of Technical Documents* and the Technical Document Preparation Plan (CRWMS M&O 1999d) and is subject to quality assurance (QA) controls which will be documented in accordance with NLP-3-18, *Documentation of QA Controls on Drawings, Specifications, Design Analysis, and Technical Documents*. It has been determined that NLP-2-0, *Determination of Importance*, is not applicable since the technical document does not include field activities.

3. METHOD/DESCRIPTION OF SOFTWARE USED

3.1 METHOD

The analytical method was used to develop a conceptual layout for EDA V based on engineering parameters, criteria, and assumptions. Thermal evaluations of the EDA were reviewed and summarized to propose a preclosure ventilation rate and to demonstrate conformance with the goals of this EDA. This document provides discussion to develop a technical basis for the LADS Group evaluation of EDA V against the LADS Phase II Evaluation Criteria (CRWMS M&O 1999c). Conclusions are drawn about the ability of EDA V to enhance repository performance. The Viability Assessment (VA) reference design will be referred to, as needed, to highlight differences between it and EDA V.

3.2 COMPUTER SOFTWARE USE

Lynx and Vulcan software was used to produce this report as described below.

3.2.1 Lynx Software

The geology for EDA V was modeled on a Silicon Graphics Octane Workstation with a Unix Operating System (CPU# 115721) using the Lynx Geoscience Modeling software (LYNX), Version 4.5. This software was qualified in 1997 and is identified by Computer Software Configuration Item (CSCI) number 30016 V4.5 (CRWMS M&O 1997c). The software was originally acquired to specifically perform this type of work and was qualified with that intent in mind. The software is appropriate for its application to this engineering calculation, was not used outside the range of validation, and was obtained from Software Configuration Management, in accordance with appropriate procedures.

3.2.2 Vulcan Software

The conceptual layout for EDA V (CRWMS M&O 1999o) was developed on the Vulcan Software. Vulcan Version 3.3 (TBV) is an unqualified software program. This software was run on a Silicon Graphics Indigo 2 computer system (CPU# 700592) with a Unix operating system. Since this software is unqualified, the layout is considered TBV and is not to be used to support construction, fabrication, or procurement. The software was originally acquired to specifically perform this type of work and the software is appropriate for its application to this engineering calculation.

4. INPUTS

All inputs used in this alternative evaluation are documented in the following sections. Due to the preliminary and conceptual nature of the evaluation, unverified and unqualified engineering parameters, criteria and assumptions are identified and designated as TBV or TBD, but will not be tracked, in accordance with NLP-3-15, *To Be Verified (TBV) and To Be Determined (TBD) Monitoring System.*

4.1 PARAMETERS

A list of parameters and their sources are provided in this section.

4.1.1 Waste Package Types and Quantities for Non-VA Assumptions

Table 1 outlines the blended waste package types and the quantities (TBV), for non-VA assumptions that were used to determine emplacement capacity, as directed by management. This information is based on CRWMS M&O (1999y, p. IX-32) and is used in Appendix A.

Table 1. Waste Package Types and Quantities for Non-VA Assumptions

Waste Package Type		Number of Waste Packages
21-PWR	No Absorber	1,638
	Absorber Plates	2,673
	Control Rods	121
12-PWR	Long	150
44-BWR	No Absorber	696
	Absorber Plates	2,107
24 BWR	Thick Plates	42
5-DHLW		1,249
5-DHLW	Long	414
Navy	Combined	285
DOE/Other		598
Total CSNF (Commercial Spent Nuclear Fuel)		7,427
Total HLW (High Level Waste)		2,546
TOTAL		9,973

4.1.2 VA Reference Design Waste Package Lengths

The VA reference design waste package utilizes two concentric barrier layers (TBV): a 10-cm-thick outer less corrosion resistant ASTM A-516 carbon steel Corrosion-Allowance Material (CAM) and an inner 2-cm-thick nickel-base Alloy 22 CRM. This information is based on CRWMS M&O (1999i, pp.1 and 12) and used in Section 5.5.2. Table 2 outlines the WP lengths (TBV) and is based on CRWMS M&O (1998a, p.3) and used in Appendix A.

Table 2. VA Reference Design Waste Package Lengths

Waste Package Type		Referenced WP Type	Length (m)
21-PWR	No Absorber	21-PWR – No Absorber	5.335
	Absorber Plates	21-PWR – Absorber Plates	5.335
	Control Rods	21-PWR – Absorber Rods, No Absorber Plates	5.335
12-PWR	Long	12-PWR – Absorber Plates - Long	5.871
44-BWR	No Absorber	44-BWR – No Absorber	5.335
	Absorber Plates	44-BWR – Absorber Plates	5.335
24 BWR	Thick Plates	24-BWR – Thick Absorber Plates	5.335
5-DHLW		5-HLW/DOE Spent Fuel	3.790
5-DHLW	Long	5-HLW/DOE Spent Fuel - Long	5.367
Navy	Combined	Navy – short and long (See Note[1])	5.848
DOE/Other		DOE/Other (See Note[2])	5.530

Note: [1] This WP type has been assigned the average length of the short and long Navy WPs.
[2] This WP type has been assigned the dimension of the Naval Fuel – Canistered – Short.

4.1.3 Single CRM Waste Package Quantities and Lengths

The EDA V blended waste package will be a single CRM WP, constructed with an interior cylindrical shell of 5-cm-thick stainless steel (CRWMS M&O 1999u, p. 20, Table 6.1-4). This interior shell will be interference fitted to an exterior cylindrical shell made of Alloy 22. Each waste package would be large enough to accommodate 21 spent nuclear fuel assemblies of the standard type used in pressurized water reactors (PWRs). Table 3 outlines the waste package lengths (TBV) for the single CRM waste package design based on the configuration of the exterior barrier and the number of waste packages based on VA assumptions (TBV). This number of waste packages is based on CRWMS M&O (1999y, p. IX-31). The waste package lengths are based on CRWMS M&O (1999b, Item 1, p.3, Table 2) and used in Appendix A. This information was updated in CRWMS M&O (1999y, pp. IX-31 and IX-32), and as a result, the waste package lengths are slightly different. Minimal impact is expected due to the change in WP lengths, however, contingency is already built into the design for EDA V.

Table 3. Waste Package Types and Quantities for VA Assumptions

Waste Package Type		Number of Waste Packages	Waste Package Length (m)
21-PWR	No Absorber	1,648	5.275
	Absorber Plates	2,683	5.275
	Control Rods	132	5.275
12-PWR	Long	155	5.781
44-BWR	No Absorber	707	5.275
	Absorber Plates	2,119	5.275
24 BWR	Thick Plates	49	5.225
5-DHLW		1,249	3.730
5-DHLW	Long	414	5.367
Navy	Combined	285	5.878[1]
DOE/Other		598	5.560
Total CSNF		7,493	
Total HLW		2,546	
TOTAL		10,039	

General Note: These WP types, lengths and quantities are used in an impact analysis in Appendix A.

Note : [1] The Navy combined WP type is based on the average of the Naval Fuel Short and Naval Fuel Long WP types.

4.1.4 Emplacement Method and Waste Package Spacing

The waste packages will be line-loaded in the emplacement drifts with a constant spacing or gap of 0.1 meter (TBV). This information is based on CRWMS M&O (1999a, p.15 of 16) and used in Section 6.4.1 and Appendix A.

4.1.5 Preclosure Period

A preclosure period of 50 years (TBV) will be incorporated into the conceptual design of EDA V (CRWMS M&O 1999a, Tables of EDAs). This information is based on a LADS Group decision and is used in Sections 5.2, and 6.3.2.

4.1.6 Increased Disposal Capacity Scenarios

Two scenarios are evaluated for increased capacity of the repository. These scenarios (TBV), as outlined in Table 4 include additional quantities of commercial spent nuclear fuel (CSNF), and high-level waste and defense spent nuclear fuel (HLW/DSNF). This information is based on the references listed in Table 4, and is used in Section 6.4.1.

Table 4. Increased Disposal Capacity Scenarios

Waste Type	Scenario 1	Scenario 2	Reference
CSNF	87,000 MTU	105,000 MTU	CRWMS M&O 1997b, p.ix
HLW/DSNF	23,270 canisters	23,270 canisters	CRWMS M&O 1997b, p.xii

4.1.7 Surface Blending

Managerial decision has indicated that up to 3,750 MTU of surface storage is required for CSNF blending. This assumption is based on CRWMS M&O (1999x, Item 1, p. 3) and used in Section 5.5.

4.1.8 Lower Block Acreage

The Lower Block as identified in CRWMS M&O (1999e, p.10), covers about 760 acres (TBV). This information is used in Section 6.4.1.

4.1.9 Upper Block Acreage

The VA reference design uses about 747 acres (TBV) of the Upper Block. This information is based on CRWMS M&O (1997a, Attachment I, p.2) and is used in Sections 6.4.1 and 6.4.4.2.

4.1.10 Drift Diameter

The excavated emplacement drift diameter will be 5.5 meters (TBV). This information is based on CRWMS M&O (1997a, p.73) and used in Sections 5.2 and 5.4.1.

4.1.11 Reserved.

4.1.12 Location of the Lower Block

The proposed emplacement area for EDA V is located within the lower block and the repository host horizon as defined in CRWMS M&O (1999e, Figure 1, p.7). The lower block lies east of the current upper repository block and extends from Pagany Wash fault in the north to the Dune Wash fault area in the south. On the east it is defined by the Imbricate fault system and on the west by the Ghost Dance fault and upper repository block. This area is at the same dip as the upper repository block, but is 73 meters lower in elevation (TBV). This information is based on CRWMS M&O (1999e, p.10) and is used in Section 5.4.2.

4.1.13 Preliminary Thermal Evaluations

Preliminary two dimensional (2-D), ANSYS thermal analysis produced results for various combinations of aging, preclosure ventilation and preclosure periods. The results of the thermal analysis (TBV) are presented in Table 5 and illustrated in Figures 4 through 9 in Section 5.7. These results are based on CRWMS M&O (1999f, pp. IV-22 to IV-27) and used in Section 5.7.

Table 5. Preliminary Thermal Evaluations

Description of Case	Peak Temperatures						Reference
	WP Surface		Drift Wall		Middle of Pillar		
	°C	Time[1]	°C	Time[1]	°C	Time[1]	
Case 1, 25 years aging and 25 years of ventilation at 10 m^3/s	204	134	202	463	183	827	CRWMS M&O 1999f, p.IV-22
Case 2, 25 years aging and 50 years of ventilation at 10 m^3/s	194	524	193	574	177	1,288	CRWMS M&O 1999f, p.IV-23
Case 3, 25 years aging and 75 years of ventilation at 10 m^3/s	186	665	185	675	172	1,388	CRWMS M&O 1999f, p.IV-24
Case 4, no aging and 100 years of ventilation at 10 m^3/s	189	648	188	657	174	1,363	CRWMS M&O 1999f, p.IV-25
Case 5, 25 years aging and 75 years of ventilation at 2 m^3/s	198	494	196	524	179	800	CRWMS M&O 1999f, p.IV-26
Case 6, one year ventilation disruption with 25 years aging and 75 years of ventilation at 10 m^3/s	130	40[2]	120	40[2]	64	40[2]	CRWMS M&O 1999f, p.IV-27
Case 6, one month ventilation disruption with 25 years aging and 75 years of ventilation at 10 m^3/s	104	60[2]	94	60[2]	64	60[2]	CRWMS M&O 1999f, p.IV-27

Note - [1] Refers to time start of emplacement (in years).
[2] These times have been approximated.

4.1.14 Post-Closure Performance

The peak dose rates (TBV) for the overall repository performance were calculated. The peak dose rate within 10,000 years is approximately 0.02 mrem per year at approximately 7,250 years (approximately 7,000 years rounded to the nearest 1,000 years) after closure (CRWMS M&O 1999j, p.14, EDA-V). The peak dose rate within 1 million years is approximately 200 mrem per year at approximately 720,000 years (CRWMS M&O 1999j, p.15, EDA-V). The time at which the 25 mrem per year regulatory standard is reach is 320,000 years (approximately 300,000 years rounded to the nearest 100,000 years). This information is used in Section 6.1.1.

The dose rates with a defense in depth (DID) neutralization (TBV) was also provided. The DID neutralization is a modeling term which indicates that the WP CRM was disregarded in the dose rate calculations. The peak dose rate with the waste package neutralized within 10,000 years is approximately 150 mrem per year at approximately 7,000 years after closure (CRWMS M&O 1999j, p.14, EDA-V, no WP). The peak dose rate with the waste package neutralized within 1 million years is approximately 1,500 mrem per year at approximately 310,000 years (CRWMS M&O 1999j, p.15, EDA-V, no WP). This information is used in Section 6.1.3.

4.1.15 Post-Closure Environment

Aggressive conditions are anticipated for parts of the repository environment for a relatively long time. Calculations have indicated that the waste package temperatures do not cool to below 100°C until after 3,000 years (TBV) (CRWMS M&O 1999h, Item 5, p.29) and the relative humidity has increased to greater than 80% within less than 1,000 years (TBV) (CRWMS M&O 1999h, Item 5, p.30). This information is used in Section 6.1.2.3.

4.1.16 Initial Concept Parameters for the Design of EDA V

The LADS Group proposed a set of design parameters (TBV) as guidance for the development of EDA V (CRWMS M&O 1999a, pp. 14 to 16 of 16), which were subsequently revised. These parameters are outlined in Table 6 and used in Section 5.1.

Table 6. Initial Concept Parameters

Parameter Description	Parameter
AML (MTU/acre)	150
Area (acres)	420
Line/Pt Load	Line Loading
WP Size (PWR)	21
Rod Consolidation	Yes (42)
Drift Diameter (m)	5.5
Drift Spacing (m)	40.0
Aging/Preclosure Ventilation	25/25
After Aging and Blending: max, avg.	17.0 kW 11.4 kW
WP Material	Carbon steel interior and high nickel alloy exterior.
Backfill	No
Drip Shield	Ti-7, 2 cm thick
CSNF WPs/Total WPs	3,704/6,562

4.1.17 Thermal Evaluation of Initial Design Concept

A 2-D ANSYS thermal evaluation for EDA V using the initial design parameters indicated by the LADS Group (Section 4.1.16) was completed (CRWMS M&O 1999n, pp. 9 and 10). This scoping study indicated that both the emplacement drift wall peak temperature and the waste package surface peak temperature would be in excess of 440°C (TBV). This information is used in Section 5.1.

4.1.18 Costs for EDA V

All cost data presented, in Table 7, are not subject to QARD (DOE 1998a) requirements. Costs are presented in constant 1998 dollars (TBV) (CRWMS M&O 1999m, p.15). The total cost estimates were prepared for this EDA (ventilated for 50 years with a flow rate of 2 cubic meters per second) based upon design element details provided that affect the Mined Geologic Repository (MGR) subsurface, surface, waste package, and engineered barrier related costs (CRWMS M&O 1999m, p.5, 9, and 15). These cost figures are used in Section 6.2.1.

Table 7. Cost Estimate Summary

Phase	Life Cycle Costs ($Billions)	Net Present Value ($Billions)
Licensing Period (2002 – 2005)	0.8	0.7
Construction Period (2005 – 2010)	3.1	2.5
Emplacement Operations Period (2010 – 2033)	10.7	6.2
Monitoring Period (2033 – 2060)	1.6	0.6
Closure and Decommissioning Period (2060 – 2066)	3.7	0.9
Grand Total	20.0	10.8

4.2 CRITERIA

Criteria that are directly applicable to this report are provided in this section.

4.2.1 Statutory Limit

The proposed repository layout will incorporate the statutory limit of 70,000 metric tons of uranium or heavy metal equivalent (MTU). This information is based on CRWMS M&O (1998c, p.6) and used in Section 7

4.2.2 Maximum Gradient

A maximum gradient of 3% is required for access mains, ramps, emplacement drifts, and turnout grades. This information is based on CRWMS M&O (1998c, p.12) and used in Section 5.4.3.

4.2.3 Thermal Goals

The thermal goals for EDA V are to keep the emplacement drift wall temperature below 225°C (TBV) and the waste package cladding temperature below 350°C (TBV). Both thermal goals will require additional study for confirmation, if EDA V progresses beyond the conceptual stage. This information is based on CRWMS M&O (1999a, p. 14 of 16) and used in Section 5.7.

4.3 ASSUMPTIONS

Assumptions made to perform this study, along with a basis for the assumptions are documented in this section.

4.3.1 Reserved.

4.3.2 Standoff Distances

The following standoff distances (CRWMS M&O 1997a, Attachment I, p.1) will be used in Appendix A:

Thermal/Radiological – A standoff distance of 15 meters (TBV) will be used from the doors on both the east and west side of the emplacement drifts. For simplification of calculations at this conceptual stage, this standoff distance is considered adequate to account for both a standoff distance to limit the surface rock temperature of the adjacent main drifts and for limiting the radiation dose rates in the adjacent main drift. This distance should be adequate for thermal considerations since during the preclosure period, ventilation will keep in-drift temperatures significantly lower than in the VA reference design. This distance already exceeds the radiological standoff distance used in the VA reference design.

Physical – A standoff distance of 4 meters (TBV) will be used in all emplacement drifts to account for the central ventilation raise, based on the VA reference design

4.3.3 Empty Emplacement Drifts

A certain number of drifts will be left empty during emplacement operations (TBV). Some of the empty drifts will be cross-block drifts for ventilation, monitoring, emergency egress, and/or performance confirmation. These drifts will be located to split the block into similar sized areas. Other empty drifts will be emplacement stand-by drifts for possible re-location of emplaced waste packages. In the proposed repository layout, there are three cross-block drifts located at emplacement drifts 18, 36, and 54. For this report, the stand-by drifts are located at emplacement drifts 52 and 53 with the understanding that the locations may change due to operational logistics. This assumption is used in Appendix A.

4.3.4 No Concrete Lining or Invert in Emplacement Drifts

There will be no concrete lining or concrete invert in the emplacement drifts (TBV). The decision of not using concrete products in the emplacement drifts is a managerial decision. A metal invert with ballast material will be used in place of the concrete invert. Rock bolts and mesh will be used for ground support in the emplacement drifts. The drift invert will be of steel construction with a sand ballast material (fill). This information is used in Section 5.6.

4.3.5 Mined Geologic Repository Schedule

The schedule for the Mined Geologic Repository (MGR) will extend from 2002 to 2066 (TBV) and is outlined in Table 8. This assumption is based on the MGR-VA schedule (DOE 1998b, p.2-1), with the preclosure period shortened to 50 years (Section 4.1.5), indicating a completion date for Decommissioning and Closure of 2066. The project will evolve through five different phases, and the schedule for each phase is outlined below. It is anticipated that the construction of the facility can be accommodated in the same time frame as that indicated by the MGR-VA schedule. This assumption is used in Section 6.2.2.

Table 8. Schedule for the MGR for EDA V

Phase	Start Date	Completion Date	Approximate Time Period
Licensing	March 2002	February 2005	3 years
Pre-Emplacement Construction	March 2005	February 2010	5 years
Emplacement Operations	March 2010	September 2033	23.5 years
Monitoring	October 2033	February 2060	26.5 years
Closure and Decommissioning	March 2060	September 2066	6.5 years

4.3.6 Commercial Spent Nuclear Fuel

The commercial SNF disposed in this scenario will total 63,000 MTU (TBV), based on CRWMS M&O (1998b, Key 003). This assumption is used in Section 6.4.1 and Appendix A

4.3.7 Openings

The openings within the proposed repository layout, with exception to the shafts, shall be sized and arranged in a similar configuration as the VA reference design (TBV). This information is based on CRWMS M&O (1997a, p.33) and used in Section 5.4.3.

4.4 CODES AND STANDARDS

No codes or standards were used in the preparation of this report.

5. ENHANCED DESIGN ALTERNATIVE CONCEPTUAL DESIGN

The EDAs were developed as part of the LADS activity and represent the consensus of the LADS Group. The LADS Group selected the concepts after evaluating a series of feature and alternative reports and a preliminary screening of design alternatives provided by three concept teams. The three teams proposed alternative designs grouped into the categories of low temperature, high temperature, and enhanced access.

An evaluation of a higher thermal loading design was completed as part of LADS Phase I. This Phase I report incorporated an averaged non-uniform areal mass loading of 109 MTU/acre (CRWMS M&O 1999v, p. ii). The EDA V conceptual design significantly deviates from this previous study, although the concept of a hot repository is consistent.

The development and evaluation for EDA V will be the focus of this technical document. EDA V is categorized as a very high thermal loading option. The purpose of this alternative design is to drive water away from the Engineered Barrier System (EBS) and the WP for as long as practicable; to avoid extended periods of warm, moist conditions; and to establish complete pillar dry out. The major goals of EDA V are to keep the temperature of the cladding on the spent nuclear fuel (SNF) below 350°C, the temperature of the drift walls below 225°C (Section 4.2.3), and to keep the drifts dry for several thousand years. With blending, the heat output from the different waste packages is more consistent from package to package, thus results in a more nearly uniform linear heat-generation rate in the drift and from drift to drift for the repository as a whole. This will possibly reduce the waste package cladding temperatures for the hottest waste packages. The design would also provide defense in depth.

5.1 INITIAL CONCEPT PARAMETERS

The LADS Group outlined initial concept parameters for EDA V (Section 4.1.16) as listed in Table 6. An initial thermal evaluation was performed (CRWMS M&O 1999n, pp. 9 and 10) using the initial parameters to determine the viability of the concept. The temperature history for EDA V as originally defined (i.e., with a factor-of-two rod consolidation) was produced.

As originally defined for EDA V, the emplacement drift wall temperature and waste package surface temperature, both in excess of 440°C (Section 4.1.17), violates the goal to keep the temperature of the emplacement drift walls below 225°C (Section 4.2.3).

As a result of these initial findings, it was determined that EDA V needed to deviate substantially from the original design elements proposed by the LADS Group. Specifically, removal of the factor-of-two rod consolidation was the main contributing factor of exceeding the thermal goals (Section 4.2.3). The following section (Section 5.2) outlines the design elements incorporated into the conceptual design for EDA V and Section 5.7 outlines the conformance of these design elements with the thermal goals.

5.2 DESIGN ELEMENTS

The final conceptual design for EDA V incorporates an areal mass loading (AML) of 150 metric tons of uranium equivalent (MTU) per acre. To achieve this loading and the elements necessary to achieve the alternatives overall goals, the design would require approximately 420 acres (Appendix A, Section A.2) of emplacement area, within the lower repository block (Section 4.1.12). The design elements are summarized in Table 9.

Table 9. Summary of Design Elements

Description	Detail
Areal Mass Loading (AML), MTU/acre	150 for commercial SNF only (Section 4.1.16)
Area, acres	420, within the Lower Block (Appendix A, Section A.2)
Line/Point Loading	Line Loading (Section 4.1.4)
Waste Package Size, PWR	21 (Section 4.1.3)
Drift Diameter, meters	5.5 (Section 4.1.10)
Drift Spacing	32 (Appendix A, Section A.1.2)
Preclosure Ventilation, years	50 (Section 4.1.5)
PWR Thermal Output maximum/average, kW [1]	11.8 maximum, 9.8 average CRWMS M&O 1999l, Item 1, p.2
Waste Package Material	Single CRM (Section 4.1.3)
Drip Shield	Ti-7, 2 cm thick (Section 4.1.16)

[1] This information was omitted from final approved documents in CRWMS M&O (1999z).

5.3 DEFENSE IN DEPTH

Defense in depth is defined as multiple layers, or multiple features which are incorporated into the design of the EDA to enhance the post closure performance in the event that a layer or feature is degraded or fails prematurely. The following features have potential benefit for developing defense in depth (DID) and are incorporated into the design of EDA V.

- Natural Barriers
- Drip Shield, Titanium-7 Construction
- Waste Package Construction, Single CRM Waste Package, including the WP fuel cladding
- High Thermal Loading (complete dry-out for 10,000 years)

The compatibility of each feature with the design concept has been considered in making a selection, as well as issues regarding the uncertainties, cost, licensability, etc. of the potential DID features and are discussed in the following text.

Natural Barriers – The natural barriers is the set of physical, mechanical, chemical, and hydrological characteristics of the geologic environment that individually and collectively act to minimize or preclude radionuclide mobilization and transport to the accessible environment.

The use of the natural barriers for DID was improved by relocating the repository to the Lower Block (Section 5.4.2). The Lower Block lies beneath Pagany Wash and Drill Hole Wash. Lower infiltration rates are realized in these areas because of the thick alluvium. The apparent reduction in infiltration rate should decrease the liquid water entering the emplacement drifts through seepage, thereby reducing the quantity of radionuclides transported.

Drip Shield - Just prior to closure of the repository, a drip shield will be placed over each waste package (Section 4.1.16). The drip shield will resemble a "mail-box" design with no end caps. These shields will overlap to provide continuous coverage. The shield will be corrugated for structural support and will rest on the invert, with no contact with the waste package itself. The drip shield's purpose is to divert water away from the waste package, protecting the entire length of the waste package as well as its ends. Because the drip shield will be made of grade 7 Titanium, two centimeters thick, it will help to avoid common mode corrosion failures with the WP Alloy 22, increasing the defense in depth. Figure 1 illustrates the configuration of the drip shield.

Waste Package Construction – The waste package construction is outlined in Section 5.5.2. The waste package construction incorporates a corrosion resistant material (CRM) barrier on the outside of the waste package. This external barrier, consisting of Alloy 22, delays the exposure of the fuel assemblies to water entering the emplacement drift.

High Thermal Load – The high thermal loading of 150 MTU/acre (Section 4.1.16) allows an extension of the heating period, with temperatures greater than 100°C in the drift walls after closure (Section 5.7.5). This extension of the heating period may prevent the water from returning to the repository horizon for several thousands of years.

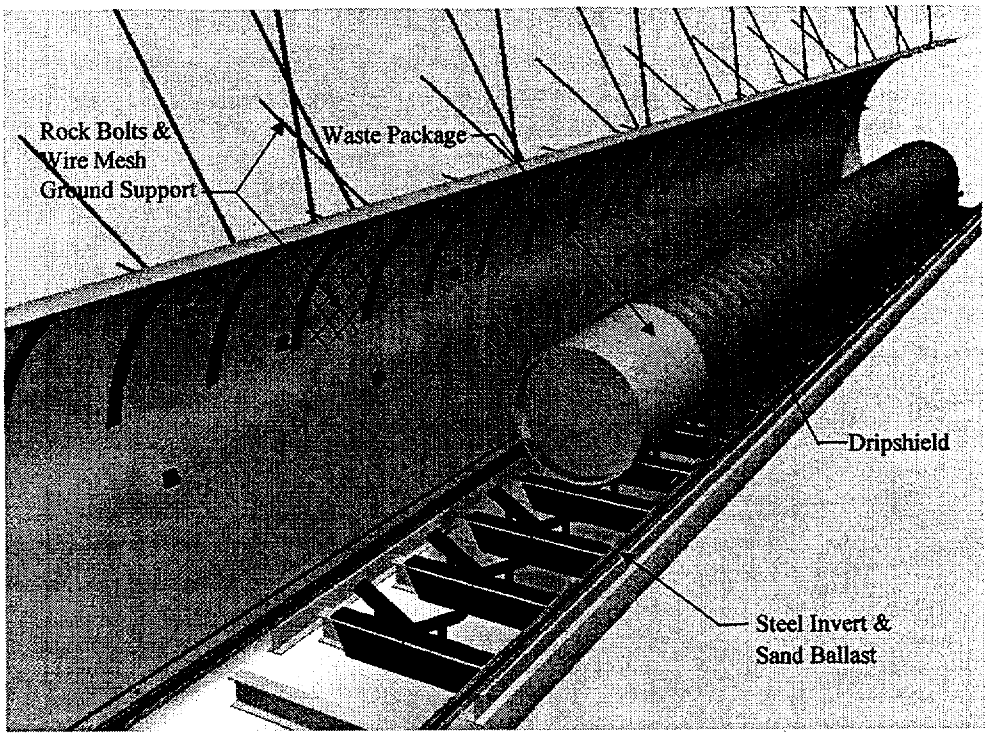

Figure 1. Drip Shield Configuration

5.4 REPOSITORY LAYOUT

This section will describe EDA V and will include a basis for the conceptual design, including emplacement method, location of the repository, and layout development.

5.4.1 Line Loading Emplacement Method

Waste package spacing and emplacement drift spacing are important parameters related to thermal performance. Decreasing the waste-package spacing leads to a nearly continuous heat source down the length of the emplacement drifts. This approach provides for more intense thermal environments near the emplacement drifts. The line load emplacement method is to place the WPs in the emplacement drift nearly end-to-end. With line loading, the waste packages are almost touching, 10 cm apart (Section 4.1.4). The main considerations of the line load approach were to generate a more even distribution of rock temperatures along the emplacement drift, to increase the time before water could contact the waste packages, and to reduce excavation costs.

Line loading, while efficient in its use of drift space, produces a higher drift temperature than point loading does, but the thermal load of the repository can be maintained by the spacing of the emplacement drifts. In this design, the drifts, themselves 5.5 meters in diameter (Section 4.1.10), would be spaced 32 meters (Appendix A, Section A.1.2) apart (center line to center line) for an areal mass loading of 150 MTU/acre. For comparison, the VA reference design incorporates a 28-meter drift spacing at 85 MTU/acre (CRWMS M&O 1997a, p.107). Combined with pre-emplacement blending of the waste (CRWMS M&O 1999a, Table of EDAs), this spacing of the drifts will help to accomplish the thermal goals detailed above, although the design will also require preclosure ventilation (Section 5.8) to maintain those goals.

5.4.2 Repository Footprint Location

The proposed emplacement area for EDA V was located within the lower block and the repository host horizon (Section 4.1.12). The lower block lies beneath both Pagany Wash and Drill Hole Wash. The highest net infiltration occurs along the Yucca Crest (directly above the upper repository block) and net infiltration is lower in the washes (DOE 1998c, pp.3-19 and 3-20). The higher net infiltration along the crests and lower net infiltration in the washes is caused by the amount of alluvial cover present. Along the crest, less alluvial cover allows more water to penetrate into the bedrock without being evaporated, but the opposite tends to be true in the washes. The washes have thick alluvium cover which can store water from storm events long enough for it to be removed by evaporation or transpiration. EDA V has approximately 38% of the layout below alluvial cover (Appendix C).

5.4.3 Layout Development

The conceptual repository layout for EDA V is shown in Figure 2. The conceptual repository layout contains openings that are sized and arranged in a similar configuration as the VA reference design (Section 4.3.7). The layout model in CRWMS M&O (1999o) indicates that the ramps and mains are within the allowable 3% gradient (Section 4.2.2).

The conceptual layout will feature 54 long, parallel emplacement drifts (Appendix A, Section A.3) and long continuous mains that will accommodate tunnel boring machine (TBM) excavation. Only the emplacement area is located within the Lower Block to ensure that adequate area for the EDA V conceptual layout was available. Thirteen contingency emplacement drifts are also incorporated into the layout.

The ramps and mains have been positioned to avoid faults and to provide the shortest drift length permissible without exceeding the allowable 3% gradient (Section 4.2.2). An additional ramp from surface is incorporated into the conceptual design. This ramp will provide intake air for the ventilation system as well as provide access to the north end of the repository block for emplacement operations. Two exhaust mains will be located below the level of the emplacement drifts to accommodate a preclosure ventilation rate of two to five cubic meters per second (Section 5.8).

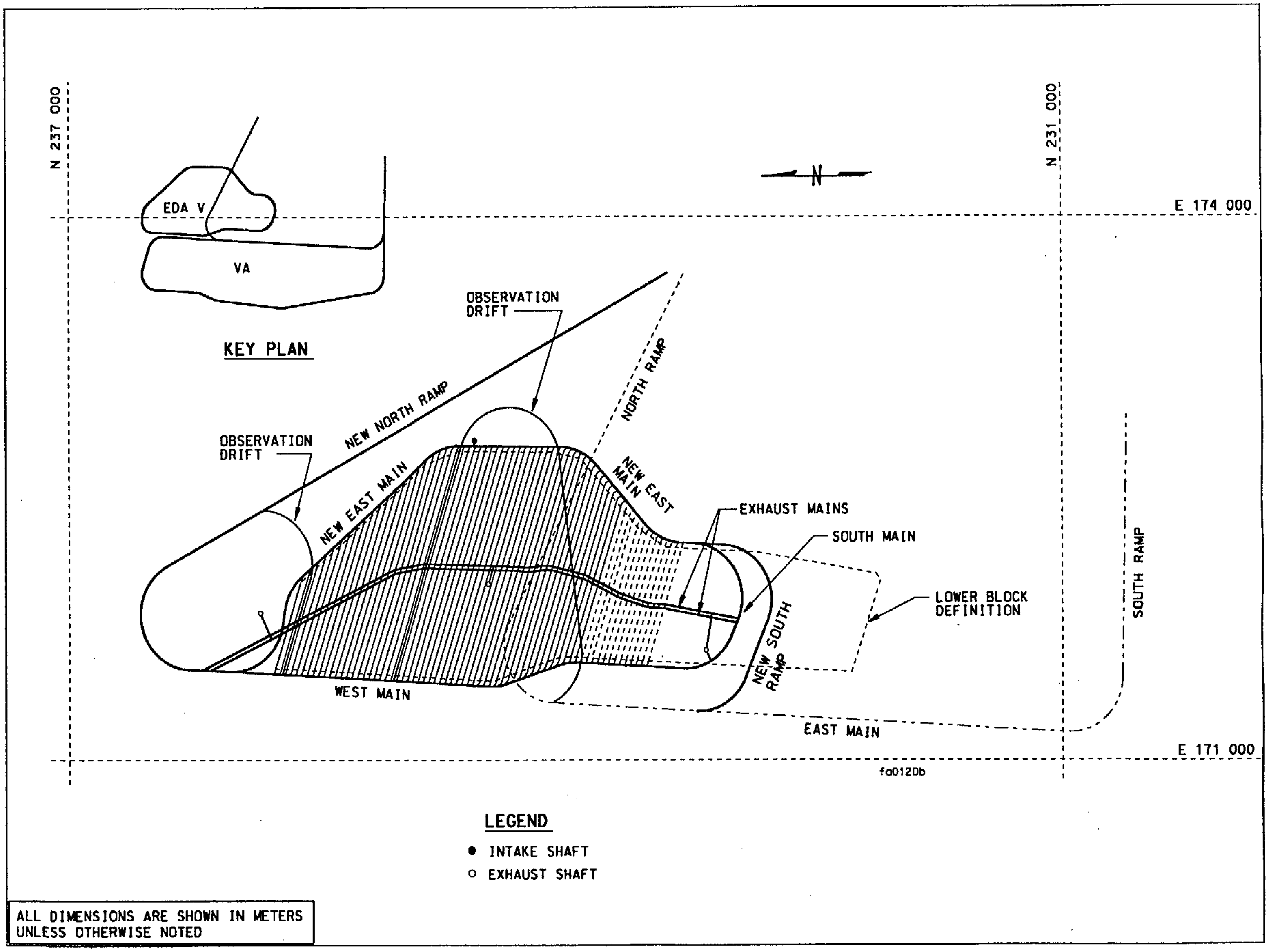

Figure 2. Conceptual Layout

Four ventilation shafts (CRWMS M&O 1999p, pp. 4 and 6), one intake and three exhaust, are anticipated for the conceptual layout in order to provide sufficient air quantities to accommodate the preclosure ventilation requirements of two to five cubic meters per second. Additional shafts and associated drifts would be required if a preclosure ventilation rate greater than five cubic meters per second were necessary for the conceptual design of EDA V. The location of the shafts are approximated and these locations could be changed upon more detailed analysis of the EDA V design concept.

A discussion of required acreage for increased disposal capacities is located in Section 6.4.1.

The conceptual layout is based on inputs from Section 4, the discussion in this section and the calculations contained in Appendix A.

5.5 WASTE PACKAGE DESIGN

This section outlines the waste package design, including a discussion of the purpose of blending the waste and WP construction.

5.5.1 Blending of the Waste Packages

Thermal blending is the selection of individual assemblies; based on thermal output, such that the peak heat-generation rate is limited. As the target range decreases, so does the variability of the waste package thermal output. Blending will not reduce the thermal energy burden of the repository, but will ensure that waste package thermal outputs are spread more evenly across the repository. An additional 3,750 MTU of surface storage (Section 4.1.7) will be required to accommodate the CSNF blending, which will impact the surface facility design, cost, and complexity.

An average PWR heat output per waste package of 9.8 kW, with a design basis of 11.8 kW, was used (Section 5.2).

5.5.2 Waste Package Construction

The VA reference design waste package utilizes two concentric barrier layers: a 10-cm-thick outer less corrosion resistant ASTM A-516 carbon steel Corrosion-Allowance Material (CAM) and an inner 2-cm-thick nickel-base Alloy 22 CRM (Section 4.1.2). Alloy 22 was chosen for the CRM in part because of its high degree of general and localized corrosion resistance under expected repository environmental conditions.

The waste package design for EDA V will incorporate a single CRM waste package (Section 4.1.3). From a corrosion performance standpoint, the use of a CRM as an outer layer will significantly lower the risk of waste package failure and provide a longer lifetime.

The EDA V waste package will be a single CRM WP, constructed with an interior cylindrical shell of 5-cm-thick stainless steel (Section 4.1.3). This interior shell will be interference-fitted to an exterior cylindrical shell made of Alloy 22. The design-basis waste package from a thermal perspective is the 21-PWR waste package, but there are waste packages for BWR, defense high-level waste glass and DOE waste forms to be emplaced as well.

5.6 GROUND SUPPORT

The ground support, within the emplacement drifts, that was incorporated into the design of EDA V includes rock bolts and mesh (Section 4.3.4). The design of EDA V is flexible in that it does not preclude the use of other forms of ground control such as steel sets, steel lining, or pre-cast concrete segments. Figure 3 illustrates the ground control installed within the emplacement drifts.

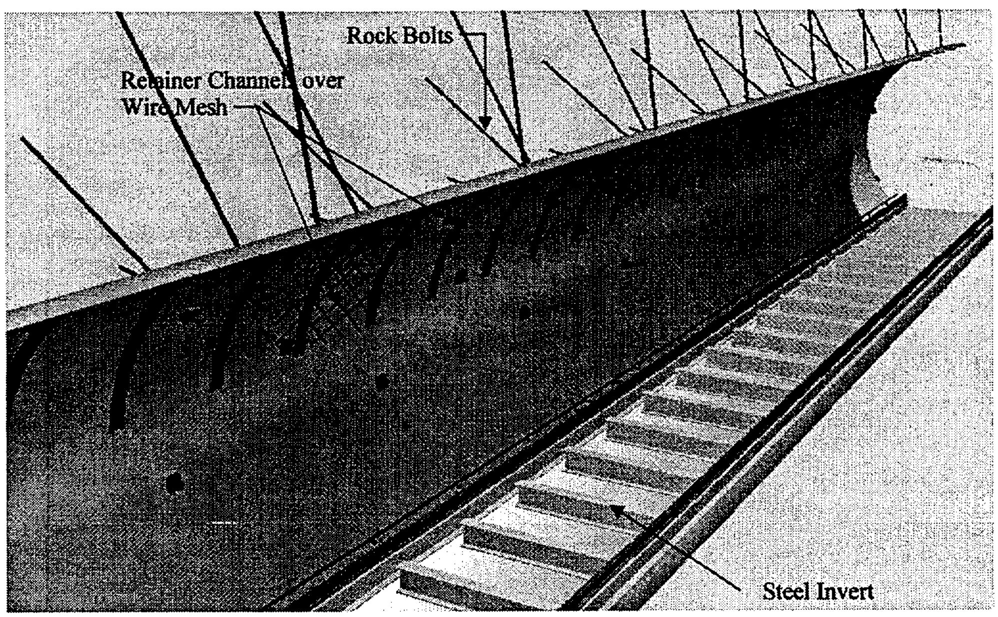

Figure 3. Ground Control Illustration

5.7 THERMAL EVALUATIONS

A number of thermal analyses were performed (Section 4.1.13) to determine if the thermal goals were met and if the repository could be closed after 50 years.

5.7.1 Preclosure Period

The initial thermal analysis was performed with 25 years of aging and 75 years of preclosure ventilation at 10 m^3/s, Case 3 (Section 4.1.13), but other runs were completed in order to find a combination of operating conditions for EDA V that are favorable. Thermal analysis produced results for 25 years of aging with 25, 50, and 75 years of ventilation, Cases 1, 2, and 3 respectively (Section 4.1.13). The results of the thermal analysis are seen in Figures 4, 5, and 6 (CRWMS M&O 1999f, pp. IV-22, IV-23, and IV-24). These results indicate that continuous preclosure ventilation flow of 10 cubic meters per second will keep the peak drift wall temperature and WP surface temperatures within the thermal goals (Section 4.2.3). Therefore, by utilizing aging, sufficient control of the heat output of the waste packages is achieved to allow closure of the repository at 50 years after emplacement starts.

A change in temperature, ΔT, to be expected by decreasing the preclosure period to 50 years would be estimated by the difference in temperatures between Case 1 and Case 3. The temperature delta (ΔT) for the drift wall and waste package surface is estimated to increase by 18°C and 17°C respectively.

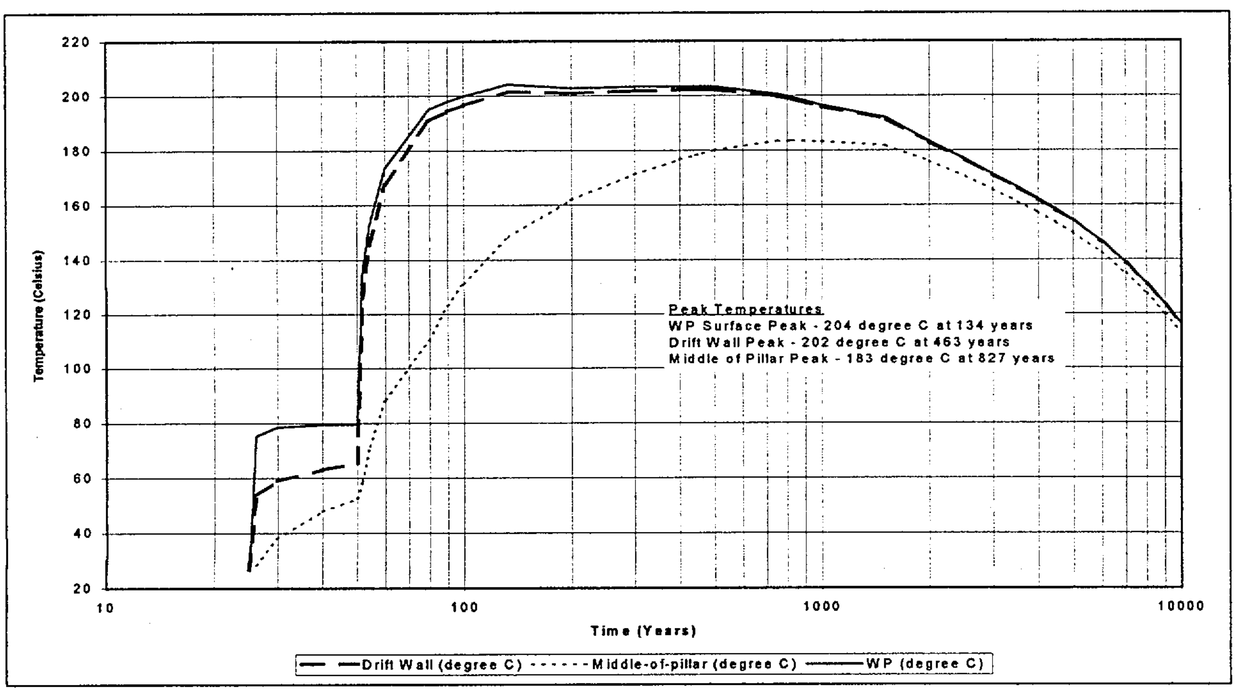

Figure 4. Case 1 - 25 Years Aging and 25 Years Ventilation at 10 m^3/s

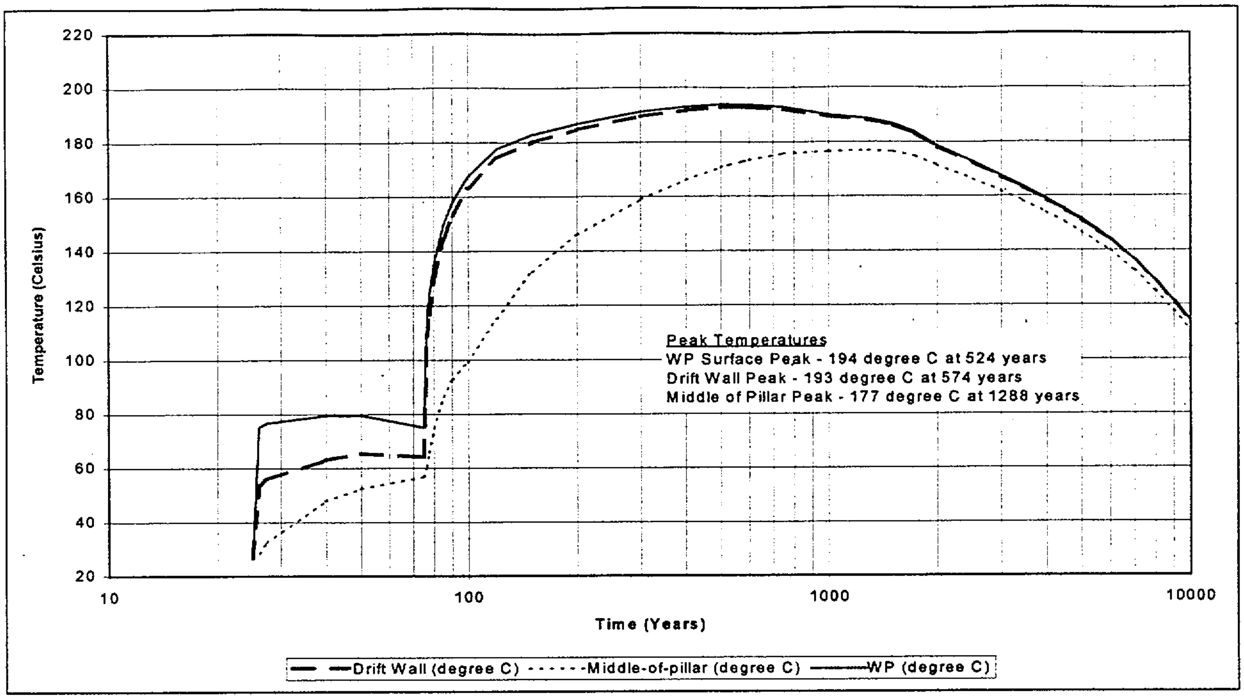

Figure 5. Case 2 - 25 Years Aging and 50 Years Ventilation at 10 m^3/s

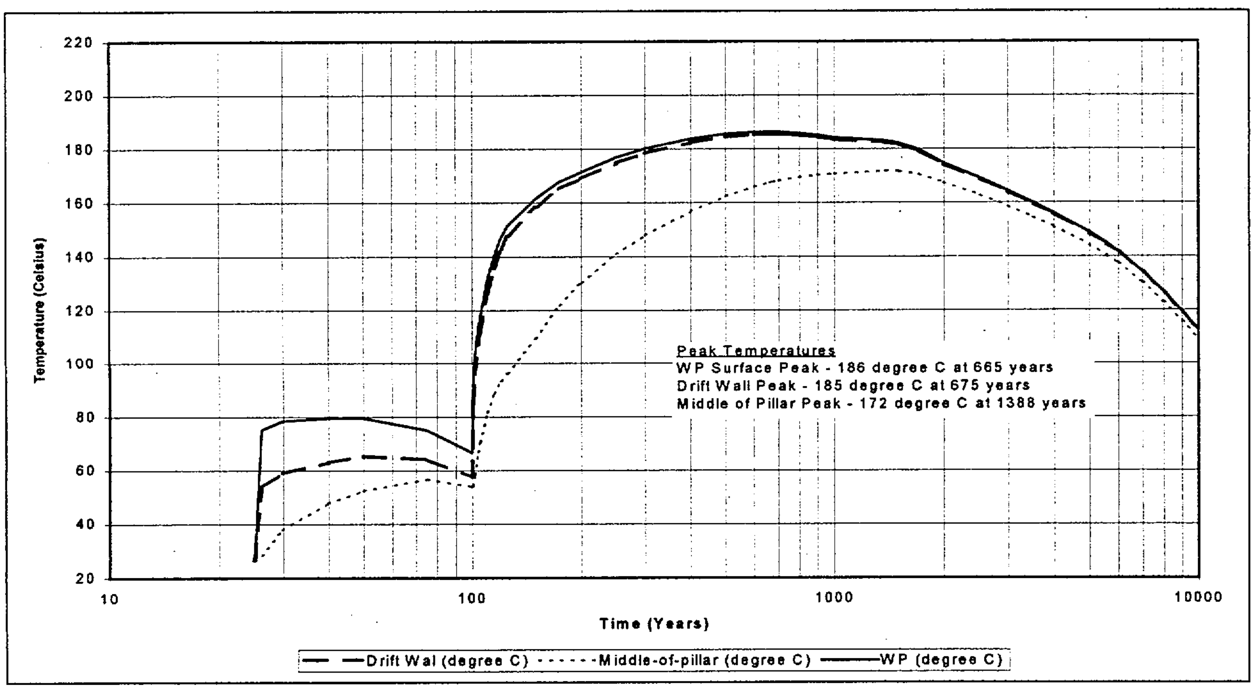

Figure 6. Case 3 - 25 Years Aging and 75 Years Ventilation at 10 m^3/s

5.7.2 Pre-Emplacement Aging versus No Aging

Thermal analyses were also performed to determine if aging of the waste could be eliminated from the design basis (Section 4.1.13), and the results are illustrated in Figure 7 (CRWMS M&O 1999f, p. IV-25). The modeling shows that a 100-year preclosure period with continuous ventilation of 10 cubic meters per second, Case 4, will keep the peak drift wall and WP surface temperatures within the thermal goals (Section 4.2.3). Therefore, sufficient control of the heat output of the waste packages is achieved and aging of the waste prior to emplacement underground is not required. A change in temperature, ΔT, to be expected by removing aging as a possible feature would be estimated by the difference in temperatures between Case 4 and Case 3. The temperature delta (ΔT) for the drift wall and waste package surface is estimated to increase by 3°C for both, when aging is replaced by additional ventilation.

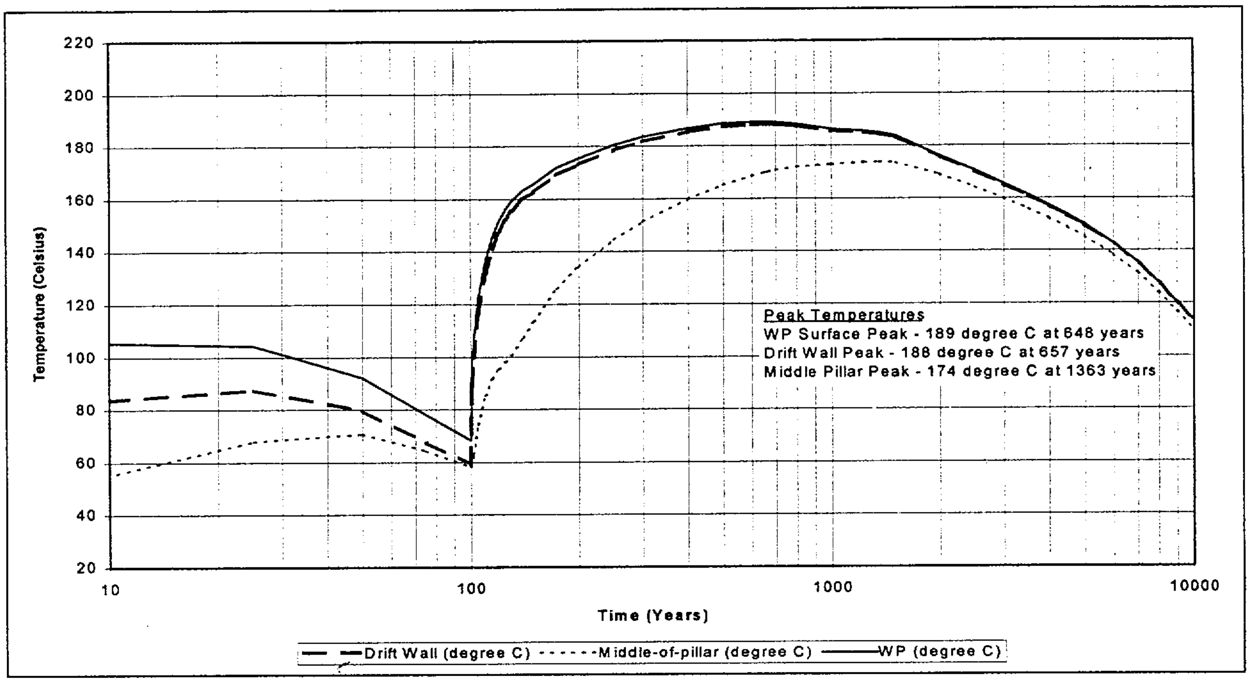

Figure 7. Case 4 – No Aging and 100 Years of Ventilation at 10 m^3/s

5.7.3 Reduction in Ventilation Rate

A thermal analysis was performed to determine the effect of reducing the ventilation quantity in each emplacement drift from the initial thermal evaluation in Section 5.7.1 (Section 4.1.13). The results, as displayed in Figure 8 (CRWMS M&O 1999f, p. IV-26), indicate 25 years of aging followed by 75 years of ventilation at two cubic meters per second, Case 5, as a conservative minimum, can also control the waste package thermal output within the temperature constraints.

The reduction in ventilation airflow increases the peak drift wall and waste package surface temperatures, but both are still within the thermal goals (Section 4.2.3). A change in temperature to be expected by reducing the ventilation rate to two cubic meters per second would be estimated by the difference in temperatures between Case 5 and Case 3. The temperature delta (ΔT) for the drift wall and waste package surface is estimated to increase by 11°C and 12°C respectively, when the ventilation rate is reduced.

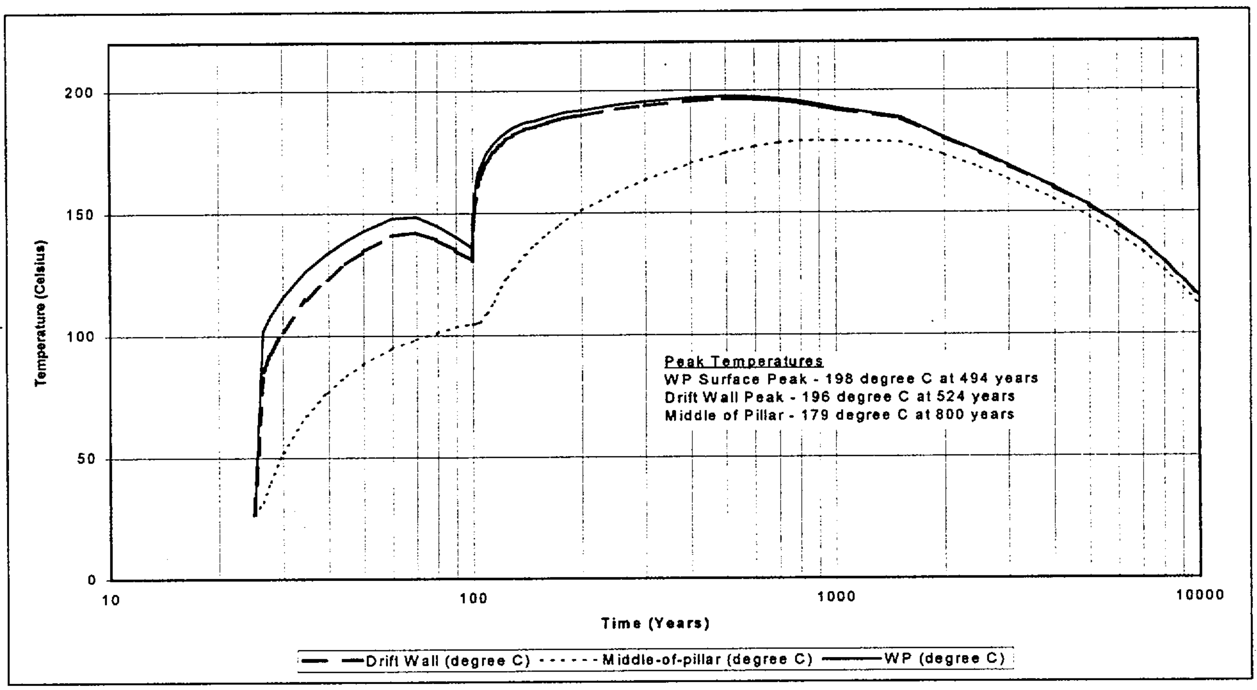

Figure 8. Case 5 – 25 Years Aging and 75 Years Ventilation at 2 m^3/s

5.7.4 Disruption in Ventilation

Thermal analyses were also performed to determine the effect of a disruption in the ventilation airflow with respect to the initial thermal evaluation in Section 5.7.1 (Section 4.1.13). Two disruptions, defined as a complete shutoff of the ventilation airflow, were simulated, as shown in Figure 9 (CRWMS M&O 1999f, p. IV-27). The first assumed disruption of the ventilation system lasts for a one-year period. This situation could occur if ventilation openings, such as a ramp or a shaft, experience a collapse. The one-year period should be adequate for repair of such an incident. The model indicates that a spike in temperature would occur in the drift walls and the waste package, but does not approach violation of the respective thermal limits (Section 4.2.3).

A one-month disruption of the ventilation system, such as a complete mechanical failure of the ventilation system or a major loss of site power was also modeled. Again, the model indicates that a spike in temperature would occur in the drift walls and the waste package, but does not approach violation of the respective thermal limits (Section 4.2.3).

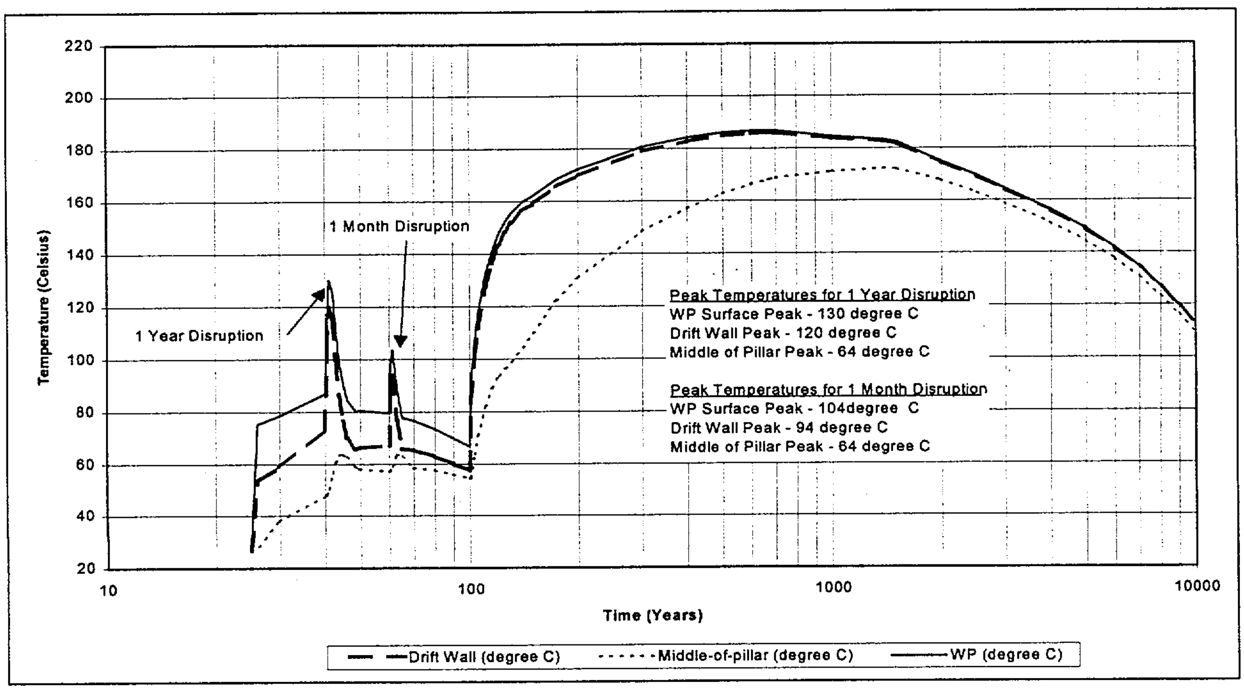

Figure 9. Case 6 - Ventilation Disruption

5.7.5 Thermal Summary

The thermal analyses have been summarized in Table 10. It is possible to eliminate aging as a feature, decrease the preclosure period to 50 years, or reduce the ventilation rate and determine the conditions which are favorable for EDA V.

Table 10. Thermal Evaluation Summary

Case	Aging (years)	Ventilation (years)	Ventilation Rate (m^3/s)	Drift Wall Temp. (°C)	Waste Package Temp (°C)	Reference
1	25	25	10	202	204	Section 5.7.1
2	25	50	10	193	194	Section 5.7.1
3	25	75	10	185	186	Section 5.7.1
4	0	100	10	188	189	Section 5.7.2
5	25	75	2	196	198	Section 5.7.3

Based on the thermal analyses from Sections 5.7.1 through 5.7.3, trends will be used to show that favorable conditions may be achievable. When Cases 3 and 4 were compared, the results of replacing aging with preclosure ventilation, the peak drift wall temperatures are within a 3°C difference. When Cases 2 and 5 were compared, the results of increasing the ventilation period and decreasing the ventilation rate, the peak drift wall temperatures are within a 3°C difference. When comparing Cases 1 and 4, by replacing aging with a longer duration of preclosure ventilation, the peak drift wall temperatures are within a 14°C difference.

Therefore, it could be inferred, that the favorable conditions of no aging, 50 years of preclosure ventilation, and a ventilation rate of two cubic meters per second should keep drift wall and waste package temperatures within the limits of the thermal goals (Section 4.2.3). It has been shown in Case 4 that 10 cubic meters per second is more than capable of meeting the thermal goals. To be conservative, a ventilation rate of two to five cubic meters per second is being recommended for EDA V, such that the system is not over designed. The particular conditions chosen, as low as two cubic meters per second and 50 years of preclosure ventilation, was not a part of the thermal analysis prepared in support of this document. Further analysis would be required to confirm these recommendations.

5.8 PRECLOSURE VENTILATION

Following emplacement of the waste packages into a drift, the drift will be ventilated until closure of the repository. Fans, ventilation regulators, and excavated main drifts will deliver approximately two to five cubic meters per second (Section 5.7.5) of air to each end of each emplacement drift containing waste packages. This continuous ventilation will reduce air and drift temperatures. This preclosure ventilation will keep the waste packages and drift walls cooler, maintaining the thermal goals of the repository. The ventilation system will be removed when the repository is closed, allowing the temperature to rise again, but within the thermal goals.

5.9 OPERATING CONCEPTS

The surface and subsurface operating concepts for the EDA V are outlined below. The surface facility is conceptually designed to perform the following functions:

- Receive waste,
- Unload, handle, store, and blend the waste prior to loading into a disposal container,
- Load the disposal container and seal as a WP, and
- Transfer the WP to the subsurface repository operations.

The subsurface portion of the repository is conceptually designed to perform the following functions:

- Accept loaded waste packages from the surface facility,
- Transport the waste packages to the emplacement drifts,
- Place the waste packages within the emplacement drifts,
- Ventilate the emplacement drifts,
- Monitor the performance of the waste packages and drift environment before closure,
- Maintain the capability to retrieve waste packages and/or the capability to repair the ground support system,
- Install the drip shields just prior to closure, and
- Install closure barriers and seals for the underground openings, including boreholes.

Construction and development of the repository will be accomplished in two phases. The construction phase encompasses repository construction work that occurs before the emplacement operations begin and includes excavation of access ramps, main drifts, ventilation shafts, and a panel of several emplacement drifts and ventilation raises. The development phase begins with the installation of the movable isolation air locks after the first panel of emplacement drifts is finished. Once the air locks are in place, the emplacement area and development area ventilation systems are separated, and simultaneous emplacement and development operations can proceed.

6. TECHNICAL BASIS FOR LADS EVALUATION

The LADS Criteria (CRWMS M&O 1999c) will be used to evaluate the EDAs by the LADS Group. This section only addresses the criteria and does not evaluate them with respect to the defined measures. Prior to the evaluation of the EDA, the concept must pass the screening criteria (CRWMS M&O 1999c, p.1). EDA V produces a calculated performance of less than 25 mrem per year (Section 6.1.1) and therefore is a candidate for selection as the Site Recommendation and License Application (SR/LA) design.

6.1 SAFETY/LICENSE PROBABILITY

The evaluation of safety and licensability is based on a consideration of the safety margin, degree of defense in depth, and various factors related to the degree of engineering acceptance.

6.1.1 Safety

The safety margin is defined as the difference between the calculated performance (central estimate) and the anticipated regulatory standard (25 mrem/year) within 10,000 years. The uncertainties in post-closure performance and the ability to reduce or mitigate those uncertainties are also an element in assessing the license probability. To evaluate whether the design would lead to significant increases in peak dose rate beyond 10,000 years, the performance up to 1,000,000 years is also considered.

The calculated performance within 10,000 years after closure is illustrated in Figure 10. The peak dose rate within 10,000 years is 0.02 mrem per year at approximately 7,000 years after closure (Section 4.1.14). This peak dose rate indicates a safety margin of 24.98 mrem per year.

The 10,000 year dose rate is produced by an assumed juvenile failure of a single WP at 1,000 years (DOE 1998c, p.3-81), and the calculated first failure of a drip shield at about 6,000 years, assuming spatial coincidence (CRWMS M&O 1999h, Item 5, p. 46). The steep rise at 6,500 years is due to flow through the failed drip shield.

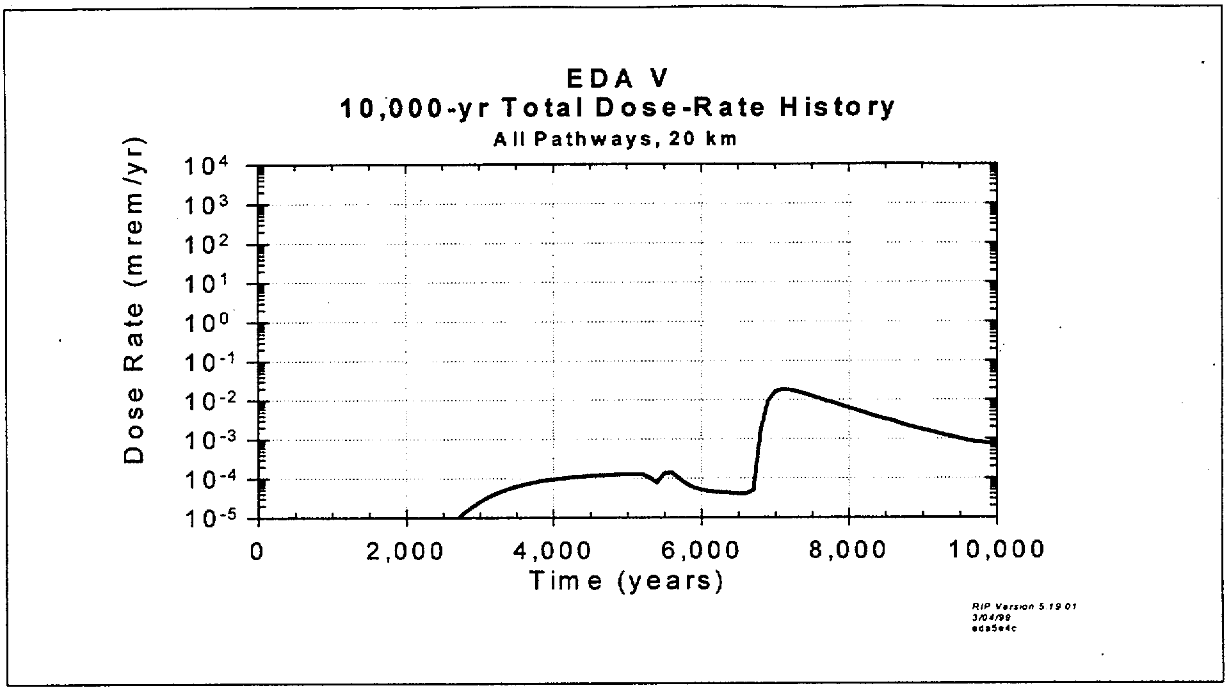

Figure 10. 10,000-yr Total Dose Rate History

The calculated performance within 1 million years after closure is illustrated in Figure 11. The peak dose rate is 200 mrem per year at approximately 720,000 years (Section 4.1.14). The time at which the 25 mrem per year screening criterion is reach is approximately 300,000 years, over 30 times later than the screening criterion duration, of 10,000 years.

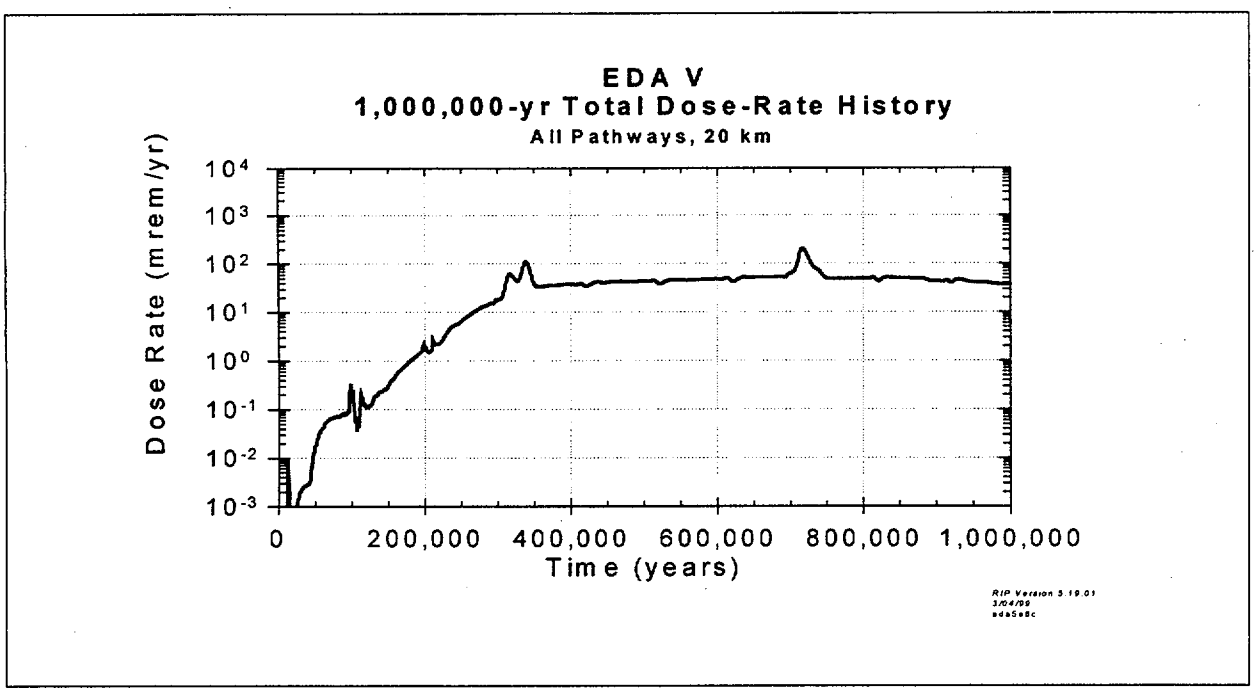

Figure 11. 1,000,000-yr Total Dose Rate History

6.1.2 Licensability

Defense in depth (Section 6.1.3) is an engineering judgement where multiple, diverse barriers exist which will lead to additional DID beyond that required by the screening criterion. In addition, licensability is related to several factors defining the degree of engineering acceptance, as outlined in the following sections.

6.1.2.1 Function of Design Elements

The function of each design element (Section 5.2) is relatively straightforward and thus its design and functions can be clearly communicated.

6.1.2.2 Accepted Methods

The design of each element can be demonstrated by analytical methods. There are no discernable differences between EDA V and the VA reference design, in terms of the methods used to arrive at the design of the elements.

6.1.2.3 Post-Closure Functions and Uncertainties

Aggressive conditions are anticipated for parts of the repository environment for a relatively long time. Calculations have indicated that the waste package temperatures do not cool to below 100°C until after 3,000 years and the relative humidity has increased to greater than 80% within less than 1,000 years (Section 4.1.15). This temperature and humidity profile may lead to localized corrosion on some of the waste packages in the aggressive environment, which introduces uncertainties in the post-closure function. A corrosive environment could be detrimental to waste isolation.

A discussion of coupled processes for a hot repository was discussed in CRWMS M&O (1999t, p. C-23). The summary is as follows: Refluxing, as a result of thermally driven processes, results in an increase in uncertainty of whether or not condensate drainage might enter the emplacement drifts, how silica redistribution might alter the hydrology, and how chemistry effects may change the waste package corrosion and radionuclide solubility. As a consequence, the waste packages not only may not stay dry, but there could be areas in the repository which become more corrosive as a result of hot, boiling water reentering the emplacement drifts. As result of refluxing, the uncertainty of when and where this occurs increases significantly. Consequently, there is also the possibility that an increased potential for systematic, significant deleterious effects to post closure performance could occur for the high thermal loads.

6.1.2.4 Regulatory and/or Engineering Precedents

The repository excavation does not deviate from current engineering precedence. The introduction of drip shields and preclosure ventilation into the design of the repository may introduce operational concerns for implementation, and any concerns would have to be resolved prior to repository construction.

Blending may make licensing more difficult and increases the amount of surface storage and waste handling.

Precedents exist for using thermal computer codes in reactor design. Complex thermal hydrologic repository calculations use codes benchmarked to laboratory field and natural analog data, but that have not been used in a licensing situation. Similarly, corrosion models have been benchmarked to available data and have licensing precedent, although with much less extrapolation.

6.1.2.5 Qualified Data

Certain inputs were required to develop the concept for EDA V. Some of these inputs are consistent with the VA reference design. Most of the inputs for the EDA V repository concept should be available prior to waste emplacement, but qualified data to support assessment of the post-closure functions may not be available.

6.1.2.6 High-Level Design Goals

A number of high-level design goals for the MGR are either violated or refined by the conceptual design of EDA V and are outlined below.

Thermal Goal for Drift Wall Temperature –The MGR high-level design goal of keeping the emplacement drift wall temperatures to less than 200°C (CRWMS M&O 1998b, EBDRD 3.7.G.2) has been violated by the conceptual design criterion of EDA V. The criterion that was established for EDA V in regards to the drift wall temperature is to keep the temperature below 225°C (Section 4.2.3). If it is determined that EDA V should progress beyond the conceptual stage, further study would be required to confirm this drift wall temperature criterion.

Retrievability Period - The retrievability period for EDA V is 50 years after emplacement. CRWMS M&O (1998b, Key 016) states that the repository be designed for a retrievabiltiy period of up to 100 years after initiation of emplacement.

Mass Loading Range – CRWMS M&O (1998b, Key 019) states that the surface, subsurface, and waste package designs will be based on a reference mass loading of 80 to 100 MTU per acre. EDA V has been designed with an areal mass loading of 150 MTU per acre.

Repository Horizon – CRWMS M&O (1998b, Key 022) states that the repository horizon will be located within the primary area (upper block). EDA V has been designed with placement of the repository horizon within the lower block.

Gantry Emplacement and Pedestal Support – CRWMS M&O (1998b, Key 066) states that the waste packages be placed on pedestals. EDA V has been designed with line loading, which may not conform to pedestal emplacement.

Emplacement Drift Ventilation – CRWMS M&O (1998b, Key 067) states that the ventilation of each emplacement drift be maintained at a low, controlled volume for monitoring purposes. EDA V employs preclosure continuous ventilation of two to five cubic meters per second (Section 5.7.5) for control of the waste package heat output.

Waste Package and Drift Spacing – CRWMS M&O (1998b, Key 077) states that the CSNF will be emplaced within the drifts by point loading. EDA V proposes using a line loading technique.

The consequences of violating these design goals of the MGR are acceptable considering the potential performance for the EDA V conceptual design.

6.1.2.7 Environmental Considerations

The environmental considerations associated with EDA V are presented in Appendix B.

6.1.3 Defense In Depth

The very high thermal loading alternative provides the following defense in depth (Section 5.3). DID present in this alternative are:

- Natural Barriers
- Drip Shield, Ti-7 construction
- Waste Package Construction, Single CRM waste package, including WP fuel cladding
- High Thermal Loading (Complete dry-out for 10,000 years)

The number of defense in depth layers indicated makes it unlikely that a significant quantity of radioactive waste can be transported away from the repository within a 10,000-year time frame. The dose rates with a DID neutralization of the WPs was calculated in CRWMS M&O (1999j, pp. 14 and 15). The peak dose rate with the waste package neutralized within 10,000 years is approximately 150 mrem per year at approximately 7,000 years after closure (Section 4.1.14), 7,500 times greater than the peak dose rate within the same time period calculated with the WP intact. The peak dose rate with the waste package neutralized within 1 million years is approximately 1,500 mrem per year at approximately 310,000 years (Section 4.1.14), 7.5 times greater than the peak dose rate calculated within the same time period with the WP intact.

The drip shield and the waste package construction provide protection from moisture. Their corrosion rates are somewhat predictable using standard corrosion models. However, corrosion is dependent upon the amount of moisture (groundwater) that will be introduced into the emplacement drifts, drift temperatures, pH, and the type of minerals dissolved in the ground water. The safety margin of 24.98 mrem per year (Section 6.1.1), indicates that the drip shield may not be necessary for the conceptual design of EDA V, but may be required for DID.

Within the first 10,000 years, parts of the repository environment could have aggressive conditions for a relatively long period of time (Section 6.1.2.3). Calculations have indicated that the waste package temperatures do not cool to below 100°C until after 3,000 years and the relative humidity has increased to greater than 80% within less than 1,000 years. This temperature and humidity profile may lead to localized corrosion on some of the waste packages in the aggressive environment. The high thermal loading, as defined by the design elements for EDA V (Section 5.2), has not provided the DID that was anticipated, although additional study and analysis may indicate that achieving temperature profiles more closely matched to the thermal criteria (Section 4.2.3) may result in better postclosure performance.

6.2 COST/SCHEDULE

This section will outline the preliminary cost and schedule developed for the EDA V conceptual design.

6.2.1 Cost

The total cost estimates were prepared for this EDA (ventilated for 50 years with a flow rate of 2 cubic meters per second) based upon design element details provided that affect the Mined Geologic Repository (MGR) subsurface, surface, waste package, and engineered barrier related costs (Section 4.1.18). Table 7 presents the life cycle costs from 2002 to 2066, in constant 1998 dollars. The total cost of EDA V is $20.0 billion (Section 4.1.18), compared to $16.8 billion for the VA reference design (adjusted to a 50 year preclosure period) (CRWMS M&O 1999m, p. 15). The net present value cost of EDA V is $10.8 billion (Section 4.1.18), compared to $10.1 billion for the VA reference design (CRWMS M&O 1999m, p. 15).

6.2.2 Schedule

EDA V has been evaluated for the time required for completing each of the following phases: site characterization and licensing, construction, operations, monitoring, and closure. The time encompassed by the Monitored Geologic Repository (MGR) extends from the year 2002 through 2066 (Section 4.3.5). During this period the project will evolve through the five distinctly different activity phases. The overall schedule for EDA V is illustrated in Figure 12 and Table 8.

6.2.2.1 Licensing Phase

The estimate for this phase includes the time required to complete the repository and waste package designs. Time to support LA and respond to issues related to the Environmental Impact Statement (EIS) are also included. The Site Characterization and Licensing Phase is anticipated to start in March of 2002 and continue through to February 2005, a period of almost 3 years (Section 4.3.5).

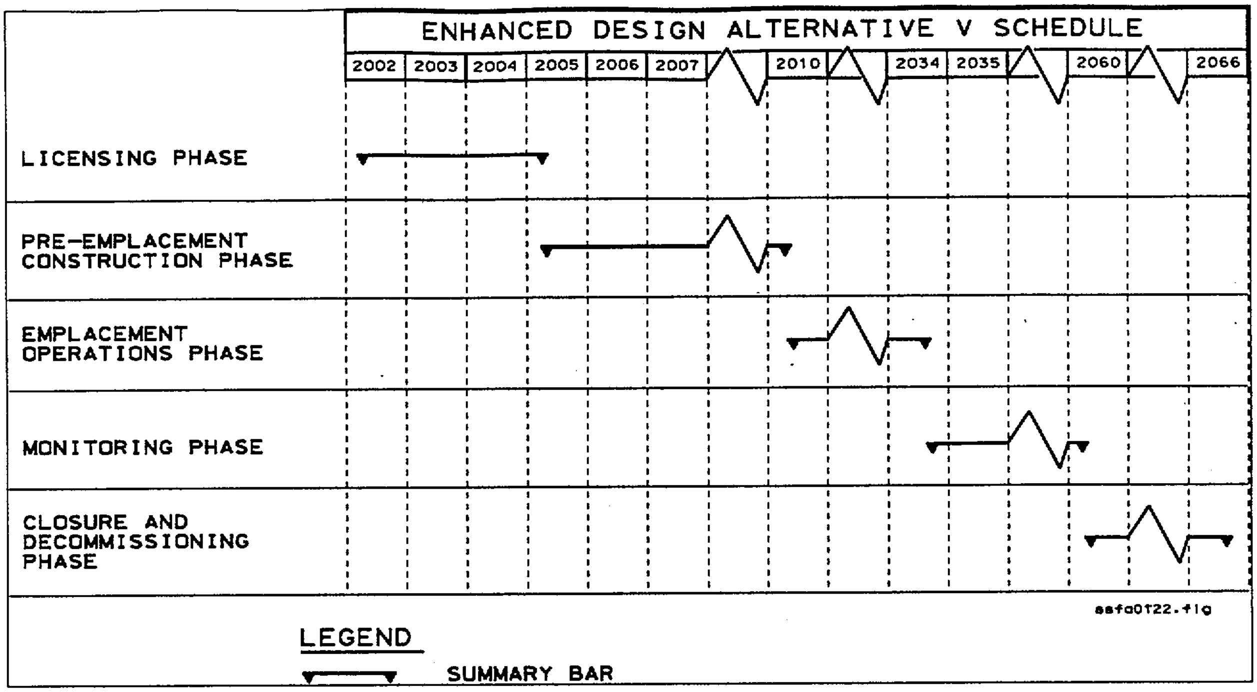

Figure 12. EDA V Schedule

6.2.2.2 Pre-emplacement Construction Phase

The Pre-Emplacement Construction Phase will start after the Nuclear Regulatory Commission (NRC) authorizes construction. The underground development will include, as a minimum, sufficient development to begin emplacing waste packages in 2010. The surface facilities construction will also be completed in this time frame. The Construction Phase is anticipated to start in March 2005 and continue through to February 2010, a period of almost 5 years (Section 4.3.5).

6.2.2.3 Emplacement Operations Phase

The Operations Phase, which incorporates simultaneous emplacement and development operations, begins after NRC issues a license amendment for the repository to receive and possess waste. This period pertains to repository operations for accepting the waste and the procurement, handling, and emplacement of waste packages. Also during this period, underground construction is completed and performance confirmation activities are initiated. The Operations Phase is anticipated to start in March of 2010 and extend to September of 2033, a period of 23.5 years (Section 4.3.5).

6.2.2.4 Monitoring Phase

During the Monitoring Phase performance confirmation activities will continue. All facilities will be kept in stand-by status with sufficient maintenance to retrieve waste packages if necessary. The Monitoring Phase is anticipated to start in October of 2033 and extend to February of 2060, a period of 26.5 years (Section 4.3.5).

6.2.2.5 Closure and Decommissioning Phase

The Closure Phase includes demobilizing the repository surface infrastructure; constructing barriers to preclude human intrusion, backfilling the access shafts, ramps, and boreholes; and restoring the site to a condition that does not require human support. The Closure Phase is anticipated to start in March 2060 and be completed in September 2066, a period of 6.5 years (Section 4.3.5).

6.3 CONSTRUCTION, OPERATIONS AND MAINTENANCE

This criterion will be used to evaluate the particular advantages or disadvantages of an EDA in addressing construction, operations, and maintenance issues and are outlined in the following sections.

6.3.1 Worker Radiation Safety/Industrial Safety

Construction of more or less repository acreage can be assumed to cause more or less injuries in a direct ratio (CRWMS M&O 1999q). The injury rate for the construction of this EDA should be consistent with the rate for other EDAs, but the total number of injuries will change based on the actual design and difference in the size of the repository.

The repository construction will be completed in accordance to the Occupational Safety and Health Administration (OSHA) and American Conference of Government Industrial Hygiene (ACGIH) standards (CRWMS M&O 1999q). In this work regime, the number of employees or the number of hours they work is immaterial and therefore no unusual industrial safety concerns are noted.

This alternative handles about 9,972 waste packages (Section 4.1.1). The waste package lengths are similar, although slightly smaller than the VA reference design (Sections 4.1.2 and 4.1.3). The waste package will be handled in a similar manner as outlined for the VA reference design, with a shielded waste transporter. Therefore there should not be an impact to the radiation exposure of workers.

6.3.2 Reliability/Availability/Maintainability/Inspectability

Reliability, availability, and maintainability (RAM) ratings are typically applied to active devices (e.g. equipment). Availability is a joint measure of reliability and maintainability in that it is a measure of reliability in terms of mean-time-between-failures (MTBF) and maintainability in terms of mean-time-to-repair (MTTR). Equipment RAM is assessed to determine its impact on waste package emplacement throughput in the sense that failure and subsequent repair reduce the rate of throughput.

There are two aspects of EDA V that have negative impacts on RAM in terms of availability, the requirement of ventilation for 50 years prior to closure (Section 5.8). The requirement for continuous preclosure ventilation will require additional heating, ventilation, and air conditioning

(HVAC) equipment for a period of 50 years (Section 4.1.5). Blending and surface storage may increase the surface operations and affect the reliability, availability and maintainability of the surface equipment.

6.3.3 Throughput Capacity

The throughput capacity of the waste handling facility, in the VA reference design should not be affected by the change in waste package design, construction, or contents proposed for EDA V provided that larger storage pools are included. The use of the storage pools, as lag storage is critical to ensuring the viability of the approach to blending. The total number of waste packages, 9,973, is slightly less than the VA reference design, as a result of blending. A throughput analysis would be required if EDA V progresses beyond the conceptual stage.

6.3.4 Performance Confirmation Activities

The most important consideration of the performance confirmation activities is the possible redefinition of the PC program to examine the long-term impacts of the increased thermal loading on the natural barriers and on boundary conditions. The following items should be examined as they can affect PC scope and cost:

- The extent of the altered zone. The long term altered zone (i.e. the zone of significant rock temperature increase) may be significantly more extensive for this alternative than in the VA reference design and could require the study of the natural barriers at different elevations within Yucca Mountain.
- The effect of elevated temperatures on zeolites and other mineralized features. At elevated temperatures, zeolites could undergo transformations, which could affect repository performance such as the transformation of clinoptilolite to analcime (CRWMS M&O 1996, p. 3-3).
- The likelihood and extent of a heat-pipe effect. A heat pipe effect (Hardin et al 1998, pp. 3-7 to 3-8) would induce a zone of complex, thermal-hydrological-mechanical process interactions in the vicinity of the emplacement drifts, which could have direct bearing on performance.
- Study of the impact of increased temperatures on the saturated zone and near-surface rock temperature. Effects of the elevated temperature on the saturated zone, which effects performances, would require further study under PC and perhaps require additional PC test facilities.
- Additional site characterization requirements. For EDA V, the repository horizon has been relocated to the north and east of the VA reference design, into an area termed the Lower Block. Additional site characterization activities may be required due to this change in location. This possibility of additional requirement for site characterization should not adversely affect the PC activities.

6.3.5 Construction Methods

The majority of the repository openings will be excavated by TBM, which require long and relatively straight headings for efficient operation. Roadheaders will be used for secondary openings. Roadheader productivity is low compared to that of a TBM and, for this reason, use of these machines for repository excavation will be limited to shorter drifts. Mechanical means of excavation, either vertical mole or raise boring if practicable will be used to excavate the shafts and raises. In the event that mechanical means of excavation can not be accommodated for excavation of the shafts and raises, due to schedule restraints for example, drill and blast methods will be employed.

6.3.6 Design Basis Events

Preclosure safety performance is evaluated in the context of radiological Design Basis Events (DBEs). DBEs are credible sequences of events that potentially lead to the release of radioactivity to the off-site general public or radiation exposure to workers.

The subsurface repository design must be evaluated for DBEs with respect to layout (horizon and acres covered), preclosure ventilation, and waste package loading (line loading with 10 cm spacing between WPs), and drip shields. Further, the proposed alternative includes blending of fuel types having different heat loads within a WP. In addition, a different WP design is used. The following sections discuss each design element with respect to its effect on preclosure safety performance.

6.3.6.1 Areal Mass Loading (AML) and Drift Spacing

This parameter defines the MTU/acre. There is no discernable, direct effect on preclosure performance. Indirect effects result from the area required and length of access drifts. The area required affects the length of access drifts and therefore can affect the likelihood of abnormal events during WP transport. The increased total length of access drifts affects the likelihood of two types of DBEs: transporter derailment on regular rails (i.e., between switches), and rockfall onto a transporter.

The consequences of derailment are negligible; given that the impacts and drop heights remain within the design basis of the WPs. Nevertheless, such derailments increase the likelihood of worker exposure.

A rockfall in an access drift is of concern only if a rock block has a mass and impact sufficient to breach a WP, strikes a WP during transport, and if the event is credible. For the VA reference design, rockfall onto the transporter was shown to be credible, but the release scenario was deemed incredible based on the annual probability. Since the length of access drifts in the alternative is somewhat comparable to the length of the VA reference design, the event remains incredible.

EDA V covers less area than the VA reference design and will transport approximately the same number of WPs, so it is less likely to experience derailment and rockfall events than the VA reference design.

By emplacing more WPs per drift, fewer emplacement drifts are required but will be spaced farther apart than the 28 meters of the VA reference design to achieve the desired MTU loading per acre (CRWMS M&O 1997a, p.107). DBEs that are potentially affected include:

- Derailment of the WP transporter (depending on the distance traveled and number of rail switches traversed) and the number of waste packages that have to be emplaced (dependent on the size); and
- Rockfall in the access drifts (depending on the length of drifts added relative to the VA reference design), as discussed previously.

6.3.6.2 Line/Point Loading

The VA reference design is based on point load. EDA V utilizes line loading. Line loading affects potential issues for DBEs because 1) the waste package spacing is different than the VA reference design; and 2) the concepts for emplacement are different than the VA reference design

Waste Package Spacing - The WP separation is to be 10 cm (Section 4.1.4). This is contrast with the VA reference design that has spacing of several meters. The closer spacing has four potential effects on DBEs (preclosure performance).

1) It is more likely that two WPs are struck at the same time in the event of a massive rockfall, but reduction in the overall number of emplacement drifts decreases the probability of rock block initiation.
2) It is more likely that one WP strikes another during emplacement, depending on the emplacement machinery used.
3) It is more likely that WPs collide during an earthquake.
4) The alternative may require a different emplacement concept since it is unclear whether the gantry emplacement on pedestal support will be conducive to the line-loading emplacement method.

Since each WP will be designed to withstand the largest credible rockfall without breaching, an increased probability of hitting two WP does not increase the likelihood of a release. The reduction in probability of rockfall initiation in emplacement drifts, due to a fewer number of drifts, represents a small increase in defense in depth for preclosure safety performance.

Alternative WP Transport and Emplacement Concepts - Alternative WP transport and emplacement concepts may be required to accommodate the close WP spacing. Without a detailed evaluation, it appears that no new DBEs for the subsurface are introduced, but the mechanism for initiating drops and impacts will be different. The emplacement concept may affect the design of WP lifting skirt, lifting hole or fixtures. This change may affect design of handling equipment in the waste handling building (WHB) and thereby may affect the likelihood of previously identified DBEs. Since WP design will have to withstand all credible drops and impacts, no credible release scenarios should occur from the alternative transport and emplacement concepts.

6.3.6.3 Continuous Pre-Closure Ventilation

Continuous ventilation will not have an effect on DBEs associated with surface facilities or operations that handle waste forms. If the ambient temperature in the emplacement drifts is significantly different from the VA reference design during emplacement, there may be an effect on the likelihood of thermally induced failures in the remotely controlled systems for emplacing WPs.

6.3.6.4 Blending and Storage

WP blending is anticipated to be performed in the spent fuel pools of the WHB. The spent fuel pool would have to be increased in size as compared to the VA reference design. Blending may create additional DBEs since this operation will require one to two extra lifts of the waste and a significant increase in the amount of lag storage.

6.3.6.5 WP Material

The waste package is constructed of two materials. The inner material is stainless steel. This provides the structural strength and isolation boundary for the waste package. The outer material is constructed of Alloy-22, a nickel-based corrosion-resistant alloy (Section 4.1.3). These two layers are interference-fitted together, with lids welded on after inserting the waste. This configuration should still be capable of withstanding the design basis WP drops and rockfall events without breaching, but further analysis would be required to confirm this conclusion if EDA V progresses beyond the conceptual stage. Therefore, there is no impact on the repository safety systems.

6.3.6.6 Drip Shield

EDA V will employ drip shields, that resemble a "mail box" (Section 5.3), that will be placed over each WP just prior to closing. The potential mechanisms that could lead to a breach of a waste package are direct impact on the waste package by dropping of the drip shield or the installation machinery, or ramming the machinery into a waste package, due to random events, or during an earthquake. The design basis of the WPs will have to withstand any credible impacts associated with abnormal events that can credibly occur during the installation phase. Therefore, this feature does not pose a penalty for preclosure safety performance.

6.3.6.7 Portable Radiation Shields

This alternative may need to include occasional human access by using "portable" radiation shields that would be placed over waste package(s) by a remotely controlled gantry. EDA V also would require a gamma shield. Although this shield is unlikely to be portable and there are no details on the operations envisioned to install and remove the shield, it is noted that they could introduce new DBEs relative to the VA reference design. Potential DBEs associated with using the shield include dropping of the shield onto one or more WPs, and impact to the WP by malfunctions of the gantry system. If the design proceeds with the concept of portable shields, the WP design bases will have to be adjusted to assure no breach of the WP can occur.

6.3.7 Off-normal Event Recovery

Recovery equipment for off-normal conditions could be used to clean up a rockfall, while emplacement equipment could be used to recover the waste package. The equipment for emplacement and recovery of the waste packages is consistent with that proposed for the VA reference design. It is not anticipated that an off-normal event will require any additional considerations for EDA V.

6.4 FLEXIBILITY

This criterion expresses the degree to which a design would be capable of remaining viable and/or able to change in the face of future regulatory or other changes. Possible changes to consider are included in the following sections.

6.4.1 Increased Disposal Capacity

EDA V design is extremely flexible in regards to an increased capacity for the repository. The high AML enables the waste to be placed in a considerably higher waste package density, resulting in a substantial decrease in the area required for waste emplacement. Two scenarios for increase repository capacity are discussed in the following sections.

6.4.1.1 Disposal Scenario One

This acreage calculation is presented to indicate the flexibility of EDA V with respect to an increased disposal capacity. The acres required for disposal scenario one is based on the AML of 150 MTU/acres (Section 4.1.16) and the CSNF of 87,000 MTU (Section 4.1.6). The drift spacing can be adjusted to accommodate all waste including CSNF and HLW canisters.

$$\text{Acreage} = \frac{\text{CSNF (MTU)}}{\text{AML}}$$

Where: CSNF = MTU of commercial spent nuclear fuel and
AML = areal mass loading in MTU/acre.

When CSNF = 87,000 MTU (Section 4.1.6)
AML = 150 MTU/acre (Section 4.1.16)

$$\text{Acreage} = \frac{87{,}000\ \text{MTU}}{150\ \text{MTU / acre}}$$

$$\text{Acreage} = 560\ \text{acres}$$

The total acreage that is required for emplacement of 87,000 MTU of CSNF and 23,270 canisters of HLW/DSNF (Section 4.1.6) is 560 acres.

The total area available in the lower block is 760 acres (Section 4.1.8), which should be sufficient to contain the waste for disposal scenario one, a total of 560 acres. Additional emplacement space is available in the upper block if needed (Section 4.1.9).

6.4.1.2 Disposal Scenario Two

This acreage calculation is presented to indicate the flexibility of EDA V with respect to an increased disposal capacity. The acres required for disposal scenario one is based on the AML of 150 MTU/acres (Section 4.1.16) and the CSNF of 105,000 MTU (Section 4.1.6). The drift spacing can be adjusted to accommodate all waste including CSNF and HLW canisters.

$$\text{Acreage} = \frac{\text{CSNF (MTU)}}{\text{AML}}$$

Where: CSNF = MTU of commercial spent nuclear fuel and
AML = areal mass loading in MTU/acre.

When CSNF = 105,000 MTU (Section 4.1.6)
AML = 150 MTU/acre (Section 4.1.16)

$$\text{Acreage} = \frac{105{,}000\ \text{MTU}}{150\ \text{MTU / acre}}$$

$$\text{Acreage} = 700\ \text{acres}$$

The total acreage that is required for emplacement of 105,000 MTU of CSNF and 23,270 canisters of HLW/DSNF (Section 4.1.6) is 700 acres.

The total area available in the lower block is 760 acres (Section 4.1.8), which may not be sufficient to contain the waste for disposal scenario two, a total of 700 acres, and expansion into the upper repository block (Section 4.1.9) may be warranted. The requirement of cross-block drifts and stand-by drifts within the repository block may affect the layout sufficiently as to exceed the acreage available within the Lower Block. This determination is outside the scope of this report.

6.4.2 Pre-Closure Period

This section provides discussion of both a lengthened preclosure period and the option of shortening the preclosure period to a period of 10 years after emplacement is completed.

6.4.2.1 Longer Pre-Closure Period

A longer preclosure period, of up to 300 years, with preclosure ventilation and the reductions in the waste package-heat-generation rates, may be detrimental to achieving the goal of keeping water away from the drift for a longer period of time.

The impact of keeping the repository open for a longer period of time is the increased ventilation, monitoring, and maintenance operations. The extension of these operations were evaluated in the LADS phase one report, *Design Feature Evaluation #9 and #10 Timing of Repository Closure – Maintenance of Underground Features and Ground Support* (CRWMS M&O 1999g, pp. v and vi). Based on a system-by-system analysis of the repository subsurface facilities, there is reasonable expectation that the facility has the capability to remain in an open state for 300 years. Delaying closure of the repository offers numerous positive considerations and few disadvantages. The advantages include flexibility to future generations to develop their own criteria and level of certainty regarding ultimate repository performance and defers decisions on incorporation of closure features such as backfilling, drip shields, etc., until further study can be completed. The disadvantages of maintaining the repository in an open state for 300 years are all time dependent features, such as the cost impact to operate a fully operational, monitored repository for 300 years.

6.4.2.2 Closure Ten Years After Emplacement

The consideration of closing the repository 10 years after emplacement may not be realistic for this alternative. The waste may not be able to decay sufficiently to maintain its heat output such that the thermal goals (Section 4.2.3) are not violated. Additional analysis, which is outside the scope of this report, would have to be completed to determine if such a preclosure period would be viable.

6.4.3 CSNF Characteristics

This section presents discussion of the acceptance of younger fuels for emplacement into the subsurface repository.

6.4.3.1 Five-Year-Old Fuel

The control of heat output from the waste packages is essential to this alternative. The introduction of five-year-old fuel presents a complication to the design. Five-year-old fuel should produce a much greater heat output. Introducing this additional high heat source in the emplacement drifts would require an increase ventilation airflow in order to control the heat conduction into the drift walls, and to maintain the waste package cladding below its thermal goal (Section 4.2.3). It may also be possible to balance the thermal load for the repository; this fuel could be placed along the outside edge of the repository block or with a greater spacing between the waste packages. Five-year old-fuel may be more difficult to blend; therefore additional storage on surface may be required.

6.4.3.2 No Constraints on Fuel Age

Since the key to success of this alternative is the control of the heat output from the waste packages some constraints on the fuel age may be necessary. This constraint is in reference to younger fuel than that reflected in the alternative's waste stream (Section 4.1.3). A more detailed analysis of younger fuel and the heat output associated with the younger fuel would be necessary if this alternative is developed beyond the conceptual stage.

6.4.4 Late Design Changes

This section presents discussion of late design changes on the conceptual design for EDA V, and the implication of such decisions.

6.4.4.1 Remote to Human Access

EDA V may be flexible enough to allow human access. Additional ventilation capacity may be incorporated into the repository design in order to achieve acceptable access temperatures in the emplacement drifts. The major constraint to human access is shielding of the waste packages. If human access were incorporated into this alternative, portable waste package shields would not be sufficient to allow uncontrolled entrance into the emplacement drifts. If this alternative develops beyond the conceptual stage, and human access is a desired feature, a shielded waste package may be necessary to sufficiently protect workers while occupying the emplacement drifts.

6.4.4.2 Change in Thermal Loading

In the event that the high thermal loading as designed for EDA V is not viable, as determined by the performance confirmation program, the design may be modified into a low thermal loading option by point-loading the waste packages as opposed to the line-loading currently incorporated.

A change in the AML of the repository would increase the required area of the repository block. Depending on how drastic a change to the AML is needed, expansion to the south end of the Lower Block is available as well as expansion into the Upper Block (Section 4.1.9). This expansion would not present difficulties in waste isolation during construction, since a contingency for expansion has been incorporated into the conceptual layout of EDA V (Section 5.4.3). The South Ramp and an exhaust shaft could be available for continued development, if required, in the Lower Block with full waste emplacement in the Lower Block.

6.4.4.3 Modifications to the Waste Package Construction and Heat Output

Modifications to the waste package construction and a change to the temperature field within the waste package components could be presented by introducing integral fillers, elimination of blending, introducing a significant waste package size change, and/or introducing rod consolidation.

These modifications would needed to be evaluated on an individual basis, if such a change is desired. A change in the waste package configuration or construction may require re-evaluation of the preclosure ventilation rate.

6.4.4.4 Other Design Changes

The addition of a getter barrier or a change in the drip shield configuration should not impact this alternative. However, the placing of backfill may prove beneficial for EDA V. The placing of backfill in the emplacement drifts upon closure may create an extension of the heating period, since the backfill will aid in heat retention within the emplacement drifts. If backfill were added to this alternative, thermal analyses would have to be completed in order to determine the post-closure impacts.

6.4.5 Disruptive Events

This section assesses the flexibility of EDA V with respect to volcanism, seismicity, human intrusion, and criticality, more commonly referred to as disruptive events.

6.4.5.1 Seismicity

There are several effects that seismic disturbances can have on repository performance, including direct effects such as rockfall damage to waste packages or container disruption by vibratory ground motion or fault displacement (CRWMS M&O 1998e, p. 10-57). Indirect effects, such as alteration of flow paths near the repository or in the saturated-zone, or changes in the water table elevation, are also possible. The EDA designs are not discrimminable based on indirect effects, so indirect effects of seismicity to the EDA designs were not evaluated.

Rockfall is expected to be the primary source of waste package disturbances (CRWMS M&O 1998e, p. 10-57). Waste package damage could result in significantly increased radionuclide source terms for groundwater based releases.

Both ground shaking and thermo-mechanical stress changes may induce rockfall (CRWMS M&O 1998e, p. 10-57). The superposition of ground shaking on rock already experiencing thermo-mechanical stresses may cause more, or larger, sections of the repository tunnel to fall. It is not expected that there will be any significant difference in the response of the packages to rockfall from the two sources. Whether the falling rock damages waste packages depends on several factors in CRWMS M&O (1998e, p.10-61):

- Whether the rock hits a package or falls between the packages.
- Whether the waste package wall is so thin that the rock can damage it.
- The availability of a sufficiently large rock.

The consequences of a rockfall are discussed in more detail in Section 6.3.6.1.

All EDA designs use a drip shield with a strong corrugated design that provides essentially complete protection from rockfall (CRWMS M&O 1999w, p.7). It was assumed that the 2-cm titanium drip shield is able to withstand all rockfalls up to 10,000 years, and that natural backfill exists after 10,000 years, protecting the WPs from rockfalls. Even if there were no drip shield, the WPs would degrade so slowly that they would be able to withstand the rockfalls that create natural backfill well beyond the time at which that backfill becomes complete. Therefore, EDA 5 is unaffected by seismicity (highly flexible) and is indistinguishable from the other EDAs in this regard.

6.4.5.2 Human Intrusion

Guidance from the NRC will be required before PA can evaluate human intrusion. The uncertainty in how this scenario will be addressed prevents an assessment of the flexibility of the EDAs with respect to human intrusion at this time.

The human intrusion analysis for EDA V assumes that a hole is drilled through the overlying rock mass into the repository and down to the saturated zone, intersecting a waste package in the process. Characteristics of the drilling process are not specified. Instead, the presence of a hole is assumed and treated as a fast hydrologic path, from the surface of the mountain, through the center of a waste package, to the saturated zone, meaning that the hole represents a faster path for groundwater flow relative to the surrounding rock. The drilling incident is assumed to occur at 100 years. The solubility of the radionuclides and the contact area of water to the waste would affect the dose rate at 10,000 years.

Water may enter the drill hole through two methods. The first method is direct surface feed from rainstorm events. The second method is through fracture flow in the rock mass, where the hole intersects major water carrying fractures.

One complicating factor is the thermal output from the repository with an areal mass loading of 150 MTU/acre. The heat generated to achieve complete pillar dry out for at least 10,000 years should prevent water from contacting the waste. The quantity of water and flow rate of the water within the drill hole may be able to quench the surrounding rock mass sufficiently to allow water to contact the waste and be transported to the saturated zone. This may be possible if a large enough quantity of water moving at a high flow rate is available. The introduction of water into the emplacement drifts by a drill hole may impact the emplacement drift environment such as to cause corrosion effects on the waste packages or introduce organic and/or microbial matter. However, the higher thermal loading of EDA V may cause significant dryout in less than 8,000 years, and therefore will not improve the performance of EDA V with respect to inadvertent human intrusion, and relative to the other EDAs, over the 10,000 year time-frame (CRWMS M&O 1999w, p.8).

6.4.5.3 Volcanism

Basaltic igneous activity includes volcanic eruptions and intrusive or extrusive events (in which molten igneous material is cooled within the earth or on the earth's surface, respectively) (CRWMS M&O 1999w, p. 2). Conceptually, a volcano could disperse radionuclides from disrupted waste packages directly into the atmosphere where a plume could carry radionuclides to a population (direct release). Intrusions which did not carry waste to the surface could compromise waste packages, resulting in waste residing in solidified magma which then could be contacted by groundwater, meaning more ready availability for contamination of groundwater (enhanced source term). Intrusive features, such as dikes, could possibly alter groundwater flow either by blocking existing paths or concentrating flow toward certain areas (indirect effects).

The design characteristics that distinguish the EDAs and that could affect the outcome of volcanism were identified (CRWMS M&O 1999w, p.3) as repository location, repository area and thermal loading, waste package and drift spacing, orientation, and arrangement, and waste package fuel content (metric tons uranium/package). The effect of these parameters on the response of EDA V to volcanism was evaluated (CRWMS M&O 1999w, p.5). Relative to the VA, EDA V was found to have somewhat decreased performance by a factor of two because of the effect of line loading on the number of waste packages affected by enhanced source terms effects. EDA V has a moderately high degree of flexibility with respect to volcanism.

6.4.5.4 Criticality

In-package criticality requires that the engineered control measures in the waste package fail and other conditions, such as the presence of water, will occur (CRWMS M&O 1999w, p. 5). Three factors are required for there to be a potential criticality: a sufficient quantity of fissile fuel; a moderator (e.g., water) of the fission neutrons; insufficient neutron absorbers (e.g., boron) for the amount of fissile material present (CRWMS M&O 1999w, p.6). The calculated probability of a criticality for EDA V is smaller than for the VA by a factor of 7 to 10, and characterizes EDA V as having a high degree of flexibility with respect to criticality.

7. CONCLUSIONS/RECOMMENDATIONS

The LADS Group outlined initial concept parameters for EDA V (Section 4.1.16). This original concept included a factor-of-two rod consolidation, 25 years of pre-emplacement aging and 25 years of preclosure ventilation. The results of initial findings indicated that EDA V needed to deviate substantially from the initial parameters proposed by the LADS Group (Section 5.1) and final conceptual design for EDA V consists of the following design elements:

- Areal mass loading of 150 MTU/acre for CSNF only (Section 4.1.16);
- The footprint covered 420 acres within the Lower Block (Appendix A, Section A.2);
- Waste packages are emplaced by a line-loading method (Section 5.4.1);
- The WP construction is a single CRM package (Section 5.5.2), constructed with an interior cylindrical shell of stainless steel. This interior shell will be interference fitted to an exterior cylindrical shell made of Alloy 22;

- The WP is based on a blended 21-PWR (Section 4.1.3);
- Waste package PWR thermal output is 11.8 kW maximum and 9.8 kW average (Section 5.5.1);
- Emplacement drifts are 5.5 meters in diameter, with a 32 meter spacing (Section 5.4.1);
- A preclosure ventilation rate of approximately two to five cubic meters per second will be employed (Section 5.8); and
- A Titanium-7 drip shield is installed over the WPs before closure (Section 5.3).

A conceptual layout was developed for EDA V (Section 5.4.3). The layout, as shown in Figure 2, contains openings that are sized and arranged in a similar configuration as the VA reference design. A total of 54 emplacement drifts will be required for emplacement of the 70,000 MTU of spent nuclear fuel and high level waste packages. A total of four ventilation shafts, one intake and three exhausts are anticipated for the layout in order to provide sufficient air quantities to the emplacement drifts. Two exhaust mains will be located below the level of the emplacement drifts to provide exhaust from the emplacement drifts.

In addition, the evaluation has confirmed that the decision to closure of the repository is possible 50 years after start of emplacement (Section 5.7.5). The licensing and preclosure encompassed by the MGR extends from the year 2002 through 2066 (Section 6.2.2). This schedule is based on the VA reference design schedule with the monitoring period shortened such that the total preclosure period from start of emplacement is 50 years.

The evaluation of EDA V has shown that the design goal of keeping the temperature of the drift wall below 225°C (Section 4.2.3) can be met (Section 5.7.5). The goal of keeping the temperature of the waste package cladding below 350°C (Section 4.2.3) has not been confirmed in this document, but is anticipated to be met. Further analysis would be required if EDA V were to develop beyond the conceptual stage.

Based on the preliminary, central estimate, performance assessment, the safety margin for EDA V is 24.98 mrem per year (Section 6.1.1). The peak dose rate within 10,000 years is 0.02 mrem per year at approximately 7,000 years after closure. The peak dose rate within 1 million years is 200 mrem per year at 720,000 years. It would take 300,000 years to reach the screening dose rate of 25 mrem per year.

Within the first 10,000 years, parts of the repository environment could have aggressive conditions for a relatively long period of time (Section 6.1.2.3). Calculations have indicated that the waste package temperatures do not cool to below 100°C until after 3,000 years and the relative humidity has increased to greater than 80% within less than 1,000 years. This temperature and humidity profile may lead to localized corrosion on some of the waste packages in the aggressive environment, which introduces uncertainties in the post-closure function. A corrosive environment could be detrimental to both waste isolation and public/environmental safety. These conditions also indicate that EDA V has not met the design goal of keeping the drifts dry for several thousand years because relative humidity returned to greater than 80% within less than 1,000 years. Further studies would be required if EDA V progresses beyond the conceptual stage.

In regards to licensing and regulatory issues, the uncertainties of the post-closure functions (Section 6.1.2.3) could present complexities that may be difficult to overcome. Specifically, it would be difficult to demonstrate the post-closure function of water being driven off for the length of time anticipated and needed to establish complete pillar dry out.

Enhanced Design Alternative V provides defense in depth (Section 6.1.3) including improvement of the natural barriers by a relocation of the repository to the Lower Block, the inclusion of a drip shield, modification to the waste package construction, and the concept of high thermal loading. The number of defense in depth layers indicated make it unlikely that radioactive waste can be transported away from the repository within a 10,000-year time frame.

No unusual issues were identified for the construction, operations, and maintenance for the EDA V conceptual design (Section 6.3). The addition of WP blending and preclosure ventilation in the conceptual design of EDA V may present implications to the reliability, availability and maintainability of equipment (Section 6.3.2).

The flexibility of EDA V is demonstrated in the concept's ability to accommodate an increased capacity, if so authorized (Section 6.4.1). EDA V is less flexible in regards to shortening the preclosure period to less than 50 years (Section 6.4.2.2) and accepting younger fuel, such as five year old fuel (Section 6.4.3.1). There may be potential problems with maintaining the waste package cladding temperature in these situations.

EDA V does show some flexibility in regards to late design changes (Section 6.4.4). The layout and design would have to change, but some of the analyses could be simplified by using lower temperature profiles in the emplacement drift. The total cost estimate for EDA V was based upon design element details provided that affect the MGR subsurface, surface, waste package, and engineered barrier related costs (Section 6.2.1). The total life cycle cost for EDA V is $20.0 billion with a net present value of $10.8 billion.

The results and conclusions discussed in this evaluation are based on input data presented in Section 4. As indicated by "TBV", some of the input data in this evaluation are considered preliminary and unqualified and therefore the conclusions and recommendations presented in this document are preliminary and considered TBV.

8. REFERENCES

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1996. *Thermal Loading Study For FY 1996 Volume I of II.* B00000000-01717-5705-00044 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19961217.0121.

CRWMS M&O 1997a. *Repository Subsurface Layout Configuration Analysis.* BCA000000-01717-0200-00008 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19971201.0879.

CRWMS M&O 1997b. *Waste Quantity, Mix and Throughput Study Report.* B00000000-01717-5705-00059 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19971210.0628.

CRWMS M&O 1997c. *Software Qualification Report for LYNX Ver. 4.5.* DI: 30016-2003 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981130.0398.

CRWMS M&O 1998a. *Preliminary List of Waste Package Designs for VA.* BBA000000-01717-3300-00008 REV 02. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980409.0021.

CRWMS M&O 1998b. *Controlled Design Assumptions Document.* B00000000-01717-4600-00032 REV 05. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980804.0481.

CRWMS M&O 1998c. *Subsurface Facility System Description Document.* BCA000000-01717-1705-00014 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980826.0161.

CRWMS M&O 1998d. *Activity Evaluation for Support Development of Repository Design Alternatives – Work Package 12012382M2.* Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981224.0055.

CRWMS M&O 1998e. *Total System Performance Assessment – Viability Assessment (TSPA-VA) Analyses Technical Basis Document – Chapter 10, Disruptive Events.* B00000000-01717-4301-00010 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0010.

CRWMS M&O 1998f. Reserved.

CRWMS M&O 1999a. *Design Input Request for LADS Phase II EDA Evaluations.* Tracking No. LAD-SSR-99112.R. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990209.0147.

CRWMS M&O 1999b. *Design Input Transmittal for Enhanced Design Alternatives I, IV & V Input.* Tracking No. SSR-WP-99087.T. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990301.0059.

CRWMS M&O 1999c. *Design Input Request for LADS Phase II EDA Evaluations.* Tracking No. LAD-SSR-99112.Ra. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990310.0061.

CRWMS M&O 1999d. *Technical Document Preparation Plan (TDPP) for Enhanced Design Alternatives (EDA) I, IV and V.* B00000000-01717-4600-00155 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990310.0080.

CRWMS M&O 1999e. *Identification of Potential Repository Expansion Areas.* BCA000000-01717-0210-00002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990126.0231.

CRWMS M&O 1999f. *ANSYS Calculations in Support of Enhanced Design Alternatives.* B00000000-01717-0210-00074 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990218.0240.

CRWMS M&O 1999g. *Design Feature Evaluation #9 and #10, Timing of Repository Closure – Maintenance of Underground Features and Ground Support.* BCAH00000-01717-2200-00001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990331.0128.

CRWMS M&O 1999h. *Design Input Transmittal for Enhanced Design Alternatives I, II, IIIa, IIIb, IV, and V. Best Available Data from NUFT (Thermal Hydrology), WAPDEG (Waste Package Degradation) and RIP (Total System Performance Assessment) Computations*. Tracking No. SSR-PA-99117.Ta. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990402.0201.

CRWMS M&O 1999i. *License Application Design Selection Feature Report: Waste Package Corrosion Resistant Materials (Metal and Ceramic) (Design Feature #14)*. B00000000-01717-2200-00216 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990317.0117.

CRWMS M&O 1999j. *Design Input Transmittal for Total System Performance Assessment Calculations for EDA V*. Tracking No. SSR-PA-99117.Tb. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990402.0195.

CRWMS M&O 1999k. *Two (2) Lynx Archive Tapes - Geology Layout for the EDA1 and EDA5 Design Options*. B00000000-01717-2200-00224 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990316.0223.

CRWMS M&O 1999l. *Design Input Transmittal for Average Waste Package Thermal Output at Loading*. Tracking No. LAD-WP-99183.T. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990401.0147.

CRWMS M&O 1999m. *License Application Design Selection Cost Summary Report*. B00000000-01717-5700-00035 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990407.0233.

CRWMS M&O 1999n. *Scoping Study of Thermal Analysis for License Application Design Selection, Phase 2, E-Mail Sent February 15, 1999*. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990518.0278.

CRWMS M&O 1999o. *Enhanced Design Alternative V, Conceptual Layout*. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990518.0277.

CRWMS M&O 1999p. *EDA Ventilation Estimate*. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990505.0330.

CRWMS M&O 1999q. *Design Input Transmittal for Enhanced Design Alternative V Occupational Safety and Health Evaluation*. Tracking No. SSR-S&H-99151.T. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990323.0240.

CRWMS M&O 1999r. *Classification of the Preliminary MGDS Repository Design*. B00000000-01717-0200-00134 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981103.0546.

CRWMS M&O 1999s. *Design Feature Evaluation #11 – Drift Diameter*. BCAA00000-01717-2200-00001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990331.0150.

CRWMS M&O 1999t. *Low Thermal Loading Alternative Evaluation.* B00000000-01717-5705-00127 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990504.0071.

CRWMS M&O 1999u. *Rock Fall and Vertical Drop Calculations of Waste Packages.* BBA000000-01717-0210-00058 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990518.0261.

CRWMS M&O 1999v. *Design Feature Evaluation #26: Higher Thermal Loading.* B00000000-01717-2200-00218 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990505.0449.

CRWMS M&O 1999w. *Design Input Transmittal for Systems Analysis input to the evaluation of License Application Design Selection (LADS) Phase II, Enhanced Design Alternative Disruptive Events Evaluation.* Tracking No. LAD-SEI-99179.Ta. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990610.0182.

CRWMS M&O 1999x. *Design Input Transmittal for Surface Facility Operations Input to Enhanced Design Alternative V.* Tracking No. SSR-SUF-99154.T. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990616.0111.

CRWMS M&O 1999y. *Commercial Waste Stream Studies to Support Enhanced Design Alternatives.* B00000000-01717-0210-00092 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990604.0089.

CRWMS M&O 1999z. *Design Input Transmittal for Enhanced Design Alternatives I, IV & V Output.* Tracking No. SSR-WP-99087.Td. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990615.0037.

DOE (U.S. Department of Energy) 1998a. *Quality Assurance Requirements and Description.* DOE/RW-0333P REV 8. Washington, D.C.: DOE Office of Civilian Radioactive Waste Management (OCRWM). ACC: MOL.19980601.0022.

DOE 1998b. *Viability Assessment of a Repository at Yucca Mountain, Costs to Construct and Operate the Repository, Volume 5.* DOE/RW-0508. Washington, D.C.: DOE OCRWM. ACC: MOL.19981007.0032.

DOE 1998c. *Viability Assessment of a Repository at Yucca Mountain, Total System Performance Assessment, Volume 3.* DOE/RW-0508. Washington, D.C.: DOE OCRWM. ACC: MOL.19981007.0030.

Hardin, E.L.; Blair, S.C.; Bourcier, W.L.; Buscheck, T.A.; Chesnut, D.A.; DeLoach, L.D.; Glassley, W.E.; Johnson, J.W.; Knapp, R.B.; Lee, K.; Meike, A.; Meyers, K.; Nitao, J.J.; Palmer, C.E.; Rogers, L.L.; Rosenberg, N.D.; Viani, B.E.; Wittwer, C.; and Wolery, T.J. 1998. *Near-Field/Altered-Zone Models Report.* UCRL-ID-129179DR. Livermore, California: Lawrence Livermore National Laboratory. ACC: MOL.19980504.0577.

9. APPENDICES

APPENDIX A

EMPLACEMENT AREA DEVELOPMENT

APPENDIX A
EMPLACEMENT AREA DEVELOPMENT

A.1 DRIFT SPACING CALCULATION

Two sets of waste package quantities and lengths will be compared to determine the impact of varying WP construction and WP numbers. The first set of calculation involve calculating the drift spacing for the WP types and quantities for Non-VA assumptions (Section 4.1.1) and using the lengths of the VA reference design WPs (Section 4.1.2). The second set of calculations will calculate the drift spacing using the single CRM waste package quantities and lengths (Section 4.1.3).

A.1.1 Using Non-VA Assumption WP Quantities and VA Reference Design Lengths

The waste packages will be emplaced in a line-loaded configuration, and this will dictate the method of calculating the required emplacement length. The total length of the waste packages is calculated as the summation of multiplying the number of waste packages (Section 4.1.1) by the length of the waste package (Section 4.1.2) for each waste package type, shown in Table A-1.

Table A-1. Total Length of Waste Packages

Waste Package Type		Number of Waste Packages	Length of Waste Package (meters	Total Length (meters)
21-PWR	No Absorber	1,638	5.335	8,739
	Absorber Plates	2,673	5.335	14,260
	Control Rods	121	5.335	646
12-PWR	Long	150	5.871	881
44-BWR	No Absorber	696	5.335	3,713
	Absorber Plates	2,107	5.335	11,241
24 BWR	Thick Plates	42	5.335	224
5-DHLW		1,249	3.790	4,734
5-DHLW	Long	414	5.367	2,222
Navy	Combined	285	5.848	1,667
DOE/Other		598	5.530	3,307
TOTAL		9,973		51,634

The waste packages are spaced within the emplacement drifts at constant 0.1 meter (Section 4.1.4) spacing or gap. The total gap length for emplacement of all 9,973 waste packages is therefore 997.3 meters.

The total required length of emplacement drift for emplacement of the 9,973 waste packages is the total length of the waste packages plus the gap length, which is 52,631 meters.

The drift spacing is an integral part of achieving the areal mass loading of the repository. The drift spacing calculation is based on the areal mass loading of 150 MTU/acre (Section 4.1.16), the required emplacement length and the total MTU of commercial SNF, which is 63,000 MTU (Section 4.3.6).

$$DS(m) = \frac{CSNF(MTU) \ \ x \ \ 4{,}047\,m^2/acre}{AML(MTU/acre) \ \ x \ \ L_u(m)}$$

Where:

DS	=	drift spacing (meters),
CSNF	=	commercial spent nuclear fuel (MTU),
AML	=	areal mass loading (MTU/acre), and
L_u	=	required emplacement length (m).

When:

CSNF	=	63,000 MTU (Section 4.3.6),
AML	=	150 MTU/acre (Section 4.1.16), and
L_u	=	52,631 m.

$$DS = \frac{63{,}000\,MTU \ \ x \ \ 4{,}047\,m^2/acre}{150\,MTU/acre \ \ x \ \ 52{,}631\,m}$$

$$DS = 32.3\,meters$$

The drift spacing of 32 meters will be used to line-load 63,000 MTU of commercial SNF and 7,000 MTU of HLW at an AML of 150 MTU/acre.

A.1.2 Affect of Single CRM Waste Package Lengths and Quantities

The VA assumption produces a larger quantity of CSNF waste packages (Section 4.1.3) and the single CRM waste package construction indicates a change in the waste package lengths (Section 4.1.3). The following calculation is to determine the impact of both changes in the quantity of waste packages and in the length of the waste package. The total length of the waste packages is calculated as the summation of multiplying the number of waste packages (Section 4.1.3) by the length of the waste package (Section 4.1.3) for each waste package type, as shown in Table A-2.

Table A-2. Total Length of Waste Packages (VA Assumption)

Waste Package Type	Number of Waste Packages	Length of Waste Package (meters)	Total Length (meters)
21 PWR – no absorbers	1,648	5.275	8,693
21 PWR – absorber plates	2,683	5.275	14,153
21 PWR – control rods, no absorbers	132	5.275	696
12 PWR – long, absorber plates	155	5.781	896
44 BWR – no absorber plates	707	5.275	3,729
44 BWR – absorber plates	2,119	5.275	11,178
24 BWR – thick absorbers	49	5.225	256
DHLW/DOE	1,249	3.730	4,659
DHLW/DOE – long	414	5.367	2,222
Navy – short and long	285	5.878	1,675
DOE/Other	598	5.560	3,325
Total	10,039		51,481

The waste packages are spaced within the emplacement drifts at constant 0.1 meter (Section 4.1.4) spacing or gap. The total gap length for emplacement of all 10,039 waste packages is therefore 1003.9 meters.

The total required length of emplacement drift for emplacement of the 10,039 waste packages is the total length of the waste packages plus the gap length, which is 52,485 meters.

The drift spacing is an integral part of achieving the areal mass loading of the repository. The drift spacing calculation is based on the areal mass loading of 150 MTU/acre (Section 4.1.16), the required emplacement length and the total MTU of commercial SNF, which is 63,000 MTU (Section 4.3.6).

The drift spacing is calculated for comparison.

$$DS(m) = \frac{CSNF(MTU) \quad x \quad 4{,}047\, m^2/acre}{AML(MTU/acre) \quad x \quad L_u(m)}$$

Where:	DS	=	drift spacing (meters),
	CSNF	=	commercial spent nuclear fuel (MTU),
	AML	=	areal mass loading (MTU/acre), and
	L_u	=	required emplacement length (m).

When:	CSNF	=	63,000 MTU (Section 4.3.6),
	AML	=	150 MTU/acre (Section 4.1.16), and
	L_u	=	52,485 m.

$$DS = \frac{63{,}000\, MTU \quad x \quad 4{,}047\, m^2/acre}{150\, MTU/acre \quad x \quad 52{,}485\, m}$$

$$DS = 32.4\ meters$$

There is minimal change in required emplacement length, which results in a drift spacing of approximately 32 meters.

A.1.3 Summary of Drift Spacing Calculations

There is no impact of either using a modified waste package construction, or varying the quantities of waste packages due to VA versus non-VA waste assumptions. A drift spacing of 32 meters will be incorporated into the conceptual design of EDA V.

A.2 DETERMINATION OF ACREAGE

The required emplacement length and the drift spacing for the non-VA assumption waste package quantities and VA reference design lengths (Section A.1.1) was used to determine the acreage required for emplacement of the waste.

$$\text{Acreage} = \frac{L_u(\text{m}) \times DS(\text{m})}{4{,}047\,\text{m}^2/\text{acre}}$$

Where: L_u = required emplacement length (m) and
DS = drift spacing (m).

When L_u = 52,625 meters (Section A.1.1) and
DS = 32.3 meters (Section A.1.1).

$$\text{Acreage} = \frac{52{,}625\,\text{meters} \times 32.3\,\text{meters}}{4{,}047\,\text{m}^2/\text{acre}}$$

$$\text{Acreage} = 420\,\text{acres}$$

The total acreage that is required for emplacement of the statutory limit of 70,000 MTU is 420 acres.

To verify the acreage complies with an AML of 150 MTU/acre (Section 4.1.16), the AML is back checked with the following calculation.

$$\text{AML} = \frac{\text{CSNF(MTU)}}{\text{Acreage}}$$

Where: AML = areal mass loading (MTU/acre),
CSNF = commercial spent nuclear fuel (MTU), and
Acreage = acreage required for emplacement area (acres).

When: CSNF = 63,000 MTU (Section 4.3.6) and
Acreage = 420 acres.

$$\text{AML} = \frac{63{,}000\,\text{MTU}}{420\,\text{acres}}$$

$$\text{AML} = 150\,\text{MTU/acre}$$

The proposed layout requires 420 acres for waste emplacement, incorporating a 150 MTU/acre areal mass loading. A discussion of required acreage for increased disposal capacities is located in Section 6.4.1.

A.3 NUMBER OF EMPLACEMENT DRIFTS

The excavation length of the emplacement drifts is from the door of the emplacement drift on the east side to the door of the emplacement drift on the west side. The excavation lengths are within the dotted outline, a representation of the emplacement drift door locations. Table A-3 tabulates the lengths from CRWMS M&O (1999o, p.3). The standoff lengths (Section 4.3.2) for each emplacement drift are outlined in Table A-4. The thermal /radiological standoff distance is 30 m, 15 m at each end of the emplacement drift; and the physical standoff distance around the central ventilation raise is a total of 4 meters for each emplacement drift. The drift length available for emplacement is the usable length of each emplacement drift. The usable length is calculated as the excavation lengths of each drift (Table A-3) subtract the total standoff length for each drift (Table A-4). The cumulative usable emplacement length and standoff lengths are shown in Table A-5. Empty drifts (Section 4.3.3) are unusable lengths.

Fifty-four emplacement drifts, with 53,174 meters (Table A-5) of cumulative usable emplacement length is required for emplacement of the waste, since the waste package arranged in a line-loaded method requires a minimum of 52,631 meters of required emplacement length (Section A.1.1).

Table A-3. Emplacement Drift Excavation Length

Drift Number	Measured Excavation Length (m)	Cumulative Excavation Length (m)
1	505	505
2	550	1,055
3	590	1,645
4	635	2,280
5	680	2,960
6	725	3,685
7	770	4,455
8	815	5,270
9	860	6,130
10	905	7,035
11	950	7,985
12	995	8,980
13	1,035	10,015
14	1,080	11,095
15	1,125	12,220
16	1,170	13,390
17	1,215	14,605
18	1,235	15,840
19	1,250	17,090
20	1,265	18,355
21	1,285	19,640
22	1,300	20,940
23	1,305	22,245
24	1,305	23,550
25	1,305	24,855
26	1,310	26,165
27	1,310	27,475
28	1,310	28,785
29	1,315	30,100
30	1,315	31,415
31	1,315	32,730
32	1,320	34,050
33	1,320	35,370
34	1,320	36,690
35	1,320	38,010
36	1,325	39,335
37	1,325	40,660
38	1,325	41,985
39	1,330	43,315
40	1,325	44,640
41	1,310	45,950
42	1,290	47,240
43	1,270	48,510
44	1,250	49,760
45	1,220	50,980
46	1,175	52,155
47	1,135	53,290
48	1,090	54,380
49	1,050	55,430
50	1,005	56,435
51	965	57,400
52	930	58,330
53	905	59,235
54	875	60,110
Total	60,110	

Table A-4. Standoff Lengths

Drift Number	Therm/Rad Standoff Length (m)	Physical Standoff Length (m)	Total Standoff Length (m)	Cumulative Standoff Length (m)
1	30	4	34	34
2	30	4	34	68
3	30	4	34	102
4	30	4	34	136
5	30	4	34	170
6	30	4	34	204
7	30	4	34	238
8	30	4	34	272
9	30	4	34	306
10	30	4	34	340
11	30	4	34	374
12	30	4	34	408
13	30	4	34	442
14	30	4	34	476
15	30	4	34	510
16	30	4	34	544
17	30	4	34	578
18	30	4	34	612
19	30	4	34	646
20	30	4	34	680
21	30	4	34	714
22	30	4	34	748
23	30	4	34	782
24	30	4	34	816
25	30	4	34	850
26	30	4	34	884
27	30	4	34	918
28	30	4	34	952
29	30	4	34	986
30	30	4	34	1,020
31	30	4	34	1,054
32	30	4	34	1,088
33	30	4	34	1,122
34	30	4	34	1,156
35	30	4	34	1,190
36	30	4	34	1,224
37	30	4	34	1,258
38	30	4	34	1,292
39	30	4	34	1,326
40	30	4	34	1,360
41	30	4	34	1,394
42	30	4	34	1,428
43	30	4	34	1,462
44	30	4	34	1,496
45	30	4	34	1,530
46	30	4	34	1,564
47	30	4	34	1,598
48	30	4	34	1,632
49	30	4	34	1,666
50	30	4	34	1,700
51	30	4	34	1,734
52	30	4	34	1,768
53	30	4	34	1,802
54	30	4	34	1,836
Total	1,620	216	1,836	

Table A-5. Usable Emplacement Length

Drift Number	Excavation Length (m)	Standoff Length (m)	Useable Emplacement Length (m)	Cumulative Usable Emplacement Length (m)
1	505	34	471	471
2	550	34	516	987
3	590	34	556	1,543
4	635	34	601	2,144
5	680	34	646	2,790
6	725	34	691	3,481
7	770	34	736	4,217
8	815	34	781	4,998
9	860	34	826	5,824
10	905	34	871	6,695
11	950	34	916	7,611
12	995	34	961	8,572
13	1,035	34	1,001	9,573
14	1,080	34	1,046	10,619
15	1,125	34	1,091	11,710
16	1,170	34	1,136	12,846
17	1,215	34	1,181	14,027
18	1,235	34	0	14,027
19	1,250	34	1,216	15,243
20	1,265	34	1,231	16,474
21	1,285	34	1,251	17,725
22	1,300	34	1,266	18,991
23	1,305	34	1,271	20,262
24	1,305	34	1,271	21,533
25	1,305	34	1,271	22,804
26	1,310	34	1,276	24,080
27	1,310	34	1,276	25,356
28	1,310	34	1,276	26,632
29	1,315	34	1,281	27,913
30	1,315	34	1,281	29,194
31	1,315	34	1,281	30,475
32	1,320	34	1,286	31,761
33	1,320	34	1,286	33,047
34	1,320	34	1,286	34,333
35	1,320	34	1,286	35,619
36	1,325	34	0	35,619
37	1,325	34	1,291	36,910
38	1,325	34	1,291	38,201
39	1,330	34	1,296	39,497
40	1,325	34	1,291	40,788
41	1,310	34	1,276	42,064
42	1,290	34	1,256	43,320
43	1,270	34	1,236	44,556
44	1,250	34	1,216	45,772
45	1,220	34	1,186	46,958
46	1,175	34	1,141	48,099
47	1,135	34	1,101	49,200
48	1,090	34	1,056	50,256
49	1,050	34	1,016	51,272
50	1,005	34	971	52,243
51	965	34	931	53,174
52	930	34	0	53,174
53	905	34	0	53,174
54	875	34	0	53,174
Total	60,110	1,836	53,174	

APPENNDIX B

ENVIRONMENTAL CONSIDERATIONS

APPENDIX B
ENVIRONMENTAL CONSIDERATIONS

Details in this appendix are not subject to QARD (DOE 1998a) requirements. The categories for discussion are similar to those provided by the EIS Support Group in CRWMS M&O (1999s, pp. A-21 to A-25).

Impacts to Land Use and Ownership - The quantity of excavated rock to be removed from the subsurface should be reduced in comparison to the Viability Assessment (VA) reference design. Therefore the surface area that is required to store this rock should be decreased. Concrete lining and invert will not be required in this alternative. It can be assumed that the lay down area originally designated for the batch plant, concrete inverts and liner segments will be approximately the same area required for the steel ground support, invert and drip shield lay down. This alternative requires blending of the commercial spent nuclear fuel. Therefore, additional surface area will be required for the blending facilities, a 43% increase in pool size is anticipated.

Impacts to Air Quality - There should be a decrease in the production of fugitive dust due to the decrease in the quantity of excavated rock. A decrease in diesel gas emissions should be anticipated, since less surface mobile equipment would be required to maintain a reduced stockpile size. The emission of radon-222 gas is proportional to the surface area of exposed rock surface within the subsurface facilities. Since less excavation is anticipated with this alternative, decreased radon emissions in the air from the subsurface should be realized.

Impacts to Hydrology, Including Surface Water and Groundwater - One of the goals of this alternative is to drive moisture away from the waste packages with a high areal mass loading. The increase in the temperature profile will be managed with ventilation to control the rock wall temperatures. The temperatures, expected in the rock wall in this alternative, are comparable to the VA reference design and therefore, should not present any additional effects to the ground water table.

Impacts to Biological Resources and Soils - As indicated in the impacts to land use, surface stockpiles of excavated rock should be reduced due to less subsurface excavation required. This is potentially a reduction of the disturbed area. The subsurface drift wall temperature limit may be increased to 225°C, in comparison to the 200°C limit in the VA reference design. It is not anticipated that this increase in temperature will be adverse to the biological resources and soils above the repository area.

Impacts to Cultural Resources - No change from the VA reference design.

Socioeconomic Impacts – No change from the VA reference design.

Impacts to Occupational and Public Health and Safety - No change from the VA reference design.

Noise Impacts - No change from the VA reference design.

Impacts on Aesthetics - The scenic quality of the area will be affected by the presence of the blending facility as well as the additional lighting required for this facility. The reduced stockpile of excavated rock should benefit the aesthetics of the site.

Impacts to Utilities, Energy, Materials, and Site Services - Changes in the essential design elements for this alternative necessitates change to the construction materials. Essential materials will be required for the steel and mesh ground support, the steel invert with ballast material and the grade-seven titanium for the drip shields. Since a steel and mesh ground support will be utilized, the materials, required for the concrete invert and liner, are no longer necessary. There will be additional utilities and energy required for the blending and aging facilities and operations. Due to the additional operations, the site services will be increased.

Impacts to Management of Repository Generated Waste and the Use of Hazardous Materials - No change from the VA reference design.

Impacts to Environmental Justice - Not applicable.

Summary of Primary Impacts on 3 Thermal Loads (high, medium, low) - This EDA option is a high thermal load with an areal mass loading of 150 MTU/acre.

Summary of Primary Impacts on Packaging Options for Transportation - This alternative will not affect the packaging options for waste transportation. This alternative does however, support a change in the waste package configuration to be performed at the repository site.

Summary of Primary Short Term Impacts (including operations, retrieval, and closure) - Additional operations are introduced to the repository activities due to the use of drip shields and the aging, and blending of the waste. Although the concrete invert and liner will not be implemented in this alternative, the installation of the steel and mesh ground support and the steel invert with ballast material will be in its place. The presence of the freestanding drip shields, above the waste packages, add an additional step to the retrieval process. Closure of the repository should be the same as in the VA reference design.

Summary of Primary Long Term Impacts (after closure) - The drifts may remain essentially dry for several thousand years, that would increase waste package lifetime and enhance post-closure performance.

APPENDIX C

GEOLOGY LAYOUT FOR THE EDA V DESIGN OPTION

APPENDIX C
GEOLOGY LAYOUT FOR THE EDA V DESIGN OPTION

C.1 PURPOSE

The purpose of this attachment is to document the geology layout for the EDA V design option as it relates to surface alluvial cover.

C.2 METHOD

The method used to perform this task can best be described as graphical analysis of the three-dimensional geology computer model of Yucca Mountain. This Lynx model representation of the geological model (CRWMS M&O 1999e) was the basis for the area calculation presented in Table C-1. Sectioning through this geologic computer model at the orientation and elevation of the EDA V repository block showed the areas of the design option that is covered by alluvium. Simple graphical tools within LYNX enabled the direct calculation of these alluvial cover areas.

The computer files supporting this task were submitted to the Records Processing Center (RPC) on 8mm tapes for storage and retrieval (CRWMS M&O 1999k). Because this work was done using the LYNX software, any viewing and manipulation of the data would require the use of a licensed LYNX Version 4.5 software system.

C.3 RESULTS

The results of this task, as calculated using the LYNX software, are listed in the Table C-1.

Table C- 1. Areas for Alluvial Cover for the EDA V Design Option

Alluvial Areas	Area (Acres)	% of Total Area
Pagany Wash	49.3	8.9
Drill Hole Wash	162.2	29.2
Total	211.5	38.3